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IMPORTANCE OF FOOD WASTE REDUCTION IN SRI LANKA: CURRENT SITUATION AND FUTURE OPPORTUNITIES

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ABSTRACT

Food waste is just not the waste that creates many environmental problems, but also represents a waste of resources used in food production such as land, water, energy and inputs. Therefore, by reducing food losses and waste, we can save money, protect environment, reduce hunger and conserve resources.

It is assumed that nearly half of the biodegradable part of Municipal Solid Waste (MSW) is food waste; biodegradable part of MSW is more than 75% in Sri Lanka. However, the awareness and concern about the levels of food waste generation, related issues or the benefits of reducing food wastage is very less in Sri Lankan community.

Under the above circumstance, the authors attempted to examine the importance of promoting food waste reduction in Sri Lanka. For this purpose, related national data and case studies were studied with the aim of analyzing positive aspects, which could be applied for food waste reduction in the country.

Study revealed that the involvement of government, industrial, commercial and community levels is essential to promote food waste reduction practices in Sri Lanka. Strengthening the national regulations and policy enhancement capacity building, awareness and educational campaigns are essential to get accelerated public participation. The reduction of food waste could make positive impacts on improving current waste management system. There are numerous opportunities for promoting symbiotic relationships and improved recycling systems for reducing food waste in Sri Lanka.

Keywords: *Food waste, food waste reduction, SCP, environmental issues, Sri Lanka*

INTRODUCTION

Food is the major necessity of any living being. Without food, no life will sustain. During the ancient times, Sri Lanka has been a country of self-sufficient and prosperity. The ancient food waste minimization concepts in Sri Lanka were well explained in traditional life styles as *"arapirimessma"* (minimizing waste) and *"sakasuruwama"* (appropriate savings) (Nimal & Perera, 2008). However, the present situation is much differs from the ancient situation, and food losses and waste do occur throughout the food supply chain including pre harvesting, post-harvesting, transporting, wholesaling, retailing, processing and consuming.

According to the Food and Agriculture Organization of the United Nations (FAO), one-third of all food produced for human consumption in the world is lost or wasted and it is approximately1.3 billion tonnes of food annually. Boston Consulting Group (BCG) study found that if current trends continued, world food lost and waste would rise to 2.1 billion tonnes annually. According to the Thomson Reuters Foundation, food waste could rise with booming world population and changing habits in developing nations, and wasting food is a real crisis at a global level (VOA, 2018). The world's population projected to reach 9.6 billion by 2050, and with most of this growth taking place in the developing world and thus the FAO has identified a need to increase food availability by 60%, by 2050 (FAO, 2013); however, it has reported that by reducing the current food wastage it can be contributed 20% of the above requirement.

Food losses do not merely reduce food available for human consumption but also cause negative externalities to the society through loss of scarce resources, greenhouse gas production and costs of waste management (FAO, 2010-11). The estimated food losses of about 30-50% of total production translates to wasting 1.47-1.96 Gha (global hectares) of arable land, 0.75-1.25 Tm^3 of water and 1% to 1.5% of global energy (Fox and Fimeche, 2013). This shows that food losses have negative environmental impacts on land, water and non-renewable resources such as fertiliser and energy that are used to produce, process, handle and transport food that no one consumes. Therefore, food waste reduction will increase food availability without increasing the use of land, water and other agricultural inputs.

Currently, food wastes have associated with growing concern about environmental protection, resource conservation and economic costs because food wastes directly linked to global resource extraction, transportation, processing, and manufacturing. Sri Lanka is among one of the developing countries, where the environmental issues are now becoming threats to the countries well-being. Increasing MSW generation and haphazard waste disposal has been directly associated with creating most of the environmental and health issues in the country; current open dumps create odour nuisance, generates leachate and landfill gases that require further mitigation measures. Problems are aggravated due to high bio degradable nature of MAW in the country. It is assumed that nearly half of the biodegradable part of MSW is food waste; in general, more than 75% of the waste generated in Sri Lanka is biodegradable (SLILG, 2008). Even though, Sri Lanka has no precise data, globally it has estimated that the greenhouse gas emissions associated with avoidable food waste is approximately 20 million tonnes of Carbon Dioxide per year (LSR, 2008).

On the other hand, the looming threat of climate change will undoubtedly have adverse effects on food production in the near future. At the same time, rapid economic expansion and population growth has put pressure on the country's natural resources. Therefore, adapting to a sustainable food waste reduction practices, mostly through proactive preventive strategies such as reduction at source, preservation of extra foods, reuse and donation etc. is very much essential to form a sustainable foundation for food waste reduction in Sri Lanka. Aiming for Zero Waste is one of the fastest, cheapest, and most effective strategies available for combating climate change (LSR, 2008).

Even though, food waste reduction has many benefits economically, environmentally and socially, the majority of Sri Lankan people is not aware and concern about their levels of food waste generation, related environmental and health issues or the benefits of reducing food losses and waste. Therefore, social, economic, and environmental impacts of food losses and waste must be addressed currently. Under the above circumstance, the authors attempted to examine the importance of promoting food waste reduction practices in Sri Lanka with the aim of analyzing positive aspects and future opportunities, which could be applied for food waste reduction practices in the country. In this paper, the authors only discuss food losses and waste in the post harvesting to final consumer stages of the food supply chain.

MATERIALS AND METHODS

Related national data required for this study was collected by reviewing previously published relevant journal papers, newspaper articles, project reports, books, and websites of related national institutions. Literature related to case studies/successful stories on food waste reduction practices already been taken in other countries were studied by reviewing their reports, published papers, web sites with the aim of evaluating the positive aspects and future opportunities, which could be applied for food waste reduction practices in Sri Lanka.

RESULTS AND DISCUSSION

Current situation of food losses and waste in Sri Lanka

Like in most of developing countries, both quantitative and qualitative food losses occur in fresh produce across all stages of postharvest chain in Sri Lanka. Results of a survey conducted by the Institute of Postharvest Technology (IPHT) and Industrial Technology Institute (ITI) of Sri Lanka revealed that the postharvest losses in vegetables vary between 16% and 40%, while in fruits between 30% and 40% in Sri Lanka.

An estimated 270,000 MT of fruits and vegetables, valued at USD 90,000 are lost during postharvest operations on an annual basis. Fruits and vegetable are dumped in metric tonnes as garbage at Dambulla and Thabuththagama Dedicated Economic Centres (vegetable and fruits collecting and whole sale centres) per day. Many traders at the Dambulla Dedicated Economic Centre opted to dump the large quantity of vegetables and fruits at the nearby forest reserve, causing a serious threat to the forest habitat and wildlife (elephants, cows, deer etc.) of the area (The Sunday Times News article, 2007).

The major reasons for high postharvest losses in the country include; harvesting at incorrect stages of maturity, improper handling, improper packaging, poor transportation facilities and inadequate storage facilities. High postharvest losses also occur due to damp weather at harvesting time, poor production practices/planning, lack of infrastructure, inadequate market system, physiological and pathological reasons. Postharvest losses in some fruits and vegetables are the result of pre-harvest diseases and infection. Artificial ripening of large quantities of fruits is also cause for fruit losses in the country.

Because of the high cost of transportation, wholesalers generally transport maximum quantities of produce without consideration for the likelihood of quality loss. Vegetables are often tightly packed by forcing them into polypropylene sacks. These sacks provide relatively little ventilation and result in a temperature build up which accelerates both toughening. Mechanical damage in poly sacks results in cracks and cuts through which the vegetables lose moisture and become susceptible to microbial attack. Therefore, it needs to urgently pay attention on how to reduce postharvest losses at the farm, transport, sell, process and consumer levels rather than increasing the level of production.

Food waste is applied to later stage of the food supply chain and generally relates to behaviour of food suppliers and consumers. In recent years, wastage of cooked/prepared foods has remarkably increased in Sri Lanka. Food waste generation is connected with the way our lives have changed and a growing demand for convenience in modern lifestyle. Prepared food is wasting mostly in homes, restaurants, food service places, wedding ceremonies, religious activities etc. Yet, no precise data is available on food waste generation and its characteristics in the country. However, it is assumed that nearly half of the biodegradable part of MSW is food waste; biodegradable part of MSW is more than 75% in Sri Lanka. The reducing food waste has economic sense at the small scale, by lowering household food bill and at the large scale by reducing cost for food bills as well as waste disposal costs for restaurants and food processors.

Successful stories/case studies of foreign initiatives to reduce food losses and waste

In last decade, many new initiatives whose aim is to recover food and convert it into valuable end uses have spread all over the world. Some of successful initiatives have been taken and their positive aspects are discussed below. It is blessed that some programmes on awareness raising, recovery of surplus food, composting of food scraps and policy enhancement have been successfully operated in many countries with the aims of preventing food losses and waste.

Awareness rising practices:

"Love Food Hate Waste" campaign, which was started in 2007 by Waste and Resources Action Programme (WRAP) in United Kingdom (UK) aims to raise awareness of the need to reduce food waste among consumers and provides them with helpful portioning and planning tips, as well as an array of recipes to make sure food will not go to waste. Since started, the campaign has aimed to encourage behavioural changes of consumers.

Waste and Resources Action Programme is working with a wide range of partners, from UK Governments, businesses, trade bodies and local authorities, community organizations, food industry, chefs and food relevant organizations to develop practical solutions and improved communications to make it easier for consumers to get the most from the food they buy, and to waste less of it. It shows that by doing some easy practical every day in the home, it will waste less food, which will ultimately benefit household and also the environment. Since launching the campaign in 2007, WRAP claims that 1.8 million UK households are taking steps to cut back on the amount of food they throw away, resulting in an overall saving of £296 million a year, stopping 137,000 tonnes of food being thrown away. However, as researches conducted by WRAP shows that 84% of UK citizens still feel they do not waste significant amounts of food, and thus the campaign aims continue to raise awareness of the issue, alongside the personal and financial benefits of wasting less food (WRAP, 2018).

"Think Eat Save" is also an international initiative, launched by the United Nation's Environment Programme and the UN Food and Agriculture Organization to work on reduction of food waste. The programme works to reverse food loss and food waste by providing consumers, retailers, leaders and the community with advice and ways to take action to reduce their yearly food waste. The campaign aggregates and shares different methods of conserving food, including policy recommendations and steps that consumers and households can take on their own to prevent waste (Prepped, 2013).

"Songhai Centre" in Sub-Saharan Africa also works to raise awareness on environmentally conscious farming practices for reduction of agricultural waste. The Songhai Centre is a sustainable development organization that, among other projects, teaches environmentally conscious farming practices in rural areas in Benin, Nigeria, Liberia, Sierra Leone, and the Democratic Republic of the Congo. Their agricultural education is based on a policy of production (*z*ero waste total production); the byproducts of one field are valuable raw materials for another (Ribbink et al., 2005).

Donating surplus food:

Donating surplus food provides economic, social and environmental benefits by reducing the amount of waste and improving assistance to people in need. Some of examples for food recovery programs have been channeling successfully and their positive impacts are given bellow. "Food Recovery Network" (FRN) in Maryland, United States (US) was initiated by University of Maryland students with the goal of delivering cafeteria leftovers to local food shelters. It has since expanded to 11 chapters on campuses across the US students involved in the FRN visit their campus dining halls nightly to rescue leftover food and deliver it to local shelters and food pantries. Close to 55,000 kilograms of leftover food has been rescued by the Network since 2011.

Food Recovery Network now goes far beyond universities. Food Recovery Verified (FRV) is a program of FRN established in 2014. The mission of FRV is to recognize and reward food businesses of any type that are working to fight waste and feed people through food recovery. Food Recovery Verified serves as a third party that verifies that food businesses are donating surplus food at least once per month to hunger fighting non-profits. The objective of FRV is to help provide resources to food-insecure Americans by enhancing national awareness and participation in food recovery (FRN, 2018).

Last Minute Market (LMM) programme in Italy also works with farmers, food processing centers, grocery stores and other food sellers who have unsold food, with people and charities who need food. Last Minute Market now runs food donation programs in more than 40 Italian communities. It also promotes initiatives aimed at drawing public, private and governmental attention to the food waste scandal.

In Australia, the nonprofit organization SecondBite facilitates food donation by linking farmers and retailers with community groups and food banks. SecondBite effectively functions as a broker, first collecting food from donors and then distributing it among community groups that are already aware of where hunger and malnutrition are most prevalent. In this way, SecondBite draws upon existing knowledge and expertise of other organizations to further its mission. In 2012, SecondBite rescued and redirected 3,000 metric tons of fresh food that otherwise would have been lost or wasted (Lipinski et al, 2013).

Composting of food scraps:

House kitchens, restaurants and food processing centers discard unavoidable food waste such as plate scraps vegetable and fruit peels, egg shells, tea bags etc., which could be convert into compost. Aya town-owned composting facility in Japan is a good example for taking initiative to promote composting. In Aya Town of Miyazaki Prefecture, southern Japan is separate organic waste from other MSW and collected organic waste from each household is turned into compost. Aya is an agricultural town and unique in its initiative to recycle nutrients from agricultural crops to food waste to compost, and again to agricultural crops. In Aya, farmers have a long history of composting their food waste into organic fertilizers, and the town started its modern food waste recycling system in 1973, when it started collecting food waste by truck and using it as feed for pigs (JFS 2003).

Now, the town collects about 500 tonnes of food waste per year from households, restaurants and other shops, and brings it to a town-owned composting facility. The compost ("Aya's Natural Fertilizer") produced by the facility is sold to the city farmers at a low price; only about 7 to 10 % the cost of commercial chemical fertilizers (JSF, 2003).

"City of Austin's Zero Waste Initiative" in Texas is also a good example for taking initiative to promote composting. In 2008, the Austin City Council voted unanimously in support of a city ordinance to require all restaurants over 460 square meters (5,000 square feet) to separate all compostable materials from other waste by 2016. Smaller restaurants also have to undertake the initiative by 2017. This is part of Austin's goal to reduce the amount of MSW sent to landfills by 90 percent by 2040.

"Dickinson College Campus Farm" in Pennsylvania, United States is student-run farm composts from daily deliveries of salad bar scraps of the cafeteria. In 2005, Dickinson expanded the compost program into a campus-wide initiative with student, farm workers partnering with facilities management to ensure that campus food waste is composted.

"Sanford and Son" in United States is a father-and-son company that works in the west side of Chicago to re-purpose food waste for urban farms. Ray Sanford and his son Nigel recycle food waste from restaurants and private homes and convert it into organic compost, which is then distributed to urban farms to use as fertilizer. They claim to save 226 kilograms of organic waste for each family that uses their composting services.

Policy enhancement:

In the last few decades, Japan has achieved considerable success in building a "Sound Material-Cycle Society" based on the 3R (Reduce, Reuse and Recycle) practices and food waste recycling received careful attention in Japan (OECD 2010). The Japanese government enacted the Food Recycling Law (Utilization of Recyclable Food Waste Act) in 2001 in order to promote reutilization of food resources and reduces the volume of food waste generated (Takara et al 2012). The law on food recycling requires all entities concerned in food waste at the stages of food production, distribution and consumption, including consumers, businesses, and the national and local governments to endeavour to control waste generation, promote recycling, and reduce waste volume. The Food Recycling Law suggests four ways to recycle; composting, producing fodder for livestock, manufacturing oil and fat products (bio-diesel, printing inks etc.) and utilizing methane from fermentation.

The success of the Food Waste Recycling Law allowed the Japanese food industry to reduce, reuse, and recycle an average of 82 % of its food waste in 2010. Currently, most food waste is composted. Some food companies have been recycling organic waste into fodder for years by supplying food residue such as soybean meals, bread, and steamed rice to livestock feed. In addition, initiatives for utilizing organic waste as fuel raw material to produce bio-diesel and methane have already been started in Japan (JSF, 2006).

Opportunities for reducing food losses and waste in Sri Lanka

People awareness programmes:

Even though, food waste reduction has many benefits economically, environmentally and socially, the majority of Sri Lankan people is not well aware and concern about their levels of food waste generation, related environmental and health issues or the benefits of reducing food waste in their homes or business. Waste management experts argue that lack of awareness and education among the public and local authorities, lack of community participation in 3R practices are common issues associate with taking effort to reduce MSW generation in the country (SLILG, 2008). Therefore, raising awareness and education in household level, farming, transporting, food processing, trading, public and private institutions, local authorities, policymakers, school and university students to get accelerated public participation for reducing food waste generation.

Public education helps to raise consumer awareness on the importance of reducing food waste. Public participation mechanisms could be developed though community based organisations such as village death donation societies, water user groups, small trader associations etc. Furthermore, each individual can play a part in raising awareness on food reduction by word of mouth especially among housewives and children.

Encouraging both producers and consumers to reduce the waste through advancing 3R practices, sustainable consumption and production is important. Conducting awareness among residents to segregate waste into organic waste, glass, plastic, paper, coconut shells, etc. prior to dispose of wastes is essential. Integrate the 3R concept in formal education at primary, secondary, and tertiary levels as well as non-formal education such as community learning and development is very important.

Capacity building:

Inadequacy of trained manpower in postharvest handling and deficiencies in agricultural extension services has adversely affected the improvement in marketing and safety aspects of fruits and vegetables in Sri Lanka. Farmers as well as wholesalers, retailers and distributors need to be trained for proper sorting, grading and packaging etc. Postharvest technologies for poor farmers should be built on the traditional approaches with the utilisation of locally available materials as much as possible. New postharvest technologies and knowledge should transfer to local farms during regular farm extension visits or through seminars and technical bulletins. Capacity building on the tips for reducing food losses and waste for staff of restaurants, hotels, and other food service establishments, staff of food processing and packaging activities, food transporters, famers, and food traders is essential.

Maturity at harvest is an important factor, which influences storage life of fruits and vegetables. Therefore, maturity indices for some fruits and vegetables have been already presented by the Institute of Postharvest Technology (IPHT), Department of Agriculture (DOA) and the Industrial Technology Institute (ITI) in Sri Lanka. However, the knowledge of determine the maturity indices for each fruit and vegetable should transfer to growers through training and extension services. Implementing the training programs in order to upgrade the knowledge of producers, processors, traders and extension officers in both the public and private sectors on protected agriculture, postharvest processing in the development of value added agro-processing enterprises is important.

Capacity building on the proper composting techniques is very important. Currently, some LAs have implemented home composting and city composting programmes in Sri Lanka. However, educating the producers about proper composting practices and encouraging the diversion of all organic materials into compost is not well organized yet. Therefore, training programmes for compost producers as well as public education to encourage the use of compost is necessary. Training of compost specialist groups (including volunteers) is important, and then they can train others on proper composting techniques.

Improvement of current solid waste management system

Reduction of food waste could make positive impacts on improving current waste management system in the country. Most common MSW disposal method in Sri Lanka is open dumping, and most of current open dumps are in environmental sensitive areas and residential areas. Most of open dumps are overloaded; generate landfill gases and leachate that cause several environmental pollutions and nuisance due to high biodegradable nature of MSW. Therefore, adapting for preventive strategies such as, waste reduction at source, reuse and recycling are very much essential to protect environment, expand the lifespan of waste disposal sites, increase opportunities for composting and bio gas production etc. In Sri Lanka 70 - 90% of municipal waste has the potential to be part of a waste reduction programme (SLILG, 2008).

On the other hand, in most of LAs in Sri Lanka, it is estimated that 15 - 25 % of the annual budget is utilized for SWM, out of which 60 - 70 % is spent on collection and transport of waste (SLILG, 2008). However, by reducing the amount of waste to be collected, LAs could use savings to expand or improve current waste management services. LAs have the opportunity to see monetary, environmental and quality of life benefits by waste reduction; these opportunities will help create a cleaner environment, create efficiencies for the constituents of the LAs through the advantages provided by solid waste reduction. On the other hand, reduction of food waste also could directly inspire to ensure the Sustainable Consumption and Production (SCP) patterns in the country.

Processing of surplus foods and new job opportunities

Potentials for development of dried fruits industry in Sri Lanka:

According to various studies, the consumption and demand for dried fruits and vegetables in world market is growing. Dried fruit is part of the preserved fruit and vegetables market that includes canned, frozen and dried fruit and vegetables, juice, jam and purees. The food processing market is accounting for an estimated 80% of world dried fruit imports. The demand for processed fruit and high quality dried fruit continues to expand in world market AIDA, (2017).

The fruit production is a very important agriculture subsector in Sri Lanka and it produces around 540,000 metric tons of fruits annually. H owever, post-harvest infrastructure and practices facilities are still below the needs, and thus fruits such as banana, mango, papaya, avocado etc. are usually wasted in large quantities in peak production periods. According to the IPHT, annual postharvest loses of fruits in Sri Lanka is around 30% and 40%. Many local mango varieties are available in large quantities and approximately 40-60% of postharvest losses occur in these varieties.

However, the fruits that wasted at peak production period could be used to prepare dry fruits. The development of dried fruit products in Sri Lanka represents significant opportunities as appropriate agro climatic conditions for production of a number of types of fruits adopted for drying (pineapple, papaya, banana, mango, grapes, ripe jack fruits, durian etc.). Current, local fruit processing companies specialize in traditional for jams and fruit juice production, while there is very limited production of dried fruits. Therefore, plenty of opportunities to develop a competitive and exports oriented dried fruit industry in Sri Lanka, and thus create opportunities for employment, income generation and overcome the problems of wastage and low prices offered for these fruits during peak harvesting periods.

Drying fruits is a cheap, simple, very effective and universal process; relatively simple drying technologies could be developed using the solar power. Development of drying fruit industry has significant advantages as adding value to fruits, long lasting nature, and transferable and lifelong skills. Drying fruit can be used for personal consumption as well as a means of income generation through sales to both domestic and especially to export market. In this context, significant improvements need to be introduced especially as regards marketing strategies, quality control, proper packaging, and distribution.

Expanding and improving composting programmes

Home composting is an increasingly popular residential waste reduction programme option for Sri Lanka. By composting, households can divert large percentages of their food scraps and yard trimmings from the MSW. Composting is nature's way of recycling organic waste such as food waste and yard waste into compost, which can be used in vegetable and flower gardens, landscaping and many other related applications. The utilization of organic component of MSW for producing compost has multiple benefits such as the reduction of waste flows to final disposal sites, reduction of greenhouse gas emissions, improvement in resource efficiency, employment creation, protecting environment, restoring soil etc.

Household level composting is being promoted by many LAs in Sri Lanka as a relatively simple and low cost solution to reduce organic waste at source. However, it needs to expand strategies to promote on-site composting at work places and home, infrastructure for residential curbside, commercial, and institutional composting. It needs to develop strategies to increase composting capacity and implement a pilot curbside composting program when composting capacity is available. It is important to encourage and support on-site composting at homes, schools, universities, businesses and institutions with sufficient space so that the producers could take care of their organic wastes by themselves.

Promoting symbiotic relationship

Symbiotic relationship concepts such as Industrial Symbiosis, Eco-Towns, Eco-Industrial Parks attempt to reduce waste and pollution, efficiently share resources, and helps achieve sustainable development, with the intention of increasing economic gains and improving environmental quality by cooperating the businesses with each other and with local community.

Symbiotic relationships promote association between two or more industrial facilities or companies in which the wastes or byproducts of one become the raw materials for another, thereby establishing an appropriate recycling system. This type of industrial synergy brings advantages to both parties and also environmental advantages. Promoting these concepts are also very much helpful to reduce food losses and waste; for examples waste coconut water of desiccated coconut industry is a raw material in fruit juice industries, vegetable trashes from wholesale markets raw material for production of compost, biogas or animal feed.

However, these relationships are not very effectively practice in Sri Lanka at percent. The most successful implementation is represented by “eco-towns” and “recycling loops” in Japan, recycling facilities working in symbiotic relationship between industrial and urban areas and improved recycling systems circulating resources respectively (JFS, 2006).

Strengthening the national regulations and policy enhancement

Any problems, which have been caused by human activities cannot be eliminated completely, but can be controlled to a certain extent with the implementation of proper management practices, public awareness, and strict implementation of rules and regulations. In many parts of the world, regulations governing source reduction programmes are increasing due to the fact that without this regulation the participation levels would remain minimal. Local Authorities can develop relevant policies and regulations to encourage participation in food waste reduction by citizens and businesses by preparing bylaws and development of policy statements/directives.Well-targeted policy interventions are needed in fund and expand food waste reduction strategies reduce postharvest losses, post-consumer waste, integrate 3R activities etc.

Chemicals are commonly used for the artificial ripening of fruit in Sri Lanka. Calcium carbide is commonly used by collectors and traders for the production of acetylene to induce fruit ripening. Acetylene is not harmful if properly used. However, traders exceed the recommended level of Calcium carbide for fruit, and also methods used in the application of Calcium carbide can cause health problems Calcium carbide. On the other hand, over ripening of fruits due to artificial ripening causes large amount in waste. Therefore, these practices should be controlled strengthening the rules and regulations. Adhered to quality standards is also important.

Research and development

Understanding where and how much food is lost is an important step in reducing waste and increasing the efficiency of food recovery efforts. However, there is no precise data is available on level of food waste and its characteristics in Sri Lanka. Updated data on foodservices, processing, and household food losses is required to provide a more complete picture of food loss across the entire marketing system in the country. Therefore, researches are needed on data collection in food losses and waste, its characteristics, statistical analyses, and compilation. The data could be intended to serve as a starting point for additional researches, decision making processes, public announcements and application of statistics to understand the state of waste management.

Technologies aimed at reducing harvest and postharvest losses exist but they are not sufficiently adopted by farmers in the country. Even though, a number of these technologies have proved to be successful, more research and piloting are needed to identify interventions that are adapted to local environments and practices.

Currently, researches on the postharvest technology of perishables are conducted in three institutions in Sri Lanka, namely the Institute of Postharvest Technology (IPHT), Department of Agriculture (DOA) and Industrial Technology Institute (ITI). However, the improvement of the existing technology and the introduction of new technologies for target groups are slow. Therefore, conduction researches related to reduce postharvest food loses, food processing, packaging, shelf life extension, freezing, refrigeration, drying/dehydration, fluidization, waste treatment are important.

Researches are also needed to find how to incorporate the traditional knowledge on local food preservation and processing practices with new technologies in effective manner. Traditional Sri Lankans was conserved the surplus food mostly to ensure future food security and to make available during the leaner periods. Most of foods that were conserved are seasonal in production. Therefore, the conserved food satisfied the needs during the off seasons. Conservation was done using simple, appropriate, economical and sustainable local technologies.

CONCLUSIONS

Based on the information collected form national literature and case studies implemented to reduce food losses and waste in many other countries, the authors made following conclusions with regards to promote food waste reducing in the country.

1) In Sri Lanka, both post-harvesting food losses and consumer level food waste were high. Therefore, public and private assistance groups, food manufacturers, food traders, policymakers, and consumers should find for ways to prevent food loss and waste.
2) The reduction of food waste could make positive impacts on improving current waste management system in Sri Lanka.
3) The food supply chains need to be strengthened by encouraging small farmers to organize and upscale their production and marketing. Investments in infrastructure, transportation, food industries and packaging industries are also required.
4) Raising public awareness, education, and capacity building in consumer level, farming, transporting, food processing, trading, public and private institutions, local authorities, policymakers, school and university students are essential to get accelerated public participation in food waste reduction in the country.
5) Public and private efforts are needed to make better use of available food supplies that would

otherwise be wasted; everyone needs shift in attitudes to reduction of food waste.

6) Strengthening the national regulations and policy enhancement are very important. Local Authorities can develop relevant policies and regulations to encourage participation in food waste reduction by citizens and businesses by preparing bylaws and development of policy statements/directives.
7) Researches are needed to collect reliable data on food losses across the postharvest food chain, food service establishments and household food waste to provide a complete picture of food losses and waste in Sri Lanka.
8) There are plenty of opportunities on developing dry fruits industry from surplus fruits and vegetables, and creating new job opportunities in Sri Lanka.
9) There are numerous opportunities for promoting symbiotic relationships and improved recycling systems for reducing food waste in Sri Lanka.

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THE ROLE OF SIMPLE RECYCLE FACILITY "TPST 3R DADAPREJO MANDIRI" TO MINIMIZE THE WASTE IN BATU MUNICIPALITY, INDONESIA

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ABSTRACT
The simple recycle facility named TPST 3R Dadaprejo Mandiri was established at March 2016, located at the Dadaprejo Village, Batu Municipality, Indonesia. The facility was conduct the collecting the waste from the villager as the member of the waste management system and separate the waste to the valuable material and the residual of waste that transported to the landfill site. This facility was reduced around 60% of the waste that produced from the society. This facility was operated by the non-government, non-profit and self-financial organization that the committee member was came from the village society as the social activity.
There were several constrain that faced when operating this facility. Constrains were came from the management of the facility; financial aspect; the society's social and culture; and the municipality agency coordination. As the self-financial organization, this facility committee needs the supporting from the entire member of the society and the municipality government to continuing the waste management system of this village.
The SWOT analysis was conducted to analyze the possibility to increase the performance of this facility operation to maintain the waste management system. This analysis was shown the role of the society member, facility committee board, and the agency of municipality government. The synergy of these parties to collaborate can increase the performance of the facility and to minimize the waste production that will collect to the landfill site.

Keywords: Recycle Facility, Batu Municipality, Non-government organization

INTRODUCTION
Batu Municipality was one of Municipality in East Java Indonesia. This municipality was laid geographically at 122°17' to 122°57' East Longitude and 7°44' to 8°26' South Latitude, with the width of area 19.909 hectares or 0,42% of East Java total width. The map location of the municipality was shown at Figure 1 below. This municipality was consisting of with 3 District (Batu, Bumiaji and Junrejo) and 23 Villages. The population of this municipality was 203.997 (BPS, 2018).

The amount of waste generation from this municipality was around 620 m3 per days; with the service level of the waste management system was 60%. The lower service condition was because of the limitation of capacity of the Municipality Agencies that handled solid waste management, as well as the low of awareness of the habitant about the importance of properly disposing of garbage.

The process of the solid waste management in this municipality was following the old method. The municipality collecting the waste from the village, school, road, market and other area and transporting the waste to dumped in the landfill site. Some recycle activities was conducted, but in general, the all of the waste will transported directly to the landfill site.

According to the system and the coverage of service of solid waste management in Batu Municipality, this area needs some supporting activities to manage and minimize the waste that produced from the area and that transported to the landfill site.

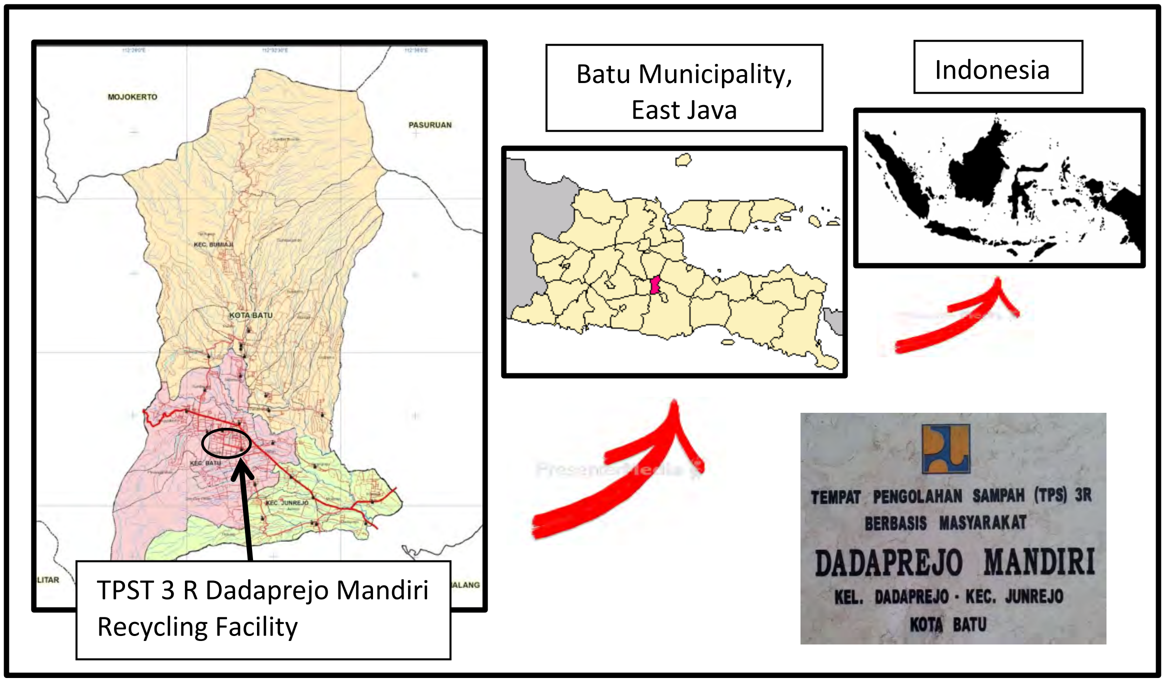

Fig 1. The Batu Municipality Map

TPST 3R Dadaprejo Mandiri Recycling facility

a. The Purpose of the Organization

One of the activities to minimize the waste that dumped to the landfill site was decrease the amount of waste that transported to the landfill site. The composition of the waste that transported was mix between the organic and an-organic material. The minimizing the waste activities were conducted with shorting the waste before it transported to the landfill. The purpose of the activity was not only minimizing the waste that transported to the landfill site, but also recycling the valuable material that containing in the waste.

TPST 3R Dadaprejo Mandiri recycling facility was one organization that conducted the shorting activities for minimize the waste transported. This TPST (Tempat Pembuangan Sampah Sementara Terpadu = Integreted Temporary Landfill Site) was located at Dadaprejo Village, Junrejo District, Batu Municipality. This recycle facility was substitute the task of municipality agencies to handle the solid waste management in this village as shown at Fig 2 below.

The Facility collecting the waste from the household and shorting the waste before transported to the landfill site. In the past system the waste was collected twice a week, but in this system the waste was collecting every day and transported to the facility and shorted before send to the landfill. The result of shorting was organic material for compost raw material, un-organic material that still have valuable component, kitchen waste for the livestock feed and residue that will transfer to the landfill.

b. Performance of the Organization

TPST 3R Dadaprejo Mandiri recycling facility was serving the entire Dadaprejo Village. The Dadaprejo Village was consist of with 4 sub-district (Areng-areng, Karangmloko, Dadaptulis Dalam and Dadaptulis Utara). According to the Junrejo District in Figures 2018 the numbers of villagers were 6.542, around 1.243 household. (BPS, 2018).

The facility supported by three small vehicle and one pick-up car. During the operation since this facility established, the amount of the waste that collected from the household was increasing. Recently the facility was collecting the waste from the household around 9 to 12 m^3 per day depending on waste produce in the day. The amount that can be shorted from the waste was around 62% became valuable material, compost and livestock food. And the 37% of waste was transported to the landfill site (Dadaprejo Mandiri, 2018).

The coverage of the service for waste management was not increased after the entire village covered. The level of service was not increased to the other village because the capacity of management and operation this facility was designed for area village. Further focus of this facility was increasing the capacity to minimize the waste that transported to the landfill site with increasing the management and capability of the workers to shorting the waste and producing the recycle and valuable material.

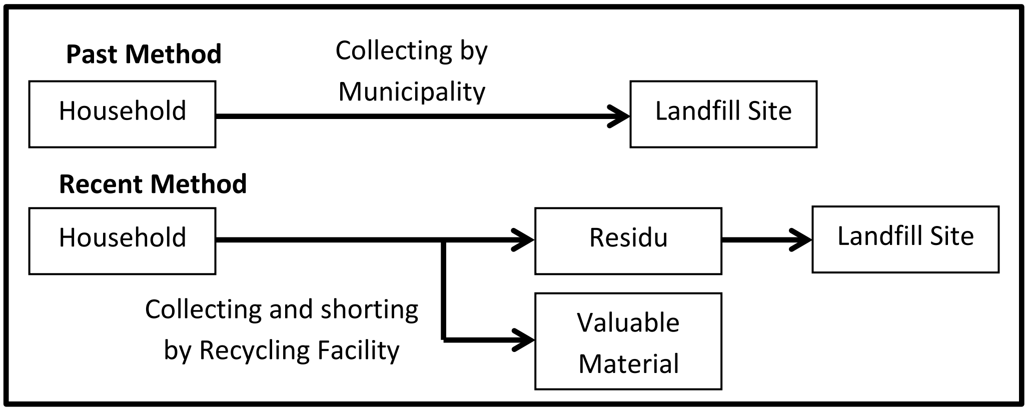

Fig 2. Method of Collecting the Waste

c. The Other Activities of Facility

Beside collecting and sorting the waste, this facility has the other activities that connected with the solid waste management. The activities were purpose to empowering and educate the villager to involve in the solid waste management.

The activity to empowering the villager was with encourages the villager, especially the housewife, to establish the group of waste bank. This group was consist with 20 – 30 household to collect the valuable material from their own waste and the group sell this valuable material to the recycle facility with the agreed price. The group of waste bank will have account from the facility to collect the money from the selling the valuable material. The raised money will be return to the group of waste bank once a year. With this activity the facility encourages the villagers to separate their waste from the source of the waste and the household have collecting some benefit from the waste.

The other purpose of this facility was to educate the villager about the importance to include in the solid waste management. This purpose was implemented with the activities such as invited the kindergarten and elementary school student regularly to visit the facility. With this activities the recycling facility introduce to the student about separating the waste activity. The purpose was to educate the young generation to care about the waste problem and willing to include in the solid waste management and its importance's.

The Facility Operating Constrains

There were several constrain that faced when operating this facility. Constrains were came from the management of the facility; financial aspect; the society's social and culture; and the municipality agency coordination. As the self-financial organization, this facility committee needs the supporting from the entire member of the society and the municipality government to continuing the waste management system of this village.

1. Management of Facility

One of the difficulties to operate the facility was to manage the people that work in the facility. The workers were including the collecting waste workers, the waste sorting workers and the worker for administration affairs. The number of workers was 6 mans of collecting waste workers, 6 women of waste shorting workers and 1 woman for the administration affairs.

As the almost entirety workers was a lower educated workers, it was some difficulty to maintain the role and the rhythm of the facility works. Some difficulty of the carry out the work discipline and to increase their knowledge about the waste management and shorting the waste was faced in the managing of this facility.

The lower educated workers sometimes disregard with the regulation that applied in the facility. The regulation of time works, the route of waste collecting, the way to shorting the waste was some problem that dealing with the workers. And it was difficult to reach the target of work in facility because of the passiveness of the worker to the regulation.

Oppositely, it was very difficult to encourage the workers to work with the fix regulation that applied in the facility. One of the reasons was difficult to find the worker to work in the facility. As the assumption that works that dealing with the waste was the improper work for the society, there were only several persons that still want to work dealing with the waste. The society assumes that work with the waste was the health high risk and dirty work. Only few persons want to deal with this profession. And that few persons usually were the an-educated person.

In the side for shorting the waste, the difficulty was faced to increasing the knowledge the waste shorting workers to separate the waste properly. The workers sometimes still refuse the valuable material that containing in the residue of waste that will dumped to the landfill site. This reason will decrease the income that received from the valuable material that could short from the waste. The separating method was the other problem for the shorting the waste. The workers separating the waste method was inappropriate with the method that that introduced by the facility. The lag of knowledge that causing the ways and method for shorting the waste was little bit difficult to increase because of the low educated workers. That in the end will slow process in the facility and decreasing the income of the facility.

The other reason that person did not want to work as the facility workers was the salary problems. The salary that provide from the facility was very low for remunerate the workers. Comparing with the workers that working as the labor for construction works, the salary from the facility was lower. Because of that, it was very difficult to increase the performance of the workers. In the other hand, if the worker's salary will be increased, it will be disturbing the cash flow of the facility. If the salary was not increased, the process and performance in the facility will be low.

Actually the facility was managed by the Recycle Facility Committee Board that consists with 5 members of the voluntaries from the villagers. Because of the committee members were the volunteers that have another job, not only managing the facility but also have official job, the time that provide to manage the facility was limited. The members can only attending the meeting at Saturday or in the holidays because of their activities outside the facility. The managing activity in the facility was only handled by the administrative worker that has low ability to handle the management in the facility. Sometimes conflict that occurred during the operation, was became prolonged, because the administrative workers could not making some decisions, waiting the decision from the committee members. This management difficulty made the operation of the facility performance became lower and lower.

2. Financial Aspect

The operation of the facility needs the some support of financial. The recycle plant facility needs the workers to collect the waste from the household and to sorting the waste, to pick up the valuable material and trashing the residue of waste. The facility was preparing the salary monthly. As the men workers have different task with the women workers, the salary for both of men and women was different.

The other needing of financial support was the necessity to support the operation of the recycle facility. The operation financial support was covered the items such as the collecting vehicle fuel, maintenance of the vehicle, workers work equipment (glove, masker, safety equipment, etc.), material to supporting the operation (basket, plastic bag, shovel, etc.) and basic needs of the workers (some food and drinks).

Beside to support the worker's salary and the operation financial support, the facility has the other expenditure in every month. The expenditure was the debt from the village's financial institution to buy the vehicle by buying on credit. The facility have the other burden of financial with paying some obligation money to the municipality that collecting the residue of waste ant dumped to the landfill area.

The income of this facility was come from the household monthly contribution and the proceeds of the valuable material that collected from the waste. The household monthly contribution was vary regarding to the type of the household and the distance of the household from the facility. The contribution was vary from 6.000 to 12.500 Indonesian Rupiahs (from 0,45 to 0,85 US Dollars). As this facility was covering service around 1.400 households, the monthly household contribution was reaching the around 9 million Indonesia Rupiahs (around 620 US Dollars). While the proceeds of the valuable material was vary depending on the amount of the valuable material that collected in the facility and the variation of the valuable material price from the collector that buying that material.

As the variation of the expenditure and the income of this facility, the balance cash flow have negative trend every month, because the income that received was not sufficient to fulfill the requirement of the facility operation. The burden of the cash flow deficit was occurred when the variation of amount and the price the proceeded material was high. The deficit of the cash flow was encumbering the facility operation because the deficit wills accumulate and getting bigger as time was going on.

3. The Society's Social and Culture

NIMBY culture and not shorted waste was the culture of society in this village. The habit to throw the garbage without properly separated and put the garbage at the collection place was the culture of the villagers. As the garbage truck from the municipality taken the garbage twice a week before the recycle facility establish, the garbage pile in the collection place that near with the residential neighborhood causing some problem such as bad odor and flies.

Since the recycle facility operated, the problem such as bad odor and flies was eliminated because the garbage was taken every day from household. But, the culture of un-separated garbage was still continuing in the society. The facility encourages the villagers to separate their waste minimally in the different plastic bag of organic and non-organic garbage when the household throw their garbage. It will be making easier to the collection the waste and separated in the recycle facility. The other reason was for the esthetic reason.

Basically, the facility encourages the villagers and household to separate the waste in the different plastic bag was the method of the facility to educate the villagers to include into the waste management system. Step by step the facility encourage the villagers have responsibility to their garbage that produced every day.

Some difficulties that faced were the financial ability of the villagers to support the monthly contribution for operating the facility. It was very difficult to increasing the contribution to support the facility, because in the last method for collecting the waste, the villagers only paying 3.000 to 5.000 rupiahs per household. Recently, the facility was increasing the contribution to 6.000 to 12.500 Indonesian Rupiahs according the type of the household and distance from the facility. The villagers was assume that the increasing of the contribution was not necessary even though the facility increasing the service of the collecting the waste. The villager said that the solid waste management was the government responsibility, and they do not want to include into that system. The facility encourage the villager to have small responsibility to their waste with increasing he contribution as the small step of education in the solid waste management. Facilitating meeting and empowering activity was conducted by the facility committee board to encourage the villager supporting by the Dadaprejo Village Office.

4. Municipality Agency Coordination

Even though this recycles facility was the independent and self-financing organization and as the part of the Batu Municipality Solid Waste Management system, the support from the Municipality was necessary to implemented. The support such as coordination to organize the solid waste management system in the village level, coordination to transporting the residue to the landfill site, technical guidance for shorting the waste and operation, supporting for subsidy for eliminating the deficit of operational cost, and coordination between institution or agency in the municipality that connected with the solid waste management system, were the supporting activity that can conducted by the municipality to ensure the operation of facility running well.

The support from the agencies in the municipality was necessary because the some assumption from the community that the solid waste management was the responsibility of the municipality government. That responsibility could not directly transfer to the community, in this case the organization that operated the recycling facility. The task of the municipality agencies was to develop and empowered the community to establish the recycle facilities until it operated well and independent in the term of operation and financial.

As the facility establish, the role of the municipality agencies was not sufficient to support the facility become running well and independent in operation and financial. The lack of communication and coordination between agencies connecting with the solid waste management was some of difficulties to give the support for the facilities. Besides that, the bereaucracy for budgeting submission for financial subsidy for example, requires a long time and process. The technical guidance was not routinely implemented from the municipality agencies. This guidance should increase the performance of the facility in operation and human resources condition. The management of workers and operation should be guided by the municipality agencies before this facility can run independently. Coordination and communication between municipality agencies and the recycle facility operator should be increasing performance of the facility to become well operated and independent.

SWOT Analysis

SWOT analysis is not a new idea in the business practice. This model originated from the Harvard Business School (Delahaye, 2000), and has dominated strategic plans since the 1950s (Lerner, 1999). A SWOT analysis is one from many tools that can be used in an organization's strategic planning process for environmental scanning. SWOT stands for Strengths, Weaknesses, Opportunities, and Threats. In the case of TPST 3R Dadaprejo Mandiri recycling facility organization, SWOT analysis was developed to produce the strategic for increasing the performance of the organization.

a. Strength

The Strength factor was the internal factor of the organization. The Strength of this organization was:

1. This village has voluntaries that willing to working with solid waste management by non-government organization.
2. The Dadaprejo Village Office supporting the TPST 3R Dadaprejo Mandiri recycling facility to manage the solid waste management in this village.
3. This facility can establish the collecting system for everyday collecting, better than collecting in past system that collect the waste twice a week.
4. This facility have ability to minimize more than 60% waste that produce from the household and

only not more than 40% become residue that transported to landfill site.

5. The organization was not only for manage the waste from the village but also used for the place for encourage the villager to willing include in the solid waste management system.

b. Weakness

1. This organization have deficit of cash flow in every month because the income from household contribution and selling the valuable material was not sufficient to fulfill the operation and maintenance cost.
2. Lack of communication and coordination between organization and Municipal Agencies to manage the solid waste management.
3. The sorting process was not optimal because the level of education the workers in this facility were low in average.
4. The household contribution every month was low, and there was some difficulty for increasing the contribution because of the villager perception that solid waste management was the municipality responsibility.

c. Opportunities

1. This facility can be increasing their capacity to minimize the waste that sending to the landfill site more than recently performance of 30%.
2. The facility can collaborate with the group of villager to enhance the sorting the waste from the source of waste and encourage the villager to include in the solid waste management system.
3. The facility can be implemented as the center education for solid waste management by educated the student and the village about the importance of sorting the waste.
4. The model of this recycle facility with community base can be used as the role model for the solid waste management system in municipality.

d. Threats

1. The numbers of the household that increasing every year can contribute the increasing of the amount of waste produced.
2. The awareness of villager for the solid waste management and for their waste was cannot increasing directly.
3. The worker that willing to work in the facility was decrease because the villager view that work in the facility was the lower level worker compare to the other work.
4. The Bureaucracy for getting support from the municipality was more complicated.

Strategy for Development

The strategy for developing the facility can be formulated from the SWOT Analysis by using pairing between the elements of it.

a. Strategy S – O:

- Collaboration with the village office and the facility must improve to maintain the villager to minimize their waste by educating and empowering activity.
- The facility can introduce the method to decreasing the residue that will transported to the landfill site.

b. Strategy S – T:

- The Municipality must increasing their awareness to the facility by shorten the bureaucracy to support the facility
- The municipality can encourage the facility to minimize the residue that transported to the landfill by enhancing the technical guidance and introducing the technology.

c. Strategy W – O:

- The facility supporting by the Village Office can encourage and empowering the villagers to increasing the household contribution gradually.
- The knowledge of the worker can be improved to sort the waste properly by Municipality technical guidance.
- Communication and coordination between facility and Municipality Agencies must increase to make the facility become the model of solid waste management with community base.

d. Strategy W – T:

- The facility find the other sources funding such as the subsidy from the municipality or collabrated with the other partner to increase the salary of the workers.
- The facility can enhance their management capability to maitain the operation of the facility by making colaboration with the village office and the villager.

CONCLUSION

The situation analysis of the TPST 3R Dadaprejo Mandiri recycling facility was shown the role of the society member, facility committee board, the Dadaprejo Village Office and the agency of municipality government. The synergy of these parties to collaborate can increase the performance of the facility, to increasing the awwarness of the villaager about solid waste management system and to minimize the waste production that will collect to the landfill site.

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REFFERENCE

BPS (2018) Batu Municipality in Figure 2018

BPS (2018) Junrejo District in Figure 2018

----- (2018) TPST 3R Dadaprejo Mandiri Recycling Facility Yeraly Report (2018)

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ASSESSING THE AGRICULTURAL BIOMASS AND ORIENTATION FOR BIOENERGY DEVELOPMENT IN HIGHLAND OF VIETNAM

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ABSTRACT

The study evaluates the amount of crop residues and their ability to turn into energy, suggesting the use of agricultural waste in highland of Vietnam for the cogeneration process. The rate of using waste burning in the field accounts for the highest rate of 52.93% followed by the use of waste to make fertilizer accounted for 39.80%. By using the method of estimating residue-to-product-ratios and calorific value of Thailand crop residues and using a 0.536 efficiency furnace; the results show that if the total amount of waste from rice, maize, peanut and coffee is collected and used for electricity generation, the total electricity generated from waste products in highland of Vietnam is about 12.9 GJ/ha/year equivalent to 3.58 MWh/ha/year. This is a very useful result for policy makers and managers in general and the environment in particular.

Keywords: Crop residues, Biomass, Residue-to-product ratio, Agriculture.

INTRODUCTION

Fossil fuels have become the main source of global energy since the beginning of the 21st century. During this time, a great deal of oil, gas and coal were mined (Abdullahi, et al., 2011). Although fossil fuels play an important role in global economic and political development, many environmental and ecological challenges have led to the problem (Ramachandra et al., 2004). Therefore, the change in using a sustainable source of energy has been neccesary and it is becoming more urgent (Shinnawi et al., 1989; Fabian, 2003). Biomass energy technology is an optimal option, not only replacing fossil fuels but also contributing to waste disposal.

Vietnam is a privileged country with vast renewable energy resources, especially biomass. However, the use of biomass for energy applications can lead to competition for land use, environmental degradation and putting food security at risk. Methods of using bio-waste and agricultural residues cause less risk (Pham Van Lang, 2006). But up to now, the potential residue has not been widely exploited worldwide (UNEP, 2009). In order to have a sustainable social and economic development plan, a comprehensive understanding of bio-energy potential of the region is very necessary. In fact, information on the socio-economic aspects of bioenergy is limited.

Chu Se district, Gia Lai province, in central of highland (case study) has a huge agricultural biomass which released into the environment after crop. From the idea to convert agricultural residues to energy, research was conducted with the aim of evaluating the biomass energy potential of post-harvest crop residues from coffee, pepper, rice, maize, cassava and peanut in Chu Se district and proposed orientations for development of biomass energy sources.

METHODS

Data collecting methods

The data were collected by surveying and interviewing farmers in Chu Se district. The questionnaire included: basic household information; area of cultivated land, type of crop, crop yield, seasonality of crop year, form of crop residue use, price of defective product and sale of crop residue. The surveyed group of 123 farmers planted 6 main crops, including coffee, pepper, rice, maize, cassava and peanut. Collecting opinions on the situation of agricultural production, using agricultural waste in the district was also conducted as the supporting data.

Collected data were supported by mobile software such as Locus free, Compass, MGH mobile and Dropsync. Locus free records the daily commute to determine the random route, choosing the direction of all production models in the district. Compass records the geographic coordinates of the survey site. Direct interviews were conducted with the MGH mobiles programmed to record information and images of the sample surveyed. Then all data collected will be saved on Dropsync. Data saved on Dropsync is processed and aggregated: Secondary data is processed by Microsoft Office Excel 2007; The data is then analyzed and compared with the variation in the quantity, type and size of the indicator as well as the factors reflecting the biomass of the crop. A comparative approach is used to assess the differences between crop groups according to the analytical criteria from which the relevant statements are derived.

The formula for assessing the status of crop residue emissions and the ability to convert agricultural by-products into energy

The formula for calculating plant residue j (Pj) is based on formula (1) as follows:

$$Pj = Aj \times Nj \times Rj \quad (1)$$

Where:

Pj: Total mass of residue j (ton);

Aj: Crop area (ha);

Nj: Productivity of crops (tons/ha);

Rj: Ratio residue to quantity.

The efficiency of the rice husk and rice husk burning equipment with reference data from the An Khe Biomass Thermal Power Plant is 0.536.

The formula for calculating the biomass energy that is burned from the co-incineration- electrical plant j (Mj) calculated by formula (2) with the moisture content and heat value of the reference waste (Bhattacharya et al., 1993)

$$Mj = Pj \times Bj \times n \times (1 - Wj) \quad (2)$$

Where:

Pj: Mass of crop residues (tons/year);

Ex: Moisture content of waste products (%);

Bj: Waste heat (GJ/ton);

n = Efficiency of burning (= 0.536).

The above value is used as the greenhouse gas (ESF) savings factor to calculate the potential for greenhouse gas emissions from the total electricity generated from straw and husk (EP). Total greenhouse gas emission reductions are determined by the equation:

$$GHGsv = Mt \times ESF \quad (3)$$

Where:

GHGsv = Greenhouse gas emissions are reduced when straw and rice husk are converted into energy (ton CO_2-eq/year);

Mt = Total electric power of straw (MWh/year);

ESF = GHG savings per MWh (ton CO_2-eq/MWh) is 1.252 (Suramaythangkoor and Gheewala, 2008).

RESULTS AND DISCUSSION

Cultivation occurrence of some crops in Chu Se district

Chu Se district has a total natural area of 64140 ha, of which 45631.70 ha is agricultural land, accounting for 71.14% of total natural area, of which 45000 ha is agricultural land. With the strength of land resources, Chu Se is a land suitable for many crops and for high productivity. Major crops produced in the region are coffee, pepper, rice, maize, cassava and peanuts. In 2010 - 2011, the total production of Chu Se crops will be 17822 tons, increasing to 20170 tons in the period of 2014 - 2015 as shown in Table 1.

Table 1. Crop productivity in years

Unit: ton

Crops	Season				
	2010 – 2011	2011– 2012	2012– 2013	2013– 2014	2014– 2015
Coffee	9036	9129	9339	9412	8941
Pepper	2121	2131	2483	3487	3750
Cassava	950	800	931	929	980
Rice	3600	4182	4330	3992	4169
Maize	1977	2139	1765	2150	2150
Peanut	138	160	132	284	180
Total	**17822**	**18541**	**18980**	**20254**	**20170**

Situation of collection and use of post-harvest waste from cultivation in Chu Se district

Based on the survey results of 123 households in Chu Se District, the percentage of waste used in each crop is determined as (Figure 2). Crop residue is burned in the field after each harvest with the highest proportion because of the farmers' economic standard. Therefore, waste used for cooking is less used. Particularly for the area as the town, people's living standards are higher, the use of coal, gas is gradually becoming popular. And with traditional farming traditions have long taken advantage of nature to improve. Naturally, in the face of growing population pressures, while the area of land for agricultural production is limited and there is a growing risk of severe degradation, intensification to increase resulting in crop productivity growing. That is concerned problem getting farmers' attention. Using agricultural waste to re-use land and improving land is one of the usual habits because of easy manipulation.

However, the use of agricultural waste burned directly in the field to obtain ash directly applying for the soil as fertilizer induces wasting the source of agricultural residues after harvest. On the other hand, residue burning causes environmental pollution that affects human health, badly affecting the lives and activities of people in research area.

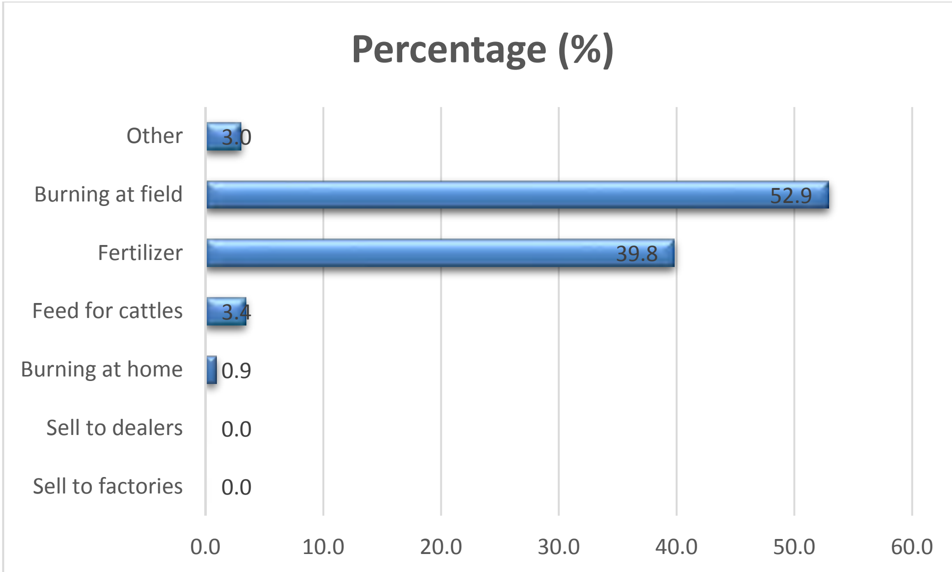

Figure 1 Ratio of residue utilization from crops

Mass of agricultural residues in Chu Se district

Based on data on major crop yields from 2011 to 2015, calculation of residues was examined from the average crop for years through the percentage of defective products collected. Data collected from the interviews of farmers in Chu Se District are not much different from those in FAO (1982) as shown in Table 2.

Table 2 Mass of residues from cultivation activities in Chu Se district

No.	Crops	Prod. (Ton/yr)	Residues		Residue ratio	Residue mass (ton/yr)
			From production processes	On field		
1	Coffee	21560		Branch and leave	2.1	45276
				Husk	1.4	30184
2	Pepper	10312		Branch and leave	-	-
3	Cassava	14810		Stem	0.062	918.2
4	Maize	10438	Cop		0.273	2849.8
				Stem	2.0	20877.6
				Husk	0.2	2087.76
5	Rice	15812	Husk		0.267	4220.8
				Straw	1.757	27782
6	Peanut	1700.6		Husk	3.5	5952

Electricity consume of Chu Se district

Over the five years from 2010 to 2015, although the electricity price increases continuously and reached the highest in 2015 is 1653 VND/kWh, the demand for electricity used by households in Chu Se district has not decreased. the corresponding increase in demand for electricity is relatively high. Transforming biomass from agricultural by-products to energy will create a new form of energy in rural areas that is complementary to traditional energy.

Table 3 Electricity production and trading data of electricity from 2010 to 2015 in Chu Se

Year	Electricity output (kWh)	Price (VND)	Customer	Customer 3P	Customer 1P	Electricity output (kWh/household)
2010	67798870	997	34949	1000	33949	1940
2011	56504949	1233	36135	1236	34899	1564
2012	67338270	1388	38105	1374	36731	1767
2013	63979791	1524	26122	872	25250	2449
2014	51658741	1581	27962	983	26979	1848
2015	58595023	1653	29395	1115	28280	1993

(*Source: Statistical yearbook, 2015*)

Estimation of power supply capacity from biomass of crop residues in Chu Se district

The energy potential of crop residues is calculated according to the research method (formula 2). The results of calculating using heat treatment of Thai crop residue in unit (GJ / ton): coffee husk: 12.38; maize stem: 5.25; maize cob: 16.28; rice husk: 19.33; rice straw: 16.02; Peanut stem: 12.38. Thailand's defected moisture content in units (%): coffee husk: 15; maize stem: 22; maize cob: 7.53; rice husk: 12.37; rice straw: 12.71; Peanut stem: 15. These are the best values to use in calculating the energy potential of crop residues.

According to the calculation results of Chu Se district, the potential energy of coffee husk is 255372 GJ/year, equivalent to 70936.62 MWh/year, accounting for 44.02% of total energy potential of waste, followed by straw for energy purposes, would generate 208236 GJ/year, or 57843.33 MWh/year, accounting for 35.90% of total energy potential. The remaining 20.89% are the crop residues such as maize stem, maize cobs, rice husks, peanut stem.

Thus, if the total amount of rice, maize, peanut and coffee waste is collected and used for electricity generation, the total electricity from waste in the whole district of Chu Se is about 580097 GJ/year equivalent to 161137.978 MWh/year.

Table 4. Annually average energy potential from residues in Chu Se district

Crops	Residue kinds	Wet mass (ton)	Humidity (%)	Dried mass (ton)	Heat (GJ/ton)	Energy* (GJ/yr)
Coffee	Husk	45276	15	38484.60	12.38	255372
Maize	Stem	20877.6	22	16284.53	5.25	45823
	Cop	2849.79	7.53	2635.20	16.28	22994
Rice	Husk	4221.86	12.37	3699.61	19.33	38329
	Straw	27782.04	12.71	24250.94	16.02	208236
Peanut	Stem	1656.55	15	1408.07	12.38	9342
Total		**103582.06**		**87543.44**		**580096**

*Remarked: * The energy potential of residues with process efficiency is 0.536*

Suggested model for biomass energy use

Rice husk and rice husk residues can be used as co-incineration fuel, including the following main components: combustion chamber, boiler, turbine, generator, heat exchanger, dryer and other auxiliary parts.

Principle of working: The pump system will supply water to the boiler, fuel (rice husk, rice straw) supplied to the burner. The heat generated from the combustion process is provided to the boiler. The amount of heat generated by the combustion at the furnace is provided to the boiler to evaporate the steam. The superheated steam creates a spinning turbine that rotates the generator, releasing electricity. Pressure for the turbine is about 9.81 Mpa. This power supply can be supplied in-house for the dryer or in the milling system.

The combustion of some high-moisture fuels releases water in the combustion chamber. As a result, the formation and evaporation of water in the combustion chamber reduces the amount of thermal energy available to work. However, this system has a secondary condensation process, below the combustion step, which condenses the water vapor in the exhaust stream and recovers most of the latent heat that is carried. Recovered heat can be used more efficiently and maximize the amount of heat generated from crop residues. Heat from the steam from the turbine (steam) is used to dry agricultural products.

CONCLUSION

Transforming crop residues into electricity would create a new form of energy in rural areas, supplementing traditional energy sources but insufficient in Chu Se District. The results show that if the total amount of rice, maize, peanut and coffee residues is collected and used for electricity generation, the total electricity generated from waste products in the whole district of Chu Se is about 580097 GJ/year equivalent to 161137.978 MWh/year, calculating for highland of Vietnam is about 12.9 GJ/ha/year equivalent to 3.58 MWh/ha/year.

Therefore, it is necessary to study the planning, collection and transportation of rice by-products as well as other agricultural by-products to determine the efficiency of investment in processing plants and the efficient use of crop residues with both economic and environmental concerns.

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LEGAL FRAMEWORK AND STANDARDS FOR CONSTRUCTION DEMOLITION AND WASTE MANAGEMENT IN VIETNAM: A REVIEW

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ABSTRACT

Vietnam is the easternmost country on the Indochina Peninsula in Southeast Asia. Like many other developing countries, Vietnam has been experiencing various kinds of environmental problems on a huge amount of Construction and Demolition Waste (CDW) being generated in big cities due to active construction activities including new construction, renovation, and demolition of buildings. The Vietnamese government has issued a series of legal documents to manage the CDW.

This paper present the institutional framework and standards for CDW being developed and implemented in Vietnam. The existing institutional framework and standards that promote the environmental management for sustainable development will be reviewed.

Keywords: Construction and Demolition Waste, framework, standards, management, sustainable development

INTRODUCTION

Vietnam is the easternmost country on the Indochina Peninsula in Southeast Asia. It is bordered by China to the north, Laos to the northwest, Cambodia to the southwest, and the South China Sea to the east. The area of Vietnam is approximately 330,000 km^2 and it is ranked as the 65th largest nation in the world. Currently the national economy relies heavily on the extraction and use of natural resources. As of July 2016, the population was approximately 91.7 million, making Vietnam the 14th most densely inhabited country in the world and 8th in the Asian region, which imposes a constant and long-lasting pressure on the country's natural resources.

With rapid urbanization and economic growth on all fronts, much construction is conducted everywhere in Vietnam, especially in big cities such as Hanoi, Haiphong, and Ho Chi Minh. All these activities, new construction, renovation, and demolition of buildings and structures, generate huge amounts of waste, called construction and demolition waste (CDW). According to the State of the Environment report of 2011 on solid waste management issued by Ministry of Natural Resources and Environment, the total municipal solid waste generation was about 60 thousand tons/day on average, of which the CDW waste accounts for 10–12% of total solid waste. In order to maximize the potential positive impacts but at the same time to minimize the negative effects of modernization and industrialization in Vietnam, it is necessary to establish a sound management system of CDW based on proper management models and references.

This paper describes how a legal and institutional framework for CDW management is being developed and implemented in Vietnam. The existing policies and institutional framework will promote the environmental management for sustainable development. With these policies, there is a need to identify the most important environmental issues, including challenges to be tackled and opportunites to be deployed towards an environmentally sound management of CDW in Vietnam.

DEFINITION OF CDW IN VIETNAM

What is CDW in Vietnam?

The Law on Construction (2014) stipulates that construction contractors are responsible for CDW management. The Law on Environmental Protection (2014) stipulates that CDW shall be collected and treated in an adequate way, and the Decree on Management of Investment Projects on the Construction of Works (2009) stipulates that construction contractors shall transport and dispose of CDW and take it to designated places.

The definition of CDW appeared first in TCVN 6705 Ordinary Solid Waste – Classification in 2009. In Article 2 of TCVN 6705, CDW (or Construction Solid Waste) is defined as “Waste discarded in dismantling or renovating old construction works, or in the process of construction of new works (house, bridge, road, etc.) such as mortar, broken brick, concrete, ceramic water pipeline, roof, gypsum, and other materials”.

In Article 50 of Decree No. 38/2015/ND-CP on Management of Waste and Discarded Materials (2015), the categorization of CDW and its applicable handling methods are described as:

a) “Soil, sludge” from excavation, dredging topsoil, and digging foundation piles shall be used to cultivate croplands or suitable land areas;

b) “Gravelly soil, solid waste from construction materials (brick, tile, grout, concrete, adhesive materials)” shall be recycled as construction materials or reused as backfill materials for the buildings or buried in construction solid waste landfills;

c) “Recyclable solid waste” such as glass, steel, wood, paper, and plastics shall be recycled and reused.

In addition, Article 50 of this Decree stipulates that the Minister of Construction shall take charge and cooperate with the Minister of Natural Resources and Environment to specify the classification, collection, reuse and recycling, and treatment methods of CDW.

Basic waste flow

In general, there are some differences of the waste flow between in urban area and rural area. However, basic waste flow on CDW can be summarized roughly in Figure 2 (JICA report, 2018).

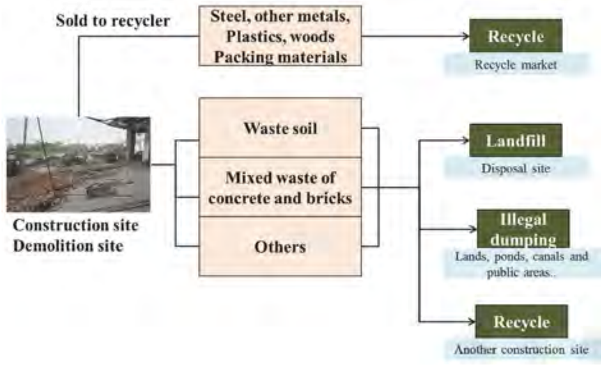

Figure 2 Waste flow on CDW in Vietnam (Modified adopted from JICA report, 2018).

Marketable materials like steel, plastics and woods are collected and recycled without public support. Other materials like soil, concrete, bricks, glass and tiles are collected, but some are disposed at landfill sites, some are dumped illegally and some are recycled at other construction sites. The data on the ratio of each amount is not available so far.

CDW Generation in Vietnam

In Vietnam, more solid waste is being generated in urban areas. As reported by MONRE in 2011 (MONRE report, 2011), the amount of municipal solid waste generated was about 12.802 million tons in 2008 and estimated to be 22.352 million tons in 2015. CDW is around 10–15% of total solid waste. Approximately 2,200 apartment buildings (about 6 million m^2) were built in 1970–80, of which approximately 90% are now seriously degraded. In 2007, the Vietnamese Government issued Resolution 34/2007/NQ-CP (Decision No.609/2014/QD-TTg, 2014) on a number of solutions for the amelioration and reconstruction of damaged or degraded condominiums by 2015. Thus, in the coming years, a huge amount of CDW will be discharged in the large cities and urban areas.

CONSTRUCTION DEMOLISHED WASTE LEGAL FRAMEWORKS

In the past two decades, the Vietnam Government has put in place a sound legal framework for environmental protection that addresses guidelines for the management and disposal of all waste streams (Viet et al. 2009). This framework is supported by many national strategies and directives that apply to solid waste management.

Outline of legal documents related to CDW (National level)

Basic outline of Vietnamese legal documents referring CDW in present are shown in Figure 1 (JICA report, 2018).

The Vietnamese government has issued a series of legal instruments stipulating CDW management to protect the environment. These are listed as below.

National strategies

i) Strategy for the Management of Solid Waste in Vietnam Cities and Industrial Parks (Decision No. 152, 1999).

ii) National Strategy on Environmental Protection up to year 2010 and Vision to 2020 (Decision No.256/2003/QĐ-TTg, 2003).

iii) Directive No. 23/2005/CT-TTg on Enhancing the Management of Solid Wastes in Urban Centres and Industrial Parks (Directive No.23/2005/CT-TTg, 2005).

iv) National Strategy for Integrated Management of Solid Waste up to 2025 and Vision towards 2050 (Decision No. 2149/2009/QD-TTg, 2009): This strategy is aiming following specific targets and to develop solutions for CDW.

- Specific targets: The target set by the National

Strategy is shown in the Table 1.

Table 1 Policy target related to construction waste stipulated in the Decision No. 2149/2009/QD-TTg

	Up to 2015	Up to 2020	Up to 2025
Collect and treat in urban areas	50%	80%	90%
Of which reusing or recycling	30%	50%	60%

- Solutions for implementing the Strategy: Proposed solutions to accomplish the target are (1) to promulgate regulations on construction waste management, (2) to promulgate technical instructions for recycling construction waste.

v) National Strategy on Environmental Protection up to the Year 2020 and Vision to 2030 (Decision No. 1216/2012/QD-TTg, 2012).

In the National Strategy for solid waste management (Decision No. 2149/2009/QD-TTg, 2009), it is expected that by 2050, all kinds of solid waste will be collected, reused, recycled and comprehensively treated by advanced, environmentally-friendly technologies, suitable to each locality, thereby limiting the amount of solid waste that needs to be landfilled.

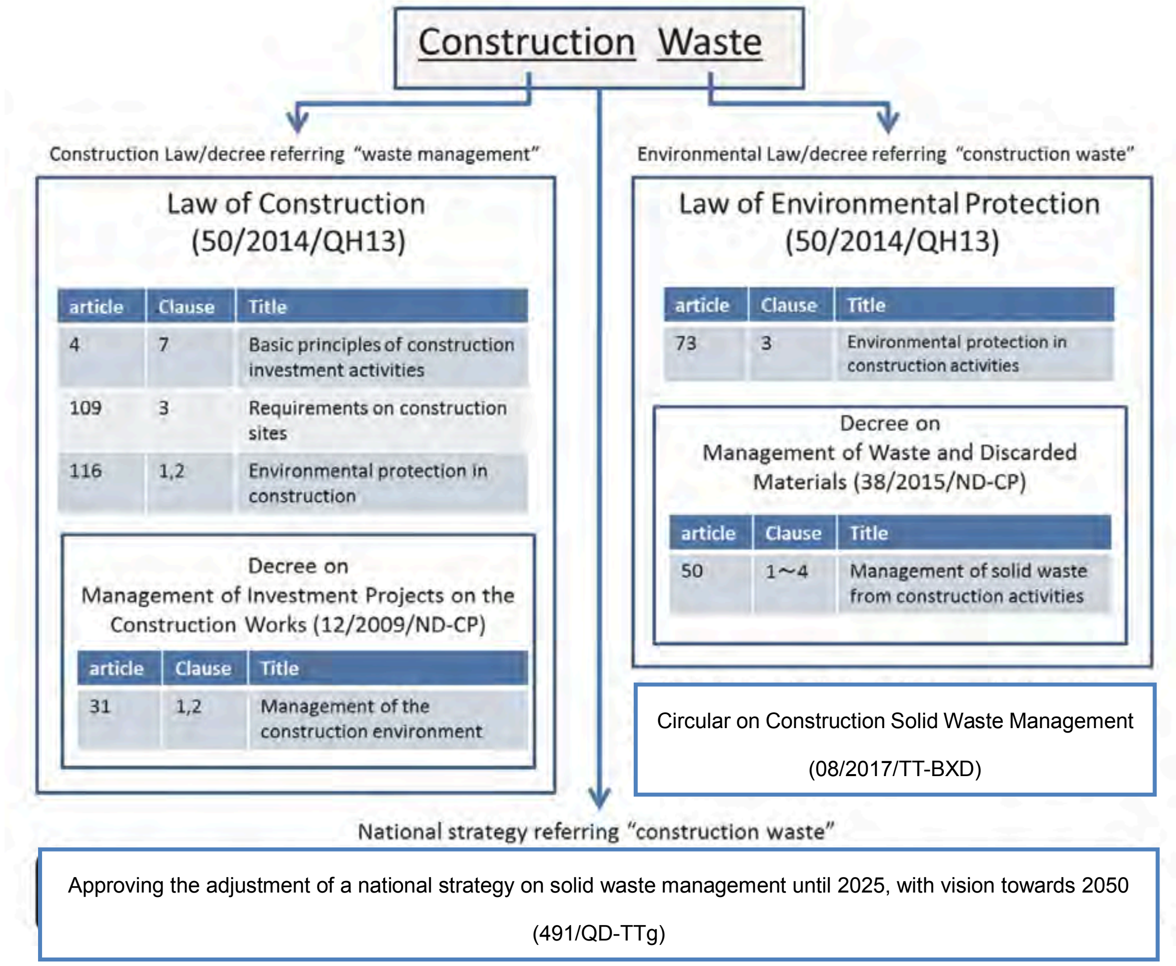

Figure 1 Outline of legal documents related to CDW in Vietnam (Modified adopted from JICA report, 2018)

Recently, Decision No. 491/QD-TTg dated 7 May

2018 of the Prime Minister has been released to approve the adjustment of a national strategy on solid waste management until 2025, with vision towards 2050.. According to the decision, by 2025, 100% of total hazardous solid waste generated from production, business, service, health care and craft villages must be collected, transported and handled. Application for environmental protection; 85% of hazardous solid waste generated in households and individuals must be collected, transported and treated to meet environmental protection requirements; To use 100% eco-friendly plastic bags at trade centres and supermarkets for domestic purposes in replacement of hard plastic bags; 80% of daily-life solid waste generated in concentrated rural residential areas shall be collected, stored, transported, handled and handled in a concentrated manner to meet environmental protection requirements; Make the most of organic waste for reuse, recycling, composting or self-disposal at home to compost for local use, etc. The targets of the national stragegy for management of solid waste up to the year of 2025 are given in Table 2.

Table 2 National strategy for management of solid waste up to the year 2025
(Decision No. 491/QD-TTg, 2018)

Targets		2020	2025
Ratio of cities that have solid waste recycling system (%)		70	90
% Use of eco-friendly plastic bags to replace normal plastic bags		65	100
% Collection	Urban house SW	90/85	100/90
	CDW	80/50	90/60
	Urban sludge	50/30	100/0
	Non-hazardous Industrial SW	90/75	100/80
	Hazardous Industrial SW	70/0	100/0

<u>Province/ City level legal framework</u>

Decision on promulgating regulation on ordinary solid waste management in Hanoi City (16/2013/QD-UBND): Hanoi city started above decision based on “Decree on Solid Waste management (59/2007/ND-CP)” which is the former decree on solid waste management before substituted by “Decree on management of waste and discarded materials (38/2015/NĐ-CP)”.

The decree is stipulating responsibilities of construction project owner and environmental sanitation agencies (such as HANOI URENCO) concerning CDW, and also following decree No. 59/2007/ND-CP on separation, transportation and treatment of CDW, and giving more instructions on especially how to care on CDW transportation.

Together with national strategies, province/city level legal framework, there have been relevant laws and policy documents such as decrees, circulars, joint circular and technical standards that have been issued to support:

<u>Laws</u>

i) Law on Construction (2014): Construction Demolished Waste (which is named as “Construction Solid Waste (CSW)”) is positioned clearly in this law.

- Basic principal is to prevent generation of waste.
- Construction contractors must be responsible on

CDW management.

ii) Law on Environmental Protection (2014): CDW generated through construction activities shall be collected and treated by adequate way. Outline of applicable methods for CDWs are stipulated in following decree.

iii) Law on Urban Planning (2009).

iv) Law on Public Investment (2014).

Decrees

i) Decree on Solid Waste Management (2007).

ii) Decree on Management of Investment Projects on the Construction of Works (2009): The Decree stipulates that contractor shall transport and dispose of CDW and take it to designated places.

iii) Decree on Management of Waste and Discarded Materials (2015): Article 50 stipulates that, "The Minister of Construction shall take charge and cooperate with the Minister of Natural Resources and Environment to specify the classification, collection, reuse and recycling and treatment of construction waste".

iv) Decree on Construction Project Management (2015).

Circulars

i) Circular on Promulgating the Regulations of Environmental Protection Applied for the Construction Sector (1999).

ii) Circular on Guiding the Elaboration of Reports on the Assessment of Environmental Impacts for Construction Planning Projects (2000).

iii) Circular on Guiding the Strategic Environmental Assessment in Construction and Urban Plans (2011).

iv) Circular on Regulation on Construction Solid Waste Management (2017): This Circular provides for classification, collection, reuse, recycling and treatment of construction solid waste specified in the Decree No. 38/2015/NĐ-CP on scrap and waste management. It is applied to domestic authorities, organizations, households and individuals and foreign organizations and individuals who carry out operations related to construction solid waste management in the Vietnamese territories.

v) Joint Circular on Guiding the Regulations on Environmental Protection for the Selection of Location for, the Construction and Operation of, Solid Waste Burial Sites (2001).

Standards

i) TCVN 6705: Ordinary Solid Waste – Classification (2009).

ii) TCVN 6706: Hazardous Solid Waste – Classification (2009).

iii) TCVN 6707: Prevention and Warning Signs for Hazardous Waste (2009).

iv) TCVN 6696: Requirements for Environmental Protection for Sanitary Landfills (2009).

Despite several national strategies and decisions, detailed technical instructions for promoting treatment and recycling of CDW are not fully available in Vietnam. Besides, necessary standards and criteria for recycled materials from CDW and guidelines on the use of recycling materials (e.g., roadbed materials, concrete aggregate) have not yet been fully regulated in Vietnam.

CHALLENGES AND OPPORTUNITIES FOR SOUND LEGAL CDW MANAGEMENT FRAMEWORK AND STANDARDS IN VIETNAM

Right now, like other developing countries in Asia, Vietnam is facing a shortage of laws and enforcement in CDW management. The priority in current solid waste management is for organic waste management and hazardous waste management (health waste and hazardous industrial waste). CDW, which is non-hazardous solid waste, is considered mostly on the research scale, and no big investment has been made so far. At present, a priority policy or investment policy for research, manufacture, and business investment in the recycling and management of CDW has not been promulgated. The recycle policy is only mentioned for general solid waste management in National Strategy on Environmental Protection up to the year 2020 and Vision to 2030 as approved by Decision No.2149/QD-TTg in 2009.

Moreover, the standards for reusing and recycling of CDW should be developed. In fact, mixture of CDW has been recycled as filling material for roadbed and reclamation at other construction sites. However, in most of the cases, the recycle is conducted without any proper treatment. Sometime improper materials are contaminated such as big size of block and other residual materials. Material quality for filling has an influence on directly strength of the building structure. Contractors who expect to utilize their CDW at other construction sites need a certain level of technical standard on recycling materials for safety construction works. The kind of standard should be developed in cooperation with national technical institute and other competent agencies like MONRE.

CONCLUSIONS

As the strong economic growth, urbanization and industrialization rates in the recent years, Vietnam have promoted the issue of solid waste management to the top of environmental challenges, in which CDW management is considered as a big issue. The shortage of laws and enforcement in CDW management will open the doors for promulgating policy in the recycling and management of CDW. This leads to priority research works to build the feasible legal framework and standards in coming time to establish the environmentally sound management of CDW in Vietnam.

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DISASTER WASTE MANAGEMENT: OCURRENCES AND PUBLIC POLICIES IN BRAZIL

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ABSTRACT

Natural disasters can occur by changes in the environment, mistakes, inadequate decisions and poor human planning, such as the lack of a specific public policy for solid waste management (urban and industrial), leakage of products and waste, improper disposal of waste, landslides, among others, causing serious consequences for the human life, health and safety of the population, contamination of rivers, lakes, oceans, air pollution and soil. It demonstrate the importance of every player cooperate with each other to improve prevention. Major environmental disasters have been repeated in many parts of the world since the industrial revolution. When human error is omitted, it is almost always irreversible, the consequences are large and negative to the ecosystems, they cause harm to the entire life form on the planet.

This paper explores the contexts wherein disasters are defined as non-routine social problems. It uses Brazil's legislative framework, public policies and disaster occurrences to illustrate the interaction between the players. In the light of this work, the motivation is to open new doors for researchers and assist emergency management professionals in critically reviewing existing public policies and future perspectives.

Key-Word: Disaster Research, Waste Management, Public Policy

INTRODUCTION

Environmental disasters have been occurring forever all over the planet. Accidents or human errors, the truth is that these events leave a negative legacy for the affected regions inhabitants, also for the environment, the recovery process may take decades or centuries. Such accidents can be the result of wars, and may be with nuclear, chemical and/or biological power, pollution, inappropriate waste disposal, among others. According to chronological review, since the second half of the last century, with the advent of the industrial revolution, the world has begun to follow up the environmental consequences and imbalances left as legacies for current and future generations (PNUD, 2015, Sovacool, 2008, WHO, 2007) .

Despite the focus on economic growth and social development, however, environmental quality has been suffering irreparable damage in many countries, affecting lives and ecosystems, such as:

Disasters in Brazil:

1980 - Death Valley

1984 – Socó Village

1987 - Cesium 137

2000 - Oil spill in the Guanabara Bay

2003 - Cataguases dam burst

2007 - Dam burst in Miraí

2011 - Oil spill in Campos Basin

2015 - Fire in Ultracargo

2015 - Collapse of a giant iron ore waste dam in Mariana MG, contamination of rivers and soil with toxic elements and heavy metals such as arsenic, besides the destruction of flora and fauna, caused a huge impact on the Atlantic coast.

Photo 1 Mariana city before / after the accident

In Brazil, even with the creation of the National Solid Waste Policy, the inadequate management of solid waste causes environment damage and serious negative consequences in various perspectives; climate change, health and safety of human and animal life.

One of the main goals in our society is quality of life. However, this quality is conditioned to the adequate use of natural and energy resources, to the production of material goods, and consequently to the generation of waste (Borges, 2003).

Inadequate disposal of these wastes (solid, liquid and gaseous) can have serious negative effects on nature, both biota and human life, interfering with environmental dynamics (EPA, 1996).

However, before intervening in environmental perception, it is necessary to acknowledge and admit that major accidents and environmental disasters compromise life on the planet, being a threat and disrespect on how to use natural resources (Sovacool, 2008).

Therefore, it is a question of conscience and commitments to the society, which hold governors, entrepreneurs, academic scientific society, and the community in general accountable.

Following the worldwide trend in the quest for sustainability, where virtually all segments of society have been involved in environmental issues, disasters or environmental accidents are a negative externality, a somatization of technical complexity, human failures, technological failures, fatalities or lack of planning, which are often ignored by various sectors such as energy production and use (Sovacool, 2008).

Disaster or accident is a "casual, fortuitous or unforeseen event" resulting in damage, injury, undesirable effects or other serious consequences such as destruction and death (Torreira, 1997; Teske, 1970 in Borges, 2003). There are fundamental types of accidents causes:

Unsafe acts - are incorrect actions of work execution, conscious or unconscious by the worker.

Unsafe conditions - these are poor working conditions, which can lead to accidents and / or occupational diseases.

Considering that accidents are caused and can be avoided, the acknowledgement of this fact leads to prevention (Borges, 2003).

Every major accident includes significant damage or loss, as well as arising illnesses and subsequent problems. An event that produces damages, losses or illness can occur in a period of hours, days, months or even years (Torreira, 1997 in Borges, 2003).

These issues have been discussed since the 1960s. According to Teske (1970), in 1958, the University of Minnesota, USA, was already conducting studies on the disposal of hazardous wastes, and concluded that the unavailability of appropriate methods to deal with them made the storage of such waste frequent. Research has reported the identification of waste dated since the year 1900.

Adequate disposal becomes a constant concern for scientists and researchers, and the disposal of products of unknown origin is a major challenge. From 1976 onwards the problem of waste disposal was reviewed and an inventory system of all the products purchased was established (Nagel, 1981), storage in convenient and safe places became the responsibility of the generators.

In 1976, the Conservation and Resource Recovery Act (RCRA) was enacted "Effective Hazardous Waste Management (Non-Radioactive)."

Later, in 1977, the concept was expanded by including condition details in the document: "State Decision- Markers Guide to Hazardous Waste Management" (Nagel, 1981 in Borges, 2003).

The main attitudes required for the establishment of a hazardous waste management system can be presented in the form of a priorities sequence (Dressen, 1980, Allen 1983, Lidskog 1993, Josephson 1993, Leonard 1995, Jardim 1998, in Borges 2003), as reported below:

1. Optimize the Generating Unit (planning before initiating new product developments, keeping track of all material that enters the stock (saving water and energy);
2. Minimize the generation of hazardous waste;
3. Segregate and concentrate the streams of waste in order to make the activity technically and economically feasible;
4. Re-use internally, or externally through the transfer of waste for other purposes, such as circular economy;
5. Recycle the material or energy component of the waste;
6. Keep all waste produced in its most usable form;
7. Dispose of waste safely (Borges, 2003).

Waste management encompasses the entire process from segregation, collection, handling, packaging, transportation, storage, treatment, recycling, reuse, industrialization and commercialization so that the final destination of solid waste becomes sustainable.

In order to evaluate the cost-effectiveness of its use, a reclassification of waste by reuse, recycling, energy recovery (STENIS, 2003 in Borges 2011) is required. According to the Brazilian standardization: Standard ABNT 10004/04 (classification, characterization, identification).

In order to reduce the amount of solid waste generated by volume or weight, some methods have been adopted, such as drying sludge from effluent treatment plants (Borges, 2011).

The awareness of all sectors of society regarding the environmental issue reinforces the need for quality and new alternatives to dispose and recover waste, transforming them into raw material for other processes. In addition to preventing pollution, this operation allows assessing the cost-effectiveness and the risk for the whole process.

However, such operations are potentially dangerous and should be conducted only by professionals who have experience and knowledge, including job safety. Many environmental problems can be avoided if waste is properly managed (Borges, 2003; 2011).

It is logical to say that a system should be standardized and unique for all states, it is also important to create a program to recover contaminated areas based on the Superfund program (USA).

In 1980, the United States government established the Superfund program to clean up abandoned or illegal toxic dumps because hazardous chemicals from many of these sites were polluting groundwater (BAIRD, 2002 in Borges 2011).

Chemical companies, current and former owners of deposits and the government share the cleaning costs.

Many billions of dollars have already been spent and much more will be needed.

EPA - U.S. Environmental Protection Agency, which identifies waste deposits that pose serious risks to human health and the ecosystem, administers the Superfund Program. According to the author, the states of New Jersey, Pennsylvania and California have the largest number of these deposits. The most common contaminants are heavy metals (lead, cadmium and mercury) and organic compounds (BTX) (BAIRD, 2002 in Borges, 2011).

In fact, humanity's use of metals has been documented throughout history. Civilizations evolved from a stage of simple metal extraction from their minerals to a stage in which they began to make different types of alloys between these elements obtaining new materials.

At any stage of metal manipulation, more or less toxic wastes have always been produced, these wastes have reached and accumulated in the environment (CALISTER, 2002 in Borges, 2011).

In addition to metals, other chemical elements have wide industrial use. The ability to combine the various chemical elements together for a variety of purposes has increased exponentially.

According to data available from the Chemical Abstract Service (CAS), a division of the American Chemical Society, there are records of more than 43 million organic and inorganic substances (CAS, 2009 in Borges 2011).

Out of the various chemicals produced, a small portion has been studied for its effects on the food chain. Great efforts have been made to understand better the role of many of these elements and chemicals in the ecosystems.

ENVIRONMENT PUBLIC POLICIES MANAGEMENT

Brazil's Legislative Framework

The United Nations Conference on Human Environment, that happened from June 5th to 16th, 1972 focused on the need and guidelines for the people of the world to preserve and improve the human environment. Regarding the principles discussed on the conference we find the 4th principle written "mankind has a special responsibility to preserve and judiciously manage the patrimony of the wild flora and fauna and their habitat, which are currently in severe danger due to a combination of adverse factors. Consequently when planning economic development the importance of nature should be considered, including the wild flora and fauna.

Following this understanding and the importance of the principle mentioned above, we find in art. 225 of the Brazilian Federal Constitution, 1988, the ideal that proclaims: “every individual has the right to an ecologically balanced environment, as well as the common use of it by the population due to the essentiality of it for a healthy quality of life, making the responsibility of the public power and the population in general the duty of defending and preserving it for the present and future generations."

The Public Power is the resources, goods and services manager and because of this responsibility, it should guarantee the fundamental right to life that is accompanied by social, economic and environmental public policies. In order to guarantee the dignity of the human life you must have a balanced environment. The declaration of the Rio 1992 stablishes the concept of environmental management as an instrument to accomplish the objectives of preserving and defending the environment, which are compatible with the objectives to the right of social and economical development.

Legislation has been expanded to organize and systematize environmental rights. Law 6.938 / 1981 was created to structure the National Environment Policy System (PNMA). The art. 6^{th} is responsible for the conception, guidelines and distribution of competences among the members of the National Environment System (SISNAMA)

The art. 9^{th}, Law 6.938 / 1981 presents an exemplary role of thirteen standard conceptions on the instruments of the National Environment Policy. They are the defense and protection means of the environment, ultimately.

They are instruments of the PNMA that focus on guaranteeing the efficiency and application of environmental norms and objectives. Each one fulfills a specific and important function within the PNMA which does not exclude other initiatives, although not typified, that facilitate the environment protection and defense.

The list presented by article 9 of Law 6.938 / 81 is as follows. They are instruments of the National Environment Policy:

I .the establishment of environmental quality standards;

II. environmental zoning;

III. environmental impact assessment;

IV. licensing and reviewing of potentially or/and polluting activities;

V. incentives for the production and installation of equipment and the production or capture of energy, aimed at improving environmental quality;

VI. creation of ecological reserves and stations, areas of environmental protection and ecological interest relevant to the Federal, State and Municipal Public Power;

VII. creation of territorial spaces protected by the Federal, State and Municipal Public Authorities, such as areas of environmental protection, of ecological interest and extractive reserves;

VIII. national information system on the environment;

IX. Federal Technical Registry of Environmental Defense Activities and Instruments;

X. disciplinary or compensatory penalties for not obeying the effective guidelines for the environment protection or actions not taken to correct the environment degradation.

XI. Creation of the Environmental Quality Report, to be released by the Brazilian Institute of Environment and Renewable Natural Resources - IBAMA;

XII. provision of the necessary information for the environment, it is an obligation for the public power to produce it, when nonexistent;

XIII. Federal Technical Record of potentially polluting activities and / or activities that use natural resources as economic instruments such as forestry and environmental concession, insurance and others, Ministry of Environment - Central Government Department.

Regarding the State of São Paulo, which is the richest and most populous State in Brazil, Cetesb is the environmental agency responsible for licensing, controlling, supervising and monitoring the potentially polluting activities, focusing its actions on the promotion, protection and monitoring of air, water and soil quality. Cetesb is included in the list of the 16 UN Reference Centers for environmental issues and cooperates with 184 countries in managing the environment, especially with the sharing of information and technology. It is also one of the five world institutions of the World Health Organization that analyzes the quality of water for supply and provides advises within the United Nations Development Program on hazardous waste in Latin America.

Initiatives and Research Support

The National Solid Waste Plan along with the National Environmental Education Policy (PNEA), which in its article 1 defines "environmental education as processes through which the individual and the community build social values, knowledge, skills, attitudes and abilities aimed at the conservation of the environment, a common good of the people, essential to the healthy quality of life and its sustainability". In its article 2, it establishes that environmental education is an essential component of national education, and must be present at all levels of education in an articulated, continuous and permanent way, in a formal and non-formal process, it is an essential condition to accomplish the educational demand presented by the Solid Waste National Plan and Policy, both in the orientation and wide diffusion of its concepts, as well as in the training of each one of the segments of the generating and destination residues chain.

The PNEA objectives are consistent with this framework when seeking to develop an integrated understanding of the environment in its multiple and complex relationships involving ecological, psychological, legal, political, social, economic, scientific, cultural and ethical aspects; ensuring the democratization of environmental information; stimulate and strengthen a critical awareness of environmental and social issues; and to encourage individual and collective participation, permanent and responsible, in preserving the balance of the environment, with the defense of environmental quality as an inseparable value of the exercise of citizenship. Accordingly, in order to implement Article 3 of Law No. 9,795 / 99, as well as Article 77 of Decree No. 7,404, which regulates PNRS, environmental and educational departments at the federal, state, district and federal levels, should organize and establish procedures and standards for the planning and execution of the environmental education programs, in order to.

I. encourage educational and pedagogical activities, in collaboration with entities from the business sector and organized civil society;

II. promote the articulation of environmental education in solid waste management along with the National Environmental Education Policy;

III. carry out educational actions aimed at manufacturers, importers, traders and distributors, with a differentiated approach for the agents involved directly and indirectly with the systems of selective collection and reverse logistics;

IV. develop educational actions aimed at raising consumer awareness regarding sustainable consumption and its responsibilities within the scope of shared responsibility mentioned in Law 12305/2010;

V. support research conducted by official departments, universities, non-governmental organizations and business sectors, as well as the preparation of studies, data collection and information on Brazilian consumer behavior;

VI. develop and implement sustainable production and consumption plans;

VII. promote the training of public managers to act as multipliers in the various aspects of integrated solid waste management;

VIII. disseminate the concepts related to selective collection, reverse logistics, conscious consumption and minimization of solid waste generation.

It is hoped, therefore, that environmental education as an instrument of the National Solid Waste Policy and the cross-cutting theme of this National Plan will serve as a parameter and support for the entire participatory process of formulation, development and monitoring of solid waste public policies, especially regarding the relevant pedagogical practice, planning and implementation of the management processes, evidencing it as a source of articulation, actions, opportunity and synergy with the various sectors involved in solid waste management. The challenge is to ensure that public policy on environmental education and solid waste management is effectively a transformation factor so that constitutional objectives and principles are fulfilled in favor of sustainability and the quality of life of all Brazilians.

The Ministry of Environment (MMA), in a joint effort with federal, state and municipal governments, private sector, non-governmental organizations and always with the participation of organized civil society, has been developing actions on different fronts in order to make feasible the implementation of the National Solid Waste Plan (PNRS).

Its functions are to plan, coordinate, supervise, and control, as a federal agency, national policy and government guidelines for the environment. (Article 6, paragraph III, of Law 6.938 / 81 and article 10 of Decree 99.274 / 90).

Regarding this integration between the different players proposed in these public policies, one aspect that deserves to be highlighted is that the university and the scientific academy society are transforming agents. In this way, CENACID - Center for Scientific Support in Disasters (UFPR) has been serving as an example and reference in this matter.

It includes the participation of researchers, specialists in many different areas, which can be used in emergencies, offer scientific contribution in how to deal with the emergencies and natural, environmental and technological disasters.

Founded in the year 2000, it has already worked on about 40 accidents and major disasters throughout the national territory in Brazil. Among the disasters Cenacid has helped are: floods, oil spills, collapsing structures, ship explosions, landslides, accidents with hazardous substances and other types of major emergencies. In addition to that it has also provided its expertise on requests from the Brazilian government (Itamarati) other organisms such as the United Nations and other countries directly affected by disasters: Argentina and Ecuador (volcano eruption), Argentina and Paraguay (Forest fires), El Salvador, Peru, Haiti (earthquakes), Dominican Republic (risk and treatment assessments), Venezuela (risk assessments in oil installations), Kenya (risk study); Granada (hurricane). It has a cooperation agreement with the UN.

Awarded with the Green Start Award by the United Nations through its Office for the Coordination of Humanitarian Affairs (UNOCHA) In the Environment Programme (UNEP) and the Green Cross International , recognizing the center´s optimal response and its efforts on reducing the consequences in natural, environmental and technological disasters. Its mission is to offer scientific knowledge when necessary to reduce society's losses and suffering in disasters.

FINAL REMARKS

This collaborative work is the product of a combined effort of two professionals with expertise on solid waste management and public policies management. Focusing on Brazil’s legislative framework, public policies and recent disasters.

This article aims to stress the importance of a cooperative action between the government, specialists, international and national agencies and the population in general throughout the whole processes of disaster waste management, to optimize the reduction of the losses and damages in disasters. Ultimately protecting and reducing the suffering of the populations in the affected areas.

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IDENTIFICATION AND EVALUATION OF ENVIRONMENTAL IMPACTS OF OPEN DUMPSITES IN KABUL CITY RESIDENTIAL AREA

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ABSTRACT

Due to the rapid urbanization and lack of planning and financial support, it is resulted that poor state of municipal solid wastes management in Kabul city of Afghanistan. A mass of solid wastes is dumped in the open area without effective collection facilities and environmental conservation measures. Management of these dumps is one of the most crucial environmental problems in Kabul.

In order to investigate the open dumpsites conditions in the residential area, field surveys were carried out in Ditrict-12 Kabul city of Afghanistan in September-2017. Before conducting the field survey, a satellite image was used to identify open dumpsites location. During field surveys the questionnaires were distributed to the local residents, SfM method was used to estimate the volume of waste, leachate and groundwater samples were collected for further chemical analysis. Based on the analysis using GIS software and SfM, estimated volume of waste which were dumped at 103 dumpsites in the study area (55,173m^2) was 5,554 tons' weight. The collected groundwater samples (n=6) and leachate samples (n=12) were analyzed in laboratory condition. Also, a correlation analysis of the analyzed parameters was performed.

To conclude, this study has shown that the groundwater source within the study area is contaminated but there was no correlation found between existence of solid waste open dumpsites and ground water contamination in the number 12 district of Kabul.

Keywords: open dumpsites identification, SfM, leachate and groundwater samples, correlation analysis

1. INTRODUCTION

Human activities produce MSW that are often throwaways because they are considered unusable. These wastes are normally solid, and the word waste suggests that the material is useless and unwanted. Municipal solid waste management (MSWM) is one of the serious environmental problems of any habitation. Shortage in this has severe environmental impacts, resulting in health sanitation problems, and environmental degradation (Abraham, Lingan-2014). Kabul City is the most significant city of Afghanistan, which houses nearly twenty percent of the country's population. Being the national capital and a major commercial center it has witnessed continuous stream of migrants from all parts of the country since 2001. However, the increase of population and unplanned urbanization has increasingly contributed to the generation of solid waste in Kabul City (Abdul Wahab Azad 2013-2015).

Kabul city is facing a critical environmental problem. Such as air pollution, water pollution, the existence of massive quantities of solid waste, and absence of appropriate management are the main and alarming issues in the city. We can also see that there is no proper planning to the efficiency of SW collection, and transportation and collection is becoming a fundamental problem for the Kabul municipality, while also affecting the residents. The management procedure by the municipality and its capacity for the management of solid waste has been very inadequate and unprofitable up to now. Compared to some other governmental organizations the solid waste management agency has received less attention (Noori Hameedullah-2017).

The results of literature reviews concerning waste compositions depicts that organic content of waste which included night soil was about 70%. The plastic, glass, and paper and cardboard contents were 3.8%, 2.2% and 5.5% respectively. While other components of waste which included textile, demolition waste and metals comprised 1.2%, 1.2%, 15%, and 1.2% respectively of the waste stream.

The specific weight or density of waste was 413 ± 52 kg/m^3 at the 95% confidence limits. The waste generation per day per capita ranged from 0.31 to 0.43 kg/d/p in Kabul for the population of 3.5 million at the time (Ali Forouhar, 2012). According to the study by JICA and the Central Statistical Agency (CSA), the entire population in Kabul city in 2007-2008 was 3.1 million and the total solid waste produced during that time is reported at 1603 tons/day, and after simple calculation per capita waste generation was 0.51kg/person/day, another survey estimated that the generation rate was 0.4kg/capita/day, the total amount of waste in 2015-2016 was1840 tons/day at a total population of 4.6 million (CIA, 2017) (Noori Hameedullah-2017).

Open dumping of waste disposal is the most ordinary method of waste disposal in Kabul city, capital of Afghanistan. Solid waste management has become more focused due to its negative effects on the urban environment, and resident concerns about the environmental issues it raises. In Kabul, the collection, transportation, and storage of solid waste is usually managed by municipality. According to UN-Habitat only 48% of solid waste in Kabul is collected and 52% of that is not even collected by Kabul municipality. According to the district-12 waste management's officer in the whole district including planned and unplanned area, there are more than 200 waste collections sites where a lot of uncollected waste exists. This research was conducted to reveal and investigate the environmental impacts and current efficiency for waste collection. Field work investigation was conducted for groundwater and leachate samples and questioners distributed to get the local residents perception regarding open dumpsites impacts nearby.

2. METHODOLOGY

2.1 Study area descriptions

The study area was set in planned area in District-12 which has about 16 km^2 of area with 117,992 populations and 16,856 households.

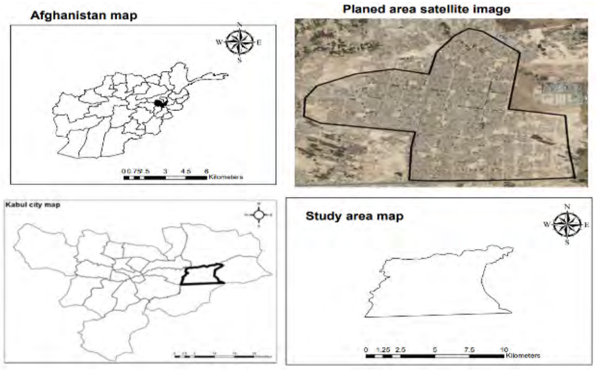

Fig1 study area description

2.2 Questionnaires

A questioner survey was conducted to the residents who are living in the vicinity of 6 open dumpsites, and the author used some closed and some open-ended questions. The questions covering the causes of open dumping, viewpoints regarding environmental impact to them and suggestions to prevent the occurrence of dumping sites.

2.3 Open dumpsites identification

Before field observation on May-2018, the author investigated to identify the number of the open dumpsites in the residential planned area in district-12. The methodology used for dumpsites identification was a satellite image which was taken on march-2018 and field visiting investigations which was conducted in May-2018.

2.4 SfM Survey for solid waste volume estimation

During fieldwork investigation six dumps were chosen, from each site, more than 150-200 photos were captured, with one-meter-long, hand-held, commercially available CASIO digital camera (EX-FR10) and analyzed in Agisoft Photoscan and Easy Mesh Map software to estimate volume of waste.

2.5 Sampling methodology

During the field surveys, six solid waste dumpsites were selected for sampling collection among 115 sites. For further chemical and physical analysis, 6 wells water which was located near to dumps and 6 leachate samples were collected, the location of dumpsites and sampling points can be seen in Fig2.

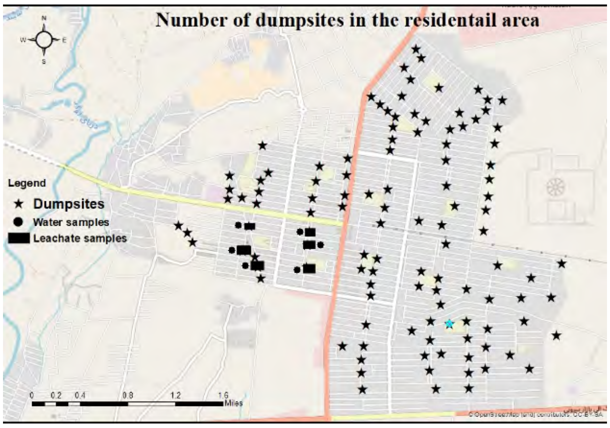

Fig2 dumpsites of waste and samples collection points

2.6 Samples preparation for laboratories analysis

The leachate and groundwater samples were analyzed for physical-chemical parameters that included: pH, electrical conductivity (EC), detected heavy metals, Al, B, Ba, Cd, Cr, Fe, Cu, Mn, Ni, Pb, and Zn. In addition, during laboratory analysis TOC, concentration at all collected samples were examined.

2.7 (ICP-MS) Analysis

For ICP analysis first of all samples were filtered (.45micrometer membrane) syringe. The filter served to collect all solid suspended sediment. Each sample was diluted by pipetting 5 mL nitric acid into a 20-mL samples, and heated 150C^o, after that 1% samples with1% nitric acid diluted with pure water in 200ml volumetric flask Figure3.

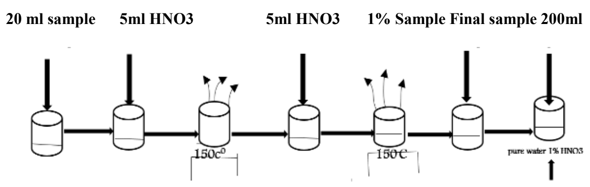

Fig3 samples preparation proccess

2.8 Total Organic Carbon Determination Analysis

For TOC concentration measurements in leachate and water samples, 1 milliliter samples and 1% HNO_3 diluted into 100 milliliter tube because the density of leachate cases breakdown instrument. For groundwater, 10 milliliter samples and 1% HNO_3 added to 100 milliliter tube.

2.9 Correlation and regression analysis

The correlation and regression analysis investigation method was used to find out the relation between dumps waste and water pollutions.

3. RESULTS AND DISCUSSTIONS

3.1 Questioners survey

During field work, a questioner survey was carried out in Ditrict-12 Kabul city of Afghanistan, in 2017. A total of 24 questionnaires were administered, six dumpsites were targeted for questionnaires, for each dumpsite four persons were chosen for interviews that they are living nearby. Household heads were chosen to represent their entire households. The authors employed a face-to-face interview approach to obtain the required responses from the household heads and this accounted for a100% response rate. All the participants gave their opinions and explained their feelings on the effects of open dumping in this area. The household respondents generally viewed the open dumpsites as an unkempt environment.

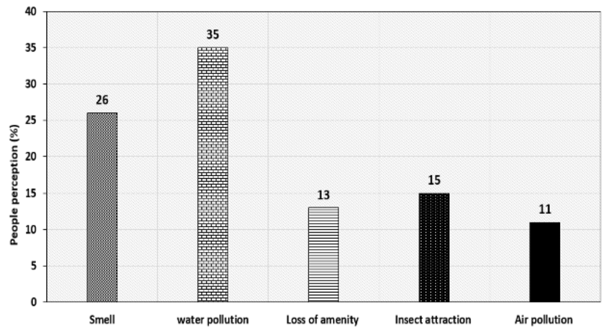

Fig4 Residential perception regarding dumps (n=24)

They described the condition as dirty, smelly and seriously filthy among others, to portray how worrisome they were. Almost all of the household respondents complained of the stench of the dumpsites which some of them even perceived it to be the cause of numerous diseases in the communities. Most participants highlighted the need to implement measures to prevent open dumping and that open dumping effects on the public health and environment.

The local community perceptions regarding environmental impacts of dumps indicated that 26.5 % of respondents believed that the presence of open dumpsites has a bad smell to the surrounding area, and 35 % of respondents believed that open dumpsites are a big threat to the groundwater due to leachate generation of solid waste and contaminated groundwater (Figure4). In addition to the above, 15.1% reported that the dumpsites constitute breeding place for rodents, disease vectors among others and 11.2% said the dumpsites had made the air pollution and environment dirty (Figure4). The study area residents (62.5 %) believed that open dumping was related to non-existing or unavailable waste collection services. This is one of the reasons that people dump their waste in open area (Figure 5). 12.5% of the local residents complained about the lack of dustbins and 26% said that the lack of public awareness is a reason to dump their waste in open area.

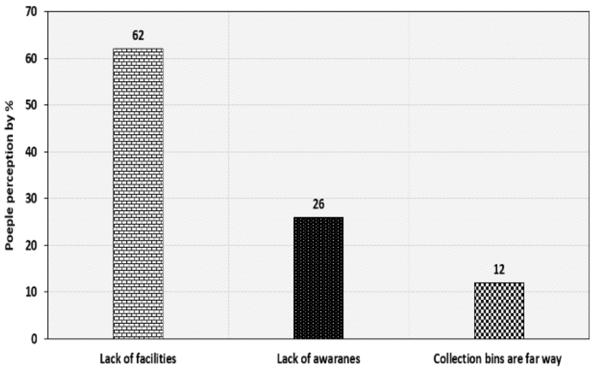

Fig5 Reasons of open dumping (n= 24)

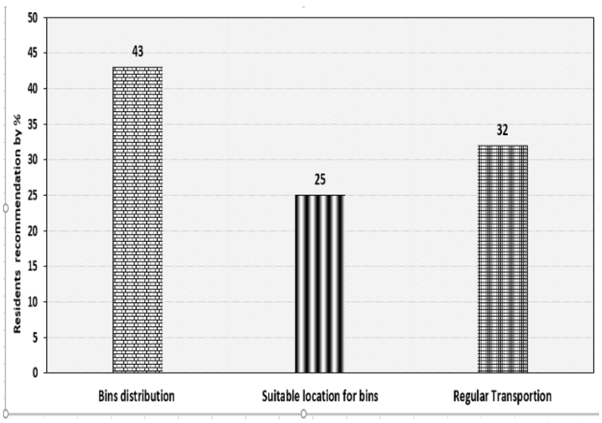

Fig6 residents' recommendation for open dumps reduction (n= 24)

The residents needed that the municipality should assist them to stop open dumpsites in their area. They mentioned that the municipality should increase and distribute the waste collection bins. As we can see in the Fig 6, 43% of the residents recommended waste collection facilities in their area. 25% of the residents recommended that the suitable location of waste containers, and about 32% of the residents emphasized that the collection system must be regular.

3.2 Dumpsites identification

In the case study area (District-12), around 115 open dumps were discovered. The tools that used for dumpsites identification was a satellite image and GIS software, visual identifications by field surveys.

Table1 dumpsites identification accuracy

Satellite image identification	Fieldwork investigations		Total sites
	Correct	Wrong	
Number of identification sites	97	5	102
Number of miss identification	13	–	–
Total	115	–	–
Accuracy (%)	97/115*100	83.4%	

Based on the observation, almost all dumps were located at public space, which is allocated for green park and sports area for residents. During dumpsites identification with satellite image at GIS software 102 dumps were identified as dumpsites. On the other hand, by field investigation, 97dumps were verified and five dumps were wrong identification. In the results of field investigation in the area, there were 13 more dumpsites were found. The total number of dumpsites were 115.

In conclusion mix approach of satellite image at GIS and fieldworks, investigation for dumpsites identification was applied. The accuracy between the mentioned approach was 84.3% and 55,173 m^2 of the area was covered by 102 SW dumpsites. The results of investigation can be observed from the Table1.

3.3 SfM method for Specific weigh and volume estimations

A survey was carried out in September 2017 in District-12, Kabul city of Afghanistan, to estimate the volume of municipal solid waste. In this study images were taken from solid waste dumpsites in the cases study area, then imported into the Agisoft Photoscan and Easy Mesh Map software system, the entire process for SW volume calculation can be seen from the (Fig7). This survey utilized two primary activities for SW volume estimation in the area. At first five small dumpsites were selected to estimate specific weight of SW. Almost 100-150 photos were taken at each sites to obtain suitable 3D models in Agisoft Photoscan software to estimate volume of solid waste (Fig8). And the weight of the SW was measured with spring type scale. The entire process for volume and weight estimation can be seen in Table2.

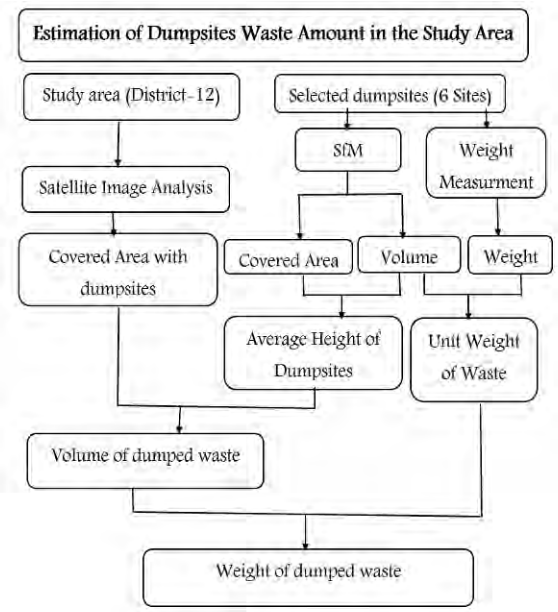

Fig7 volume estimation process

Table2 solid waste specific weight estimation

No	Weight of waste (kg)	Volume of waste (m^3)	Unit weight (kg/m^3)	
i.	210	0.229	917	
ii.	50	0.226	221	
iii.	55	0.3	183.3	**Average 503.4**
iv	53	0.078	679	
v	45	0.087	517	

Fig.8 open dumpsite and camera position

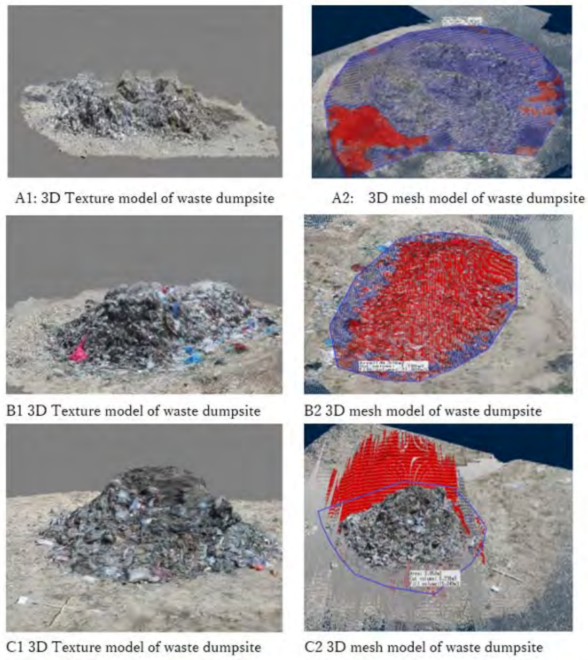

Fig. 9 3D texture models and 3D mesh models of dumps

As Second activity, six relativity big dumps were chosen for SfM survey, at each dumpsites 150-200 photos were taken and analyzed in computer by using the software. Image processing began with importing photos into Agisoft Photoscan. All photos for each open dumpsite were imported separately into Agisoft photoscan software to build 3D model for volume and covered area estimation. After all processing accomplished in computer used software for all six dumps, the volume and covered area were calculated (Fig9).

According to SfM investigation results for six dumpsites volume, weight and the covered area was estimated. Based on covered area and volume the average high for six dumpsites were calculated. In the case study area 102 dumpsites were recognized by a satellite image, and field investigation. For all 102 sites, covered area, weight and volume of SW were estimated with GIS and SfM software (equation 1, 2, 3).

Table 3 SfM results for volume and weight of waste

No of open dumpsite	Covered area (m^2)	Volume (m^3)	Weight ton (ton)
1.	517.9	17.8	9.0
2.	1158	139	70.0
3.	4	15	7.6
4.	351	153.6	77.4
5.	156.7	70.5	35.5
6.	149.5	71.9	36.2
Total	2,337.1	468	235.6

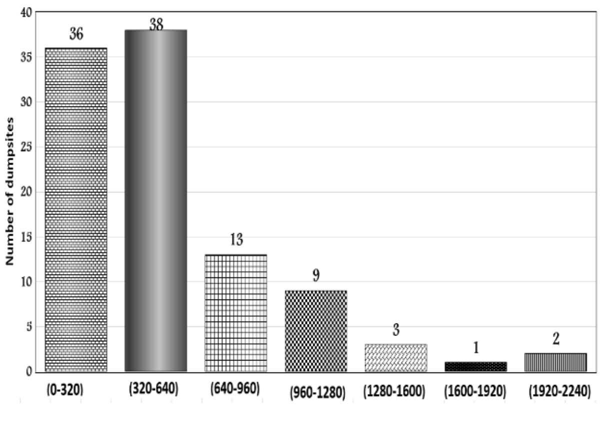

Fig. 11 Number of dumpsites categorized by (m^2) the size of the covered area with SW

Average unit weight of waste: 503.4kg/m3 (Table2):

Total waste volume of six dumps: 468m^3,

Total covred area with six dumps: 2,337 m^2 (Table3):

Average height: $Hm= Vm^3/Am^2= 468m^3/2{,}337\ m^2=$ **0.2m**…………………………………………...…. 1

Total volume=$\sum_{k=1}^{102}$ area m^2* average high m=55,173 m^2*0.2m= **11,034.5 m^3**……………………………. .2

Total weight: Unit weight* volume/1000=
503.4*11,034/1,000=**5,550.4ton** ……........................3

Covered area with SW was categorized into seven groups based on covered area size. Approximately 38 dumpsites covered area between 0-320 m^2, and about 36 dumpsites covered area between 320-640 m^2. As observed from the results, 76% of land covered with dumpsites which are ranged between 0-640.5m^2. Finally, around 28 dumpsites covered area, ranged between 640-2240 m^2, it means 24% area covered with relatively big sized dumpsites Fig11.

3.4 Laboratory analysis

3.4.1Groundwater sample analysis: Dug wells and bore wells were selected for sampling, which are functional and continuously used for drinking and domestic purposes. During the field survey totally six groundwater samples from wells which are located nearby dumpsites and 6 leachate samples were collected for laboratory analysis. The groundwater samples were analyzed for different heavy metals by ICP/MS and compared with WHO and Afghanistan standard for drinking water. As observed from the (Table 4), the highest concentration of Al detected in well-1 (12.8 mg/l) and the lowest concentration is detected in well-5 (5.4mg/l), respectively.

Table 4 detected heavy metals in groundwater samples

Parameters	Gw-1	Gw-2	Gw3	Gw-4	Gw-5	Gw-6	WHO	Afghanistan standard
Al	12.8	10.3	6.9	5.4	6.8	6.4	0.2 mg/l	0.2 mg/l
B	1.6	1.4	2.3	4.2	3.4	2.4	2.4 mg/l	2.4 mg/l
Ba	0.5	0.2	0.2	0.1	0.2	0.2	0.7 mg/l	0.7 mg/l
Cd	0.03	0.02	0	0	0.02	0.03	0.003 mg/l	0.003 mg/l
Cr	0.1	0.08	0.08	0.08	0.06	0.08	0.05 mg/l	0.05 mg/l
Pb	0.8	0.6	0	0	0.4	0.6	0.01	0.01 mg/l
Mg	103	35.5	86.4	152.8	74.7	71.9	-	30 mg/l
Mn	0.1	0.05	0.07	0.04	0.04	0.06	0.4 mg/l	0.3 mg/l
Mo	0.2	0.3	0.1	0	0.1	0.08	-	-
Cu	1.3	1.0	2.0	2.0	0.5	1.4	2 mg/l	2 mg/l
Fe	3.5	3.5	2.8	4.4	3.3	4.7	0.3 mg/l	0.3 mg/l
Ni	0.4	01.9	0.7	1.0	0.2	0.6	0.07 mg/l	0.7 mg/l
Zn	2.8	2.4	2.9	3.3	2.2	2.3	3.00 mg/l	-

The results obtained, it shows that Al concentration in all groundwater samples was exceeded the WHO and Afghanistan standards for drinking water (WHO 0.2 mg/l). B concentration amount in W-4 and W-5 exceeded, the WHO standards for drinking too. Ba concentration is lower than WHO limit in all collected groundwater samples. The minimum and maximum concentrations amount of Cd was started from not detected to 0.03 mg/L respectively. Whereas the maximum allowable limit for Cd as per WHO guidelines is 0.003 mg/L (Table 4). The minimum and maximum concentrations of Cr were 0.08 to 0.1 mg/L respectively, whereas the maximum allowable limit for Cr as per WHO guidelines is 0.05 mg/L. Cr concentration levels in all studied groundwater samples was detected and exceed the allowed limit of WHO for drinking water (0.05mg/l). The concentration of Cd starts from not detected to maximum 0.2 mg/L have been recorded at different groundwater samples. This study result shows most of the groundwater samples except W-3 and W-4 has higher lead concentration. According to WHO standards for drinking water, the allowable Pb concentration amount in drinking water is 0.01mg/L. The minimum and maximum concentrations level of Ni was 0.4 to 1.8 mg/L respectively.

Whereas the maximum allowable limit for Ni as per WHO guidelines is 0.07 mg/L.

As observed from the Table4, Ni concentration levels in all studied samples are exceeding the allowed limit of WHO standards for drinking water. The minimum and maximum Zn concentrations varied between 4.9 and 22.5 Mg/L. The results indicate that, concentrations of Zn were found in all 6 samples exceeded the WHO limits as per drinking water (3.0 mg/l). The highest concentration of Zn is detected in W-1 and the lowest concentration is W-3 in the study area (Table 4).

3.4.2 Cluster analysis for heavy metals: In the present study, cluster analysis is based on the major groundwater quality parameters of the groundwater samples. Cluster analysis classified into three groups, groups 1, 2 and 3. The variations of metals in between the groups are shown in table5. The groundwater wells from group (1) indicate higher concentrations of AL, Pb, Cd and Fe. In addition, the group (2) observes higher Mg and Cu value fig12.

Degree of exceeding ratio equation=

Heavy metals concentration/Afghanistan standards for drinking water……………………………………… (4)

Table5 Heavy metals degree of exceeding ratio

No	GW-1	GW-2	GW-3	GW-4	GW-5	GW-6	Afghanistan ST
Al	64	51.5	34.5	27	34	32	0.2 mg/l
B	0.66	0.58	0.95	1.7	1.4	1	2.4 mg/l
Ba	0.7	0.28	0.28	0.14	0.28	0.28	0.7 mg/l
Cd	10	6.6	0	0	6.6	10	0.003 mg/l
Cr	2	1.6	1.6	1.6	1.2	1.6	0.05 mg/l
Pb	80	60	0	0	40	60	0.01 mg/
Mg	3.4	1.2	2.8	5.0	2.5	2.4	30 mg/l
Mn	0.3	0.16	0.23	0.13	0.13	0.2	0.3 mg/l
Mo	-	-	-	-	-	-	-
Cu	0.65	0.5	1	1	0.25	0.7	2 mg/l
Fe	11.6	11.6	9.3	14.6	11	15.6	0.3 mg/l
Ni	0.57	2.7	1	1.4	0.28	0.85	0.7 mg/l
Zn	0.93	0.8	0.96	1.1	0.7	0.76	3.0 mg/l

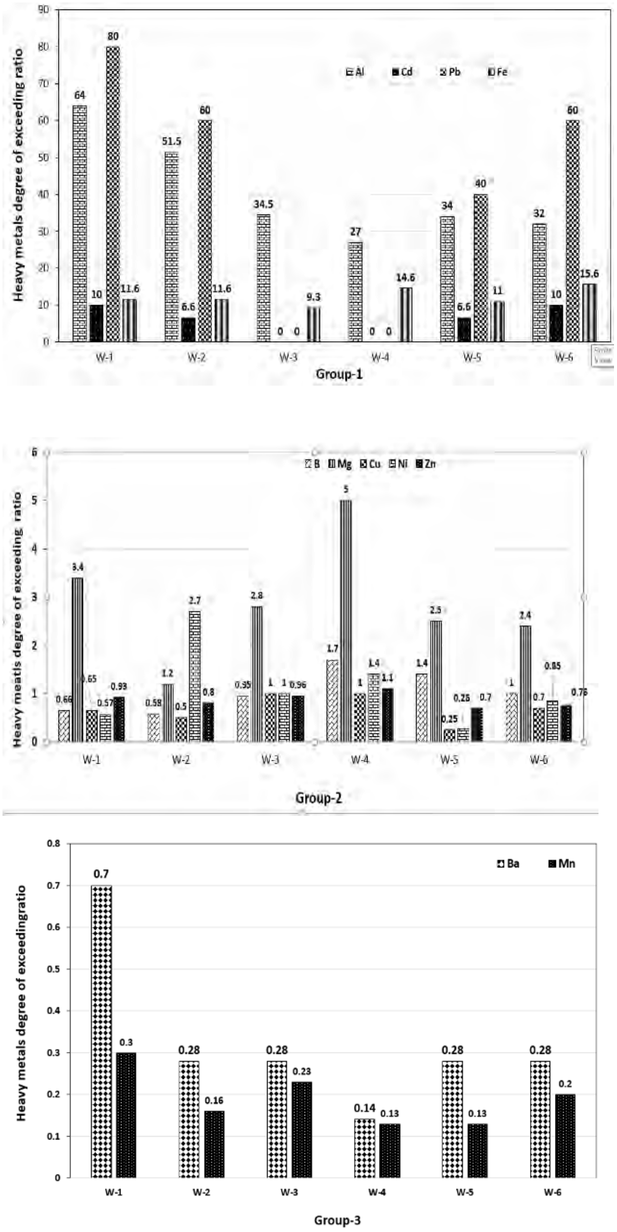

Fig12. Heavy metal culster analysis ratio

3.4.3 TOC concentration in collected samples: TOC or total organic carbon is a composite measure of the overall organic matter content in a water sample. Because TOC is easily measured and monitored, TOC is used as an indicator of the natural organic matter (NOM) in water.

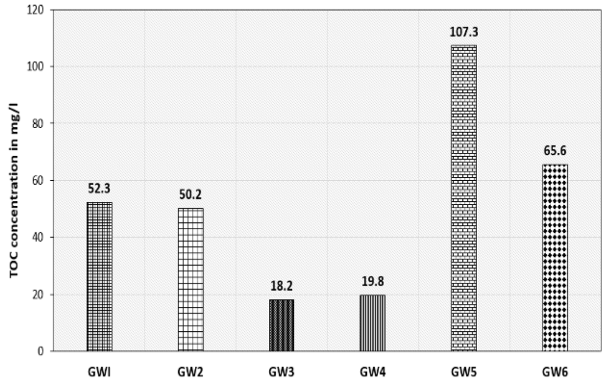

Figure 18: TOC concentration in groundwater

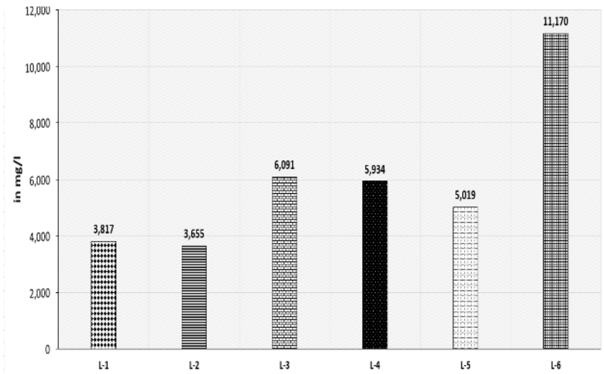

Figure 18: TOC concentration in leachate

3.4.4 Correlation and regersion analysis: In a regression analysis we study the relationship, between two variables, one variable y (groundwater), called the dependent variable, and others variable x1, x2, (Solid waste leachate and dumpsites waste volume), called the independent variables. As we can see, P-Values of each of these parameter in Table7, it was resulted that there was no clear relationship was found between groundwater quality and dumped waste. The results of the correlation analysis which are shown in Table8, indicated that TOC in soil has a positive and signification correlation with dumpsite waste voluem and TN in soil also has positive relationship.

Table7 Regression analysis for heavy metals

Y	X1	X2	R Square	Adjusted R Square	Coefficients			P- Value		
					Intercepts	X1	X2	Intercepts	X1	X2
Al Con - GW	Volume of SW	Al Con- LC	0.061	-0.56	0.353	0.002	0.239	**0.924**	**0.8219**	**0.6964**
B Con- GW	Volume of SW	B Con- LC	0.291	-0.18	1.483	0.008	-0.151	**0.4608**	**0.3536**	**0.7554**
Ba Con-Gw	Volume of SW	Ba Con-LC	0.61	0.36	0.48	-0.002	-0.20	**0.036**	**0.12**	**0.3**
Cr Con-GW	Volume of SW	Cr Con- LC	0.32	-0.13	0.872	-0.018	4.285	**0.9091**	**0.6845**	**0.6421**
Ni Con- GW	Volume of SW	Ni Con- LC	0.524	0.20	0.621	-0.009	1.623	**0.8458**	**0.1949**	**0.737**
Pb Con Gw	Volume of SW	Pb Con-LC	0.03	-0.60	0.49	-0.001	-0.01	**0.41**	**0.81**	**0.98**
F Con - GW	Volume of SW	F Con- LC	0.228	-0.285	84.744	-2E-04	-0.0009	**4.008**	**0.976**	**0.421**
Zn Con-GW	Volume of SW	Zn Con-LC	0.399	-0.001	8.362	-0.034	3.804	**0.3684**	**0.5679**	**0.4096**
TOC Con-GW	Volume of SW	TOC Con-LC	0.025	-0.624	64.538	-0.071	-0.001	**0.2648**	**0.8431**	**0.8377**
PH - GW	Volume of SW	PH - LC	0.436	0.061	9.2	-0.005	-0.096	**0.0066**	**0.273**	**0.659**
EC GW	Volume of SW	EC LC	0.069	-0.55	1.979	0.002	-0.004	**0.2585**	**0.779**	**0.925**

Table8 Correlation analysis

–	GW-TOC	Volume	Soil-TOC	GW-TN	Volume	Soil-TN	GW-PH	Volume	Soil-PH	GW-EC	Volume	Soil-EC
GW TOC	–											
Volume	-0.08	–										
Soil-TOC	-0.63	0.59	–									
GW-TN	-0.10	0.52	-0.11	–								
Volume	0.08	1	0.59	0.52	–							
Soil-TN	0.72	0.37	0.77	0.05	0.37	–						
GW-PH	0.06	0.05	-0.40	0.71	0.05	0.11	–					
Volume	-0.08	1	0.59	0.52	1	0.37	0.05	–				
Soil-PH	0.10	-0.44	0.04	-0.63	-0.44	-0.12	-0.31	-0.44	–			
GW-EC	-0.36	-0.23	0.52	-0.68	-0.23	0.31	-0.53	-0.23	0.83	–		
Volume	-0.08	1	0.59	0.52	1	0.37	0.05	1	-0.44	-0.23	–	
Soil-EC	-0.62	0.31	0.37	0.57	0.31	0.60	0.56	0.31	-0.007	0.13	0.31	–

CONCLUSION

A field survey was carried out in September 2017, during the field survey, six solid waste dumpsites were selected for leachate samples and groundwater samples from the vicinities of dumpsites for further laboratory analysis and questioner's survey was administered in order to get the viewpoints of the residents regarding open dumpsites to their area. In addition, during the fieldwork investigation, 115 dumpsites were identified and the volume of the dumpsites was estimated by SfM and GIS software. Result of groundwater quality analysis said that Al, B, Ba, Cd, Cr, Pb, Fe, Ni, Zn concentration were higher than WHO standard. This study has shown that the groundwater source within the study area is contaminated but it is not due to existence of solid waste open dumpsites in the number 12 district of Kabul. This can be considered as a menace for people who daily intake the waters, as drinking water.

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DEVELOPMENT AND PROMOTION OF SOLID WASTE MANAGEMENT EDUCATION IN ELEMENTARY SCHOOL USING THE JAPANESE MODEL: CASE STUDY IN DA NANG, VIETNAM

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ABSTRACT

This paper presents the differences in characteristics of environmental education in elementary schools of Japan to those of Vietnam, using how we develop and promote solid waste management in Vietnam by conducting a case study in Da Nang city. According to observed solid waste management education in 4th grade elementary schools in Kitakyushu, Japan in 2016, we created our solid waste management teaching materials for elementary school students in Vietnam. In the Kitakyushu elementary school there was one class where a waste collection truck come to the school and students were educated on the importance of waste collection using the truck as a tool for education. In addition, we observed students serve themselves food and clean up after eating at lunchtime. At the end of the solid waste education section, students made a newspaper to show their understanding about solid waste management. We made one environmental education class every 2 weeks for 6 months in Da Nang. We tested environmental programs based upon the model used in Kitakyushu. Because of a difference in class size and schedule, we modified the teaching method from the Kitakyushu model. With 20 students in class in Japan, the student can have individual activities, but with over 30 students in Vietnamese elementary classes, we modified the group work activities in our environmental education in Vietnam. To reinforce material taught in the environmental education class, information was printed onto notebook covers and distributed to the students at the beginning of each class. This helped to refresh material taught about solid waste.

Keywords: Environmental education, elementary school, solid waste management.

INTRODUCTION

The United Nations Conference on Human Environment held in Stockholm in 1972 allowed the world's communities to recognize the importance of environmental education, preservation of environment, as well as balanced development (Ministry of External Relations, 2009). Since then, environmental education has significant agendas on both local and international communities.

However, environmental education provides the necessary knowledge, awareness, values and skills needed by citizens, as well as decision makers to understand the complexities of the environment. Vietnam is one of the developing countries in South East Asia and it has expressed at the development planning level has undertaken a number of measures to control hazards of development activities, and ensure a healthy environment of the country.

The main purpose of the study is to apply the environmental education for elementary schools in Vietnam and their solution through the adoption of Japanese experience of environmental education. For this reason, it is necessary to understand the environmental problem of both countries. But considering constraints, like distance between Japan and Vietnam, linguistic differences, resources and time, it was decided to undertake the study mainly on the observation in elementary schools in both countries and conducted in research papers.

BACKGROUD OF ENVIRONMENTAL EDUCAIOTN IN TWO COUNTRIES

Characteristics of elementary education

Environmental problems are different in country to country, and not same type of problems. It depends on social culture and natural conditions. Therefore, it may require different type of solution including education, technology. To apply education solution from Japan to Vietnam, the study wanted to understand difference between characteristics of elementary education between Japan and Vietnam (Table 1).

Table 1 characteristics of elementary education in Japan and Vietnam

	Japan	Vietnam
School year segmentation	Total: 12 years - Elementary 6 years - Junior high school 3 years - High school 3 years	Total: 12 years - Elementary 5 years - Junior high school 4 years - High school 3 years
Enrollment ratio	The Japanese primary school enrolment rate exceeds 99%.	Viet Nam achieved universal primary education in 2000, during the period between 2001 and 2010, the net enrolment rates increased significantly. Enrolment primary education enrolment increased from 94 per cent to 97 per cent. (TheWorldEducationForum, 2015).
Student teacher ratio	Class size and school size tend to be smaller in rural areas. By law, the maximum class size for public elementary is set at 40, and at 35 for the first and second grades in elementary school. Most elementary schools have a class size of 26 to 30. The number of regular teachers in each public compulsory school is determined by the number of classes in the school, according to the public school standard law (Yamasaki, 2016).	By law, he maximum class size for public elementary is set at 35. Most elementary school have a class size of 40-50, some elementary school have a class size of 60 in big cities, such as Ha Noi or Ho Chi Minh (According to Article 17 of the Charter of the Vietnamese elementary school).
Textbook policy	No national text book	National text book

National environmental education policy

Environmental education emerges as one of the possible strategies to face up to the double-order, cultural and social, civilization crisis. The government must play the role of strengthening civil society as the mainstay of superstructure (Sorrentino, Trajber, Mendonça, & Ferraro Jr, 2005). The study want to show national policies and objectives in environmental education in Japan and Vietnam (Table 2).

Table 2 Environmental education objectives in Japan and Vietnam

Japan	Vietnam
Education in the environment is to foster interest in the environmental and rich receptivity toward nature through various experiences in natural and in local communities. *Objectives:* 1. Foster receptivity towards nature: Enable students to be interested in all events and phenomena in their surrounding environments, to be highly motivated to interact with such environments and to be highly receptive towards nature. 2. Foster environmental perspectives and thinking: Foster views and ways of thinking about the environment that will lead to building a sustainable society by providing children with the ability to seek out and solve problems in events and phenomena in their immediate environmental and social surroundings. 3. Foster ability to take action concerning the environment: Enable students to think and act upon choices about lifestyles that conserve the environment and about what practical steps to take, to take responsible action on their own, and cooperate in problem-solving. Additionally, cultivate not only efforts for change in daily lifestyles but also the ability to take action to build a brighter environment in the future towards creating a sustainable society. (Curriculum Research Center of Japan, 2007)	The Prime Minister's Decision No. 153/2004/QD-TTg, publicizing the strategic orientation for sustainable development in Vietnam which implements Agenda 21 in Vietnam (the main features of which include sustainable development components). Sustainable development is the harmonious development in terms of Economic - Social - Environmental aspects to meet the needs of present generations without compromising, hindering the ability to provide resources for economic development, quality of life of the future generations (Hoang, Do, & Perera, 2009). *Objectives:* 1. Environmental education as ESD through educating of water resource and planting value. 2. Life skills education as ESD: For pre-school education, life skills education in primary level, life skills education in lower secondary level, life skills education for upper secondary students 3. Cleaner Production

Environmental policy of Kitakyushu and Da Nang

In addition, local government can use difference ways to apply national policy. To understand situation between 2 cities Kitakyushu and Da Nang, the study summarized city policy from Kitakyushu and Da Nang (shown in Table 3).

Table 3 city policy from Kitakyushu and Da Nang

Kitakyushu	Da Nang
The City of Kitakyushu in Fukuoka Prefecture is the 13th largest city in Japan. Located on Kyushu island just south of the Japanese main island, and it is regarded as a gateway to Asian economies. In 1971, prior to the establishment of the Environmental Agency by the national government, Kitakyushu founded the Environmental Pollution Control Bureau (currently the Environment Bureau). Kitakyushu City also established a number of regulations, including the Kitakyushu Pollution Control Ordinance which was more stringent than the national laws at that time and enforced a series of effective measures that targeted major companies in the city, including the execution of agreement to prevent pollution. Responding to the local government request, private enterprises introduced cleaner production, including energy conservation, resource, recycling, and pollution reduction through technological innovation and capital investment. These collaborative efforts between citizens, businesses, and local government helped to bring significant improvement in Kitakyushu's environment (Ministry of Foreign Affairs of Japan, 2015). The Organization for Economic Co-operation and Development (OECD) of 1985 introduced Kitakyushu's improved environment to the world as the example of city transformed from a 'Gray city' to a 'Green city'.	The City People's Committee Decision on the "Promulgation of the Plan for Developing Da Nang—The Environmental City" lays the foundation for city planning in the context of sustainability and encourages resource efficiency (TheWorldBank, 2013). The year 2020 was set as a target for many different environmental issues such as air pollution reduction, waste treatment and recycling, energy conservation, and renewable energy. The plan is based on Agenda 21 of the Vietnamese government (Prime Minister's Decision No. 153/2004) and Vietnamese Environmental Standards 2. The general goals for the Environmental City Plan are to: (1) Provide a safe and healthy environment for people, assuring land, water, and air quality; (2) Prevent environmental pollution and degradation; and (3) Make the people of Da Nang city aware of environmental protection and Da Nang's development as an environmental city (Phan Hoang & Kato, 2016).

SOURCE SEPARATION PRACTICE IN KITAKYUSHU AND DA NANG

According to the Waste Management and Public Cleansing Law (1970), solid waste is divided into two broad categories such as municipal waste and industrial waste in Japan (Ministry of Foreign Affairs of Japan, 2015).

Kitakyushu

Figure 1 Municipal Solid Waste Management Systems in Kitakyushu City

*Source: Background Paper on the City of Kitakyushu, OECD Green Cities Programmer (Final), City of Kitakyushu, 2012

The City of Kitakyushu applies the separated waste collection system, each household separates waste into 15 types or 21 categories and dispose of them accordingly (Ministry of Foreign Affairs of Japan, 2015).

The residents are requested to purchase the designated bags to put their household or kitchen waste and others separately. The household waste collects twice a week while other recyclable items collect once a week. The city has established waste collection stations at a ratio of one location for 10-20 households to ensure efficient operation. Residents bring their waste to collection points by 8:30AM of the specified collection day. Each collection point has a blue colour net to cover the waste to prevent from animals. The residents have responsible to clean, manage and monitored of the collection points. (Ministry of Foreign Affairs of Japan, 2015).

"The city also placed special collection boxes at different locations including selected supermarkets, community centres, and convenience stores to collect some recycling materials, such as cartons and trays, electric appliances, and other materials". The city provides approximately seven JPY per kg for the recovering group, to motivate voluntary groups for the recycling activities (Ministry of Foreign Affairs of Japan, 2015).

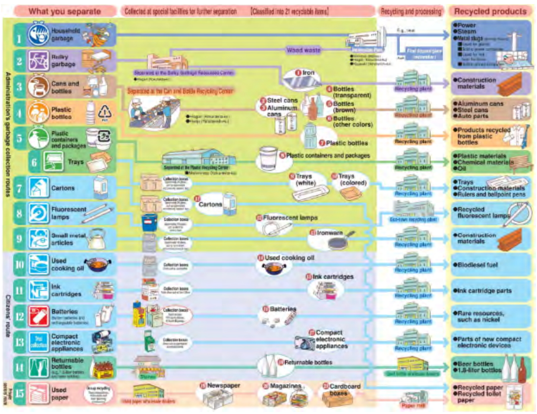

Figure 2 Waste Separation Types in Kitakyushu City

*Source: Solid Waste Management System of City of Kitakyushu, Kitakyushu City, 3rd Asian Sanitation Dialogue, 28 May 2014, http://wastewaterinfo.asia/sites/default/files/downloads/S5-03-Ikeda.pdf, Accessed on 23 September 2018.

Based on the past experience in improving the environmental problems, Kitakyushu City promotes the environmental actions with residents as an environmental learning system in the city.

- These activities focus on creating an interest in resource and waste management based on the 3R principles.
- The city implements awareness raising activities through various environmental events such as Eco Life Stage.
- My Bag Campaign was established to reduce the consumption of shopping bags, encouraging residents to use their own bags.
- A variety of measures are introduced to educate young and school kids on the environmental education and 3R activities.
- The city has established the Environmental Museum in 2001 as a historical place for environmental issues and learning.
- A set of comprehensive and systematic environmental education text books (Midori Note) was published in collaboration with the Education Council targeting different age groups, from infants to junior high schools (Ministry of Foreign Affairs of Japan, 2015).

Da Nang

According to the Da Nang Urban Environment Company Limited (Da Nang URENCO), SMW in the city and the quantity of solid waste in the city is increasing. In most urban areas, municipal solid waste (MSW) is not officially sorted at source. Few households separate their solid waste by selling bottles, jars, metal, and paper to scrap collectors. However, in recent years, a number of pilot projects promoting solid waste separation have been implemented in the large cities of Hanoi, Da Nang, and Ho Chi Minh. For several reasons, these efforts have not been very successful, partly due to the lack of community awareness; collection and treatment problem.

Da Nang City promotes the environmental activities:

- The 3R (Reduce, reuse, and recycle) approach focusing on community participation (Dao, Downs, & Delauer, 2013).
- Promote environmental education for sustainable development at elementary schools in Da Nang city (Phan Hoang & Kato, 2016).

ELEMENTARY ENVIRONMENTAL EDUCATION EXAMPLE IN KITAKYUSHU

Goals of this environmental education

1) Understanding the fact that projects and policies related to disposal of waste is helping people in the neighbourhood improve and maintain their living conditions.

As a member of local community, develop interests in disposal of waste and participate in activities to reduce wastes and recycle resources.

2) By observing, researching and reading documents about disposal of waste, which is necessary for people in the area, understand that projects and policies have been managed by planning and participation as well as helping improvement of living conditions for the people in the area.

Evaluation criteria

Table 4 summarizes evaluation criteria of students that were prepared by the teacher of this environmental education course.

Table 4 Evaluation criteria of students

Interests, willingness and attitude toward social events ・Having interest in activities related to disposal of waste, which is necessary for people in the area, and research is done with enthusiasm. ・Participation in activities to reduce wastes and recycle resources are done as a member of local community.
Social consideration, determination and expressions ・Policies and projects related to disposal of waste are expressed according to consideration of learning issues and plans. ・Understand that polities and projects related to disposal of waste are helping people in the area improve and maintain good environment by connecting our everyday life and they are expressed in appropriate manner.
Skills of observation and research ・Activities related to disposal of waste which is necessary for people in the area Summary is made by collecting necessary information through one-site observation, research, and collection of concrete documents
Understanding and knowledge of social events ・Understanding that policies and projects related to disposal of waste help people in the area maintain good living conditions

Course outline

Total time: 13 hours

Class hour: 14:15 ~ 15:00 (5^{th} period)

Number of lessons: 5

Number of students per class: 23

Contents of each lesson

- *Lesson 1: Observe waste truck when it collects waste at school*

Objectives:

Students were educated on the importance of waste collection using the truck as a tool for education.

- *Lesson 2: Let's examine garbage disposal efforts in Kitakyushu city*

Objectives:

Shop, local government and citizen cooperation to reduce waste in city

Content:

- 14:15 ~ 14:25: Teacher go over last lesson's contents.
- 14:25 ~ 14:36: 10 minutes for students to answer questions from teacher
- 14:36: Teacher show super market pictures
- 14:40 ~ 14:45: Students answer questions to their note
- 14:50 ~ 15:00: Questions and comments from student

- *Lesson 3: Let's reduce the waste and think about what we can do*

Objectives:

To protect environment, we will try our best to reduce waste

Content:

- 14:15 ~ 14:20: Teacher go over last lesson's contents.
- 14:20 ~ 14:25: Teacher asks questions about recycle waste
- 14:25 ~ 14:35: 10 minutes for students to answer questions from teacher
- 14:35 ~ 14:40: Teacher shows student how much waste/day/ person can discharge to environment in Kitakyushu
- 14:40 ~ 14:50: Students works
- 14:50 ~ 15:00: Students answer question: how to reduce, reuse and recycle waste to their note

- *Lesson 4: Please summarize what you studied in a newspaper*

Objectives:

Student should promote how to reduce the waste

Content:

- 14:15 ~ 14:35: Teacher ask student: what student can do to reduce the waste.
- 14:35 ~ 15:00: Student make newspaper

- *Lesson 5: Please summarize what you studied in a newspaper*

Objectives:

Student should promote how to reduce the waste

Content:

- 14:15 ~ 14:25: Teacher go over last lesson's contents
- 14:35 ~ 15:00: Student make newspaper

Observation survey of students

We observed 4th grade and 5th grade student clean up school in morning before lessons.

In addition, we observed students serve themselves food and clean up after eating at lunchtime.

APPLICATION TO DA NANG

Objectives

Promote and develop solid waste management education for student in elementary school in Vietnam, especially in Da Nang city.

Evaluation method of student performance

Use questionnaire survey to evaluate student knowledge after education.

Course outline

Table 5 Course outline of Da Nang application

	Class 4.1	Class 4.2
Student number	37	40
Date	Tuesday, every 2 weeks	Tuesday, every 2 weeks
Period	1	3
Number of lessons	10	10
Time	14:00 ~ 14:30	15:50 ~ 16:20
Duration	6 months From October, 2016 to March, 2017	6 months From October, 2016 to March, 2017

Contents of each lesson

- *Lesson 1: Introduction*

Objective:

1) Give student basic information about solid waste management will teach at next 9 lesson
2) Student will do questionnaire survey to evaluate student knowledge before lesson.

Content:

- 14:00 ~ 14:05: Introduced lesson contents and myself
- 14:05 ~ 14:10: Made student groups
- 14:10 ~ 14:30: Questionnaire survey

- *Lesson 2: Solid waste management situation in Da Nang city*

Objective:

1) Understand students knowledge about the situation of solid waste in Da Nang city
2) Introduce to student the situation of solid waste management in Da Nang city

Content:

- 14:00 ~ 14:05: Played small game to understand student knowledge
- 14:05 ~ 14:18: Give students basic knowledge about solid waste management in Da Nang city
- 14:18 ~ 14:20: Give student waste bags to understand how much waste every day one person discharges to the environment every day.
- 14:20 ~ 14:30: Questions and comments from student

- <u>*Lesson 3: 3Rs (Reduce, reuse, and recycle)*</u>

Objective:

1) Introduce 3Rs concepts to students

Content:

- 14:00 ~ 14:05: Remind student about last lesson contents
- 14:05 ~ 14:15: Questions time

Question 1: How can we reduce waste?

Question 2: What is 3Rs?

- 14:15 ~ 14:25: Teach student 3Rs concepts
- 14:25 ~ 14:30: Questions and comments from student

- <u>*Lesson 4: Recycle produce*</u>

Objective:

1) Introduce recycle products to student
2) Teach students how to make toys from waste

Content:

- 14:00 ~ 14:05: Remind students about last lesson contents
- 14:05 ~ 14:15: Introduce student to recycled products
- 14:15 ~ 14:30: Made recycle products with student

- <u>*Lesson 5: Food waste situation in Da Nang city*</u>

Objective:

1) Introduce food waste systems in Da Nang city
2) Introduce food waste systems in general

Content:

- 14:00 ~ 14:10: Questions to go over the last lessons contents with the students

Table 6 Questions to go over material learned in last lesson

Question 1: Please circle your answer, what kind of waste can we recycle? a) Pet bottle b) Can c) Newspaper d) Bin
Question 2: What will we can do with food waste at home?
Question 3: What do you think of using food waste to feed pigs? Why?

- 14:10 ~ 14:20: Introduce food waste systems in Da Nang city in general to students
- 14:20 ~ 14:30: Questions and comments from student

- <u>*Lesson 6: Waste separation game*</u>

Objective:

1) Give student opportunity to practice waste separation
2) Go over material taught during the last 5 lessons

Content:

- 14:00 ~ 14:05: Go over last lesson's contents
- 14:05 ~ 14:20: Play separation of waste game
- 14:20 ~ 14:30: Introduce next lesson, and questions and comments from student

- <u>*Lesson 7: Newspaper game*</u>

Objective:

1) Understand student thinking about environment
2) Remind students about information that they studied

Content:

- 14:00 ~ 14:10: Provide newspaper stuffs for student and contents of newspaper
- 14:10 ~ 14:30: Students start to write and draw their new paper

- <u>*Lesson 8: Newspaper game and newspaper presentation activity*</u>

Content:

- 14:00 ~ 14:10: Students complete their new paper
- 14:10 ~ 14:30: Students start to present their newspaper contents. 1 group has 6 minutes (4 minutes to explain contents, 2 minutes for questions and answers)

- *Lesson 9: Newspaper presentation activity*

Objective:

1) Understand students idea about their newspaper

Content:

- 14:00 ~ 14:25: Student start to present their newspaper contents. 1 group has 6 minutes (4 minutes to explain contents, 2 minutes for questions and answers)
- 14:25 ~ 14:30: Close activity

- *Lesson 10: Final lesson*

Objective:

1) Give students comments about their newspaper
2) Remind student what did they study from environmental education
3) Give students prizes for their activities

Content:

- 14:00 ~ 14:15: Comments about newspaper activities
- 14:15 ~ 14:20: Award for group and student had good score for all activities. We provide a note with a cover that contains environmental education contents that student studied during 9 lessons.
- 14:20 ~ 14:30: Close activities, and questions and comments from student

DISCUSSION

Because of differences between Japanese and Vietnamese systems for elementary school, the environmental education activities that where designed with cultural difference take into account increased Vietnamese students environmental education knowledge:

- Made group works for student. Because class size in Vietnam is larger than class size in Japan, so individual works may have some difficult to evaluate student.
- Create many games for student to practice separation of waste. Because in Vietnam, we don't have separation systems like Japan. So our study gave students the opportunity to practice.
- Newspaper presentation lesson, to understand student attitude and thinking, after making the newspaper, the study contained a lesson for students to explain their ideas in their newspaper.
- This education activity provided a notebook with a cover containing environmental education contents that student studied during the first 9 lessons. We want to remind students about environment education lesson for a long time.

CONCLUSION

This study has understood situation between Kitakyushu city, Japan and Da Nang city, Vietnam before created environmental education activities for elementary student in Da Nang city from Kitakyushu experience.

This study has discussed the present situation of students' environmental knowledge and a detailed description of environmental education for elementary students in Vietnam and Japan, with special emphasis on solid waste management.

In addition, because of a difference in class size and schedule, we modified the teaching method from the Kitakyushu model to suitable for elementary school in Vietnam, such as: Group work, create games for student to practice waste separation at school.

We believe that environmental education at elementary schools is an effective approach to raising awareness of sustainability issues among people in Vietnam, and by extension Southeast Asian countries.

Vietnam could launch a fresh start by taking lessons from Japan and study the way Japanese environmental education uses the application of pollution prevention measures, waste disposal system. If Vietnam designs its system from the experiences of the Japanese environmental education a favourable situation will emerge in the long run which will help it avoid problems which Japan faced at its early stage of development.

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PROPOSAL OF A DISTRIBUTED MATERIAL RECYCLING FACILITY SYSTEM IN SURABAYA, INDONESIA

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ABSTRACT
The objective of this research is to determine the best option to achieve the least waste to be disposed to the landfill and the highest waste recovery in Surabaya, a city in Indonesia which has 2,913.26 ton/day of municipal solid waste generation. Waste reduction is being carried out in Surabaya, yet mainly, most of the recovery is done by the waste collector at the transfer station (TS) during unloading the waste from the collection cart. This is proven to be ineffective as it is known to only cover 3.39% of the waste input. In contrast, due to the presence of belt conveyor, where on its side multiple workers separate the waste, also the incorporated composting site, material recycling facility (MRF) recovers 63.79% of the whole waste received by recovering both organic and inorganic waste. In this study, four different possible scenarios, which are the existing condition, distributed merged TS, one-point MRF, and the distributed MRF system, will be compared by utilizing QGIS as the main method. This paper shows that having the distributed MRF systems, projecting the condition of a replacement of TS, is proven to be the foremost solution to the issue of the solid waste amount, recover the recyclables, and lessening the fuel cost of solid waste transportation truck.

Keywords: Distributed MRF System, Municipal Solid Waste, Surabaya

INTRODUCTION

Surabaya as the second largest city in Indonesia, with the population over 3 million, generates approximately 2,913.26 ton/day of municipal solid waste (Surabaya City Government, 2017). Having 72.41% of organic waste (Dhokhikah and Trihadiningrum, 2012) as the composition and the fact that source separation is still very low, landfill has always been the main final treatment. Dealing this huge amount of waste produced on a daily basis without an appropriate step could lead to an unwanted environmental condition. The visible solid waste management method to be done is reduction and handling (Republic of Indonesia, 2008). Separation of solid waste are highly recommended and should be prioritized which is why included as the most important step to do (Damanhuri and Padmi, 2010).

Surabaya has already implementing several actions to diminish the load of waste from the source, such as household composting and Waste Bank—the handling of recyclable waste where people can get some cash for selling particular recyclable waste. Waste Bank started to be promoted in Surabaya back in 2010 with only 15 but the number climbed to 180 unit in 2013 (Wijayanti, and Suryani, 2015). In addition, waste scavengers and the waste collectors as the informal sector also take a leading role in reducing the waste from the source, transfer stations, or even at the landfill. The recycling rates achieved by the informal sector in several developing countries are quite high (Wilson et al., 2009).

The reduction of waste also happening at the temporary waste disposal sites by the waste collector. There are two types of temporary waste disposal sites in Surabaya, the TS, where waste collector individually separates the recyclable waste while unloading the cart, and the MRF, where the collected wastes are placed on a conveyor belt and going through a multi-level manual separation. Due to that reasons, MRF recovers recyclable materials up to 63.79% of total waste input while TS could only do up to 3.39% (Warmadewanthi et al., 2015). Other than the multiple segments of waste separation which increases the reduction of each type of recyclable material, the huge gap is also caused by the integrated composting site at the MRF, making it possible to reduce and recycle the organic waste. MRF became even more superior since it has the storage for the already separated waste and a roofed working place, protecting the worker from the sun and the rain. Moreover, the more complex system in MRF allows it to employ more workers than the TS.

Though MRF appears to be a better option for a temporary waste disposal site, various aspects and criteria should be assessed before taking any decision. A sustainable system for solid waste management must be environmentally effective, economically affordable, and socially acceptable. Economically affordable means that waste management system must operate at an acceptable cost to the community, which includes all private citizens, business and government (Rahim et al., 2012).

To achieve the economically affordable, transportation cost should be taken into account due to its highest contribution, in comparison to other sectors, in solid waste management service cost (Rahim et al., 2012). One of the biggest expenses should be covered under the transportation sector is the fuel cost. Therefore, multiple scenarios will be constructed and evaluated thoroughly to find out the best temporary disposal waste system with the existing condition of solid waste collection and transportation as the base scenario.

SOLID WASTE MANAGEMENT IN SURABAYA

Surabaya located in the East Java, Indonesia with the total area of 350.5 km^2. In Surabaya, as in other big cities in Indonesia, the waste generated from both household and non-household, such as commercial and educational sector, are dropped into a container in front of the household or public facility. Figure 1 displays the detail of waste flow in the city. Approximately 0.97 kg/day/person of solid waste is generated and 0.97 ton/day of recyclable waste, such as plastic bottle, recyclable paper, and cardboard, is separated at the source and being sold to the Waste Bank. 19.74 ton/day of organic waste, which are mainly from the city parks, goes directly to the composting sites, yet, the rest of the waste is collected altogether using the pushcart or the motor cart, being taken to the responsible temporary waste disposal site near the area. The 2 MRFs in Surabaya, Sutorejo and Jambangan, receive 10.10 ton/day and 3.13 ton/day respectively. More than half of the waste generated is collected and dropped at the TSs. On the other hand, 44.75% remains unknown whether it is individually dumped to the temporary waste disposal sites by the residences nearby, illegally dumped, or open burning. Based on the Regional Regulation of Surabaya No. 5/2014, those who are generating more than 30m^3/month of waste are responsible to dispose of their own waste to the landfill. Thus, 16.92ton/day of waste is directly transported to the landfill by the industries and other public facilities which generate that high load of waste.

The composting sites receive 27.53 ton/day and generate 19.80 ton/day of compost for the city parks and the residence. The recyclables from the TSs and MRFs goes to either the waste broker or recycling center, which in total with those from the Waste Bank adds up to 8.72 ton/day.

METHODOLOGY

In this study, the Geographic Information System (GIS) is mainly used to interpret the location of each temporary waste disposal sites and the landfill. Since the main purpose of this study is to find the best system to transport the waste in the least possible load by maximizing the recovery possibilities at the temporary waste disposal sites, rather than to optimize the transportation route, a free open-source QGIS 2.18.20 'Las Palmas' is utilized with the built-in extension of GRASS GIS. The algorithms used in this study allows the user to obtain the shortest path available from one to another point under the restriction applied, giving the exact distance which then will be used for further analysis.

Then, four scenarios are prepared to execute the simulations to understand the difference in the reduction of waste and overall cost require considering the alteration of temporary waste disposal site system. The first scenario or the scenario 0 works as the base scenario, picturing the existing condition of the municipal solid waste management in Surabaya. In the Scenario 1, multiple TSs, which are located nearby and having a small capacity (one container), are merged into one TS while in the Scenario 2, a one-point MRF is added at the end of the transportation route or right before the landfill. Every waste, except from the existing MRF, will undergo a multi-segment separation before disposed to the landfill. The Scenario 3 would be a distributed MRF system, upgrading the existing TS which has a high waste load into MRF to escalate the waste recovery and at the same time reducing the waste needed to be transported and disposed to the landfill.

The cost and recycling rate would be the main comparison between each scenario using Scenario 0 and the known information as the basic calculation. The fuel

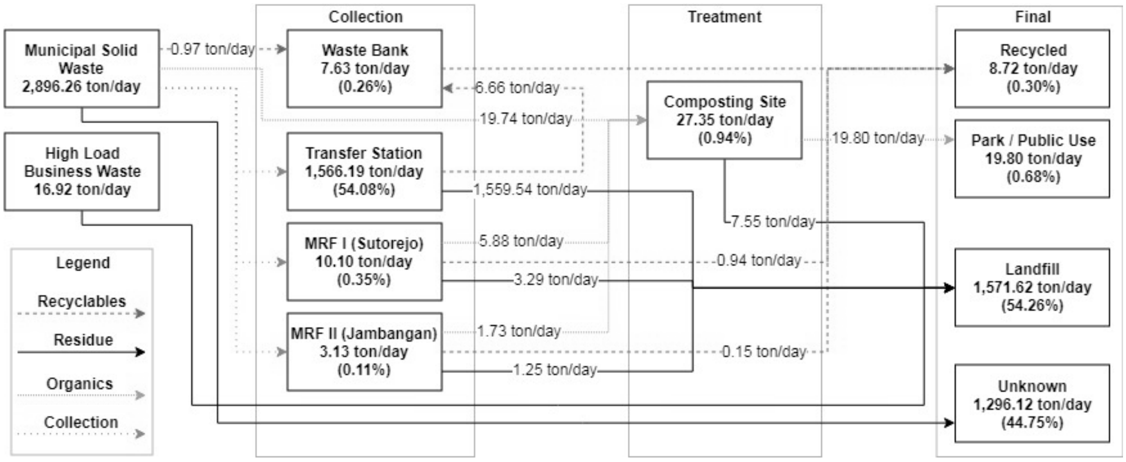

Figure 1. The Flow of Solid Waste in Surabaya

cost is calculated as the total use of fuel in one trip from the temporary waste disposal site to the landfill. The calculation of cost will be based on the current situation, IDR7,800 (USD0.52)/L of diesel and the currency value of USD1 is equal to IDR14,903 (2018).

RESULTS AND DISCUSSION

After utilizing the QGIS to acquire the shortest path between TS/MRF and the landfill, the distance was obtained, and the operational cost could be calculated.

Figure 2 shows the existing waste transportation routes. The thick grey line over the thin one represents the route taken out of the possibly used road. The road was simplified by removing most of it, for example, the residential road, from the model to make it more comprehensible. The distance traveled to transport the waste from both TSs and MRFs in Scenario 0 vary from 1.89 km to 41.67 km with the average distance of 20.90 km. In each trip, the diesel fuel usage ranging from 20.73 – 29.09 L and the average of 24.91 L with the cost of IDR161,660 (USD10.78) – IDR226,891 (USD15.13) and an average of IDR194,276 (USD12.95). Yearly expenses on the fuel reach IDR70,910,650 (USD4,727.38).

In scenario 1, two or more TSs which have a small input and located close to one another will be merged. For this case, 53 units are known to have a very small load of waste, stretching from one trip every 4 days to every 2 days. The potential TSs to be merged are those who are separated not more than 1 km apart (Figure 3). This is due to the reason of maintaining the collection coverage area in a reasonable portion. This combination of TSs, which require more than one day to fill the container to be picked up and transported to the landfill, eases the waste transportation. Instead of going to two different locations in two different/same time, the

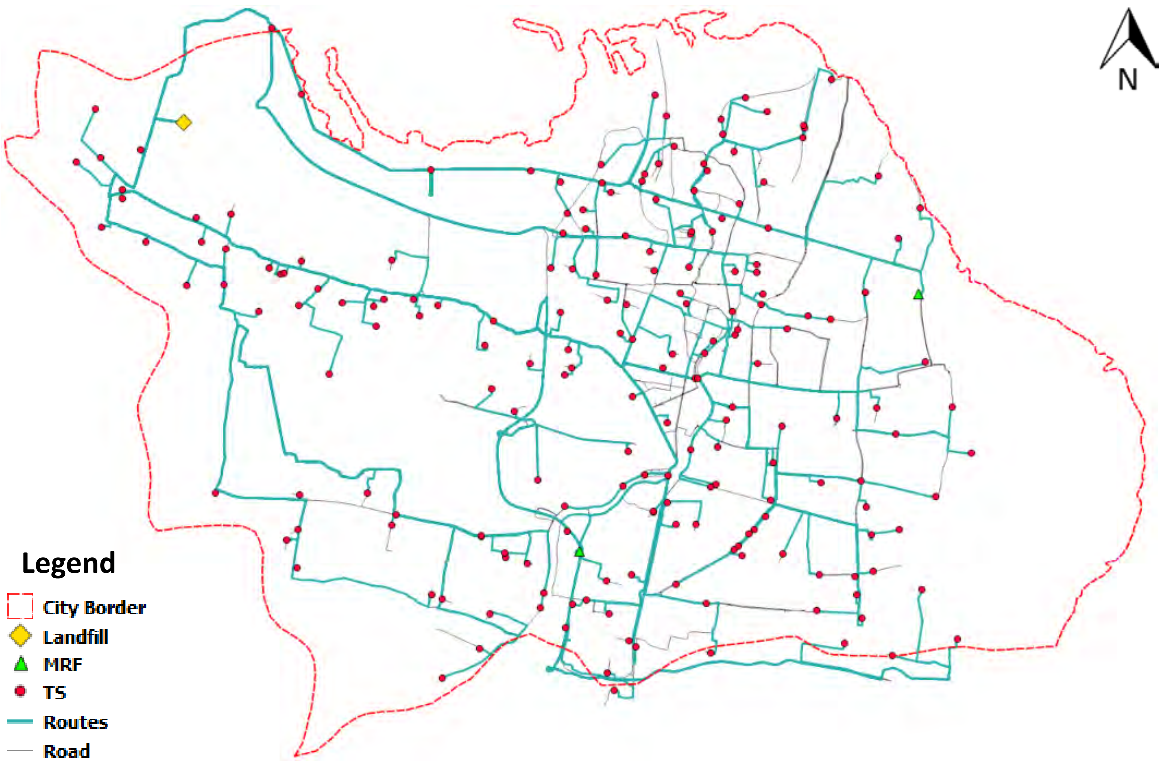

Figure 2. Scenario 0: Existing Waste Transportation Routes

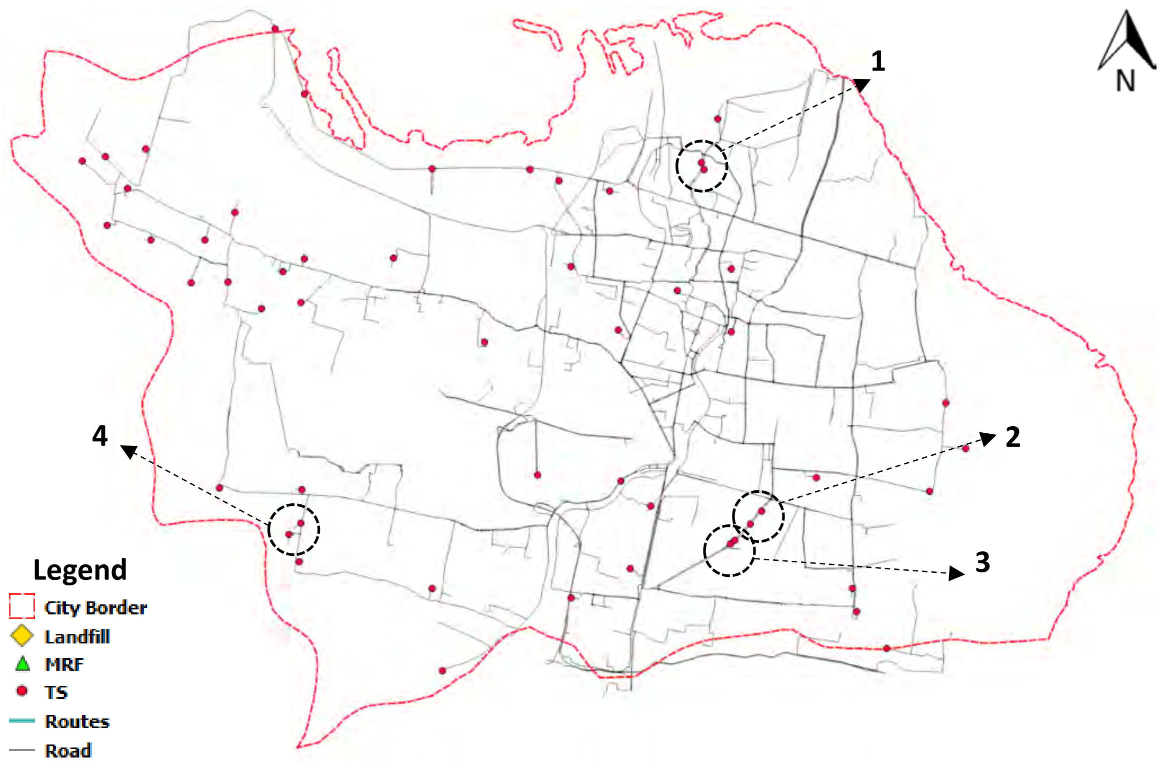

Figure 3. Scenario 1: Potential and Candidate Units

truck will only have to go to one location in one time. The location with a closer position to landfill was chosen and since the merging of two TSs is only as if expanding the coverage area of one TS and removing the other, no necessary space upgrading was needed. The major changes are in the waste transportation trip and the fuel cost (Table 1). Merging 4 pairs of TSs resulting in fuel cost saving up to IDR194,486,947 (USD1,744.99) per year and a reduction number of TS into 193 unit. Still, no improvement of recycling rate present due to the identical system between the merged units.

Table 1. Scenario 0 and 1: Distance, Trip, and Fuel Cost/Year

	Transfer Station	Scenario 0			Scenario 1		
		Distance (km)	Trip/ Year	Fuel Cost/Year (in thousand)	Distance (km)	Trip/ Year	Fuel Cost/Year (in thousand)
1	Ampel Makam	21.5	48	Rp9,151	21.5	209	Rp39,846
	Ampel Pariwisata	21.6	180	Rp34,436			
2	SMA 16	25.5	120	Rp25,329	25.5	243	Rp51,292
	Prapen	25.9	180	Rp38,290			
3	Prapen 88	26.5	180	Rp38,587	26.5	360	Rp77,174
	Prapen DKK	26.6	180	Rp38,765			
4	Lidah Kulon	16.9	132	Rp23,122	16.9	256	Rp44,843
	Bangkingan	17.5	180	Rp31,649			

There is no alteration in terms of TSs location, yet the only difference between Scenario 1 and 2 is the presence of one-point MRF right before the landfill (Figure 4). All the solid waste taken from the TSs are being transported to the one-point MRF in order to maximize the recycling rate. Despite being promising with the multi-segment waste separation, this scenario has several drawbacks. Firstly, this would be the secondary separation, or even tertiary, after the separation done in the source and/or the TS, leaving a smaller number of recyclables to be picked up. Moreover, compared to cart with a volume of 1 m^3, all the waste which has been mixed in a 6-14 m^3 container with other types of waste seems likely to be contaminated, deformed, destroyed, or not in a condition to be categorized as recyclable anymore. Additionally, the number of workers and working hours should be highly considered and the availability of mechanical waste separator might be needed to keep up with the incoming waste since the amount of waste to be dealt with are more than 2000 ton/day.

In Scenario 3, as an alternative of constructing the large one-point MRF as in Scenario 2, the existing TS with a condition of more than 2 trip/day of transportation was selected to be upgraded into MRF. 5 TSs was known to have a 3-5 trip/day (Figure 5). Thus, calculating based on the average waste reduction at the MRF of 63.79%, the 5 new MRFs recovered 23,171.36 ton/year (Table 2). The system with the total of 7 MRFs and 192 TSs shows a rocketing result compared to the existing recovery condition of 1,231.40 ton/year. The drop of the solid waste load will be followed by less transportation trip that should be done to be averagely 482 trip/year from the average original trip frequency of 1332 trip/year. The reduction of solid waste transportation from the temporary waste disposal sites to the landfill directly.

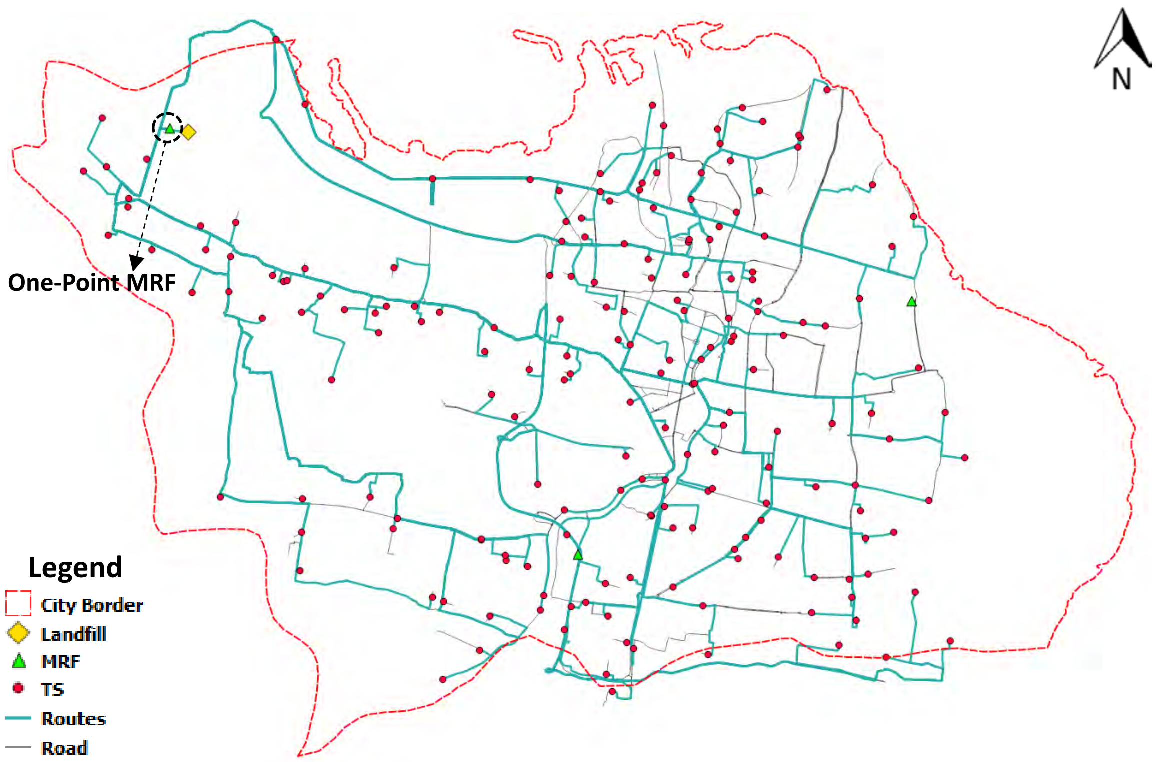

Figure 4. Scenario 2: Transportation Route from TSs to One-Point MRF to Landfill

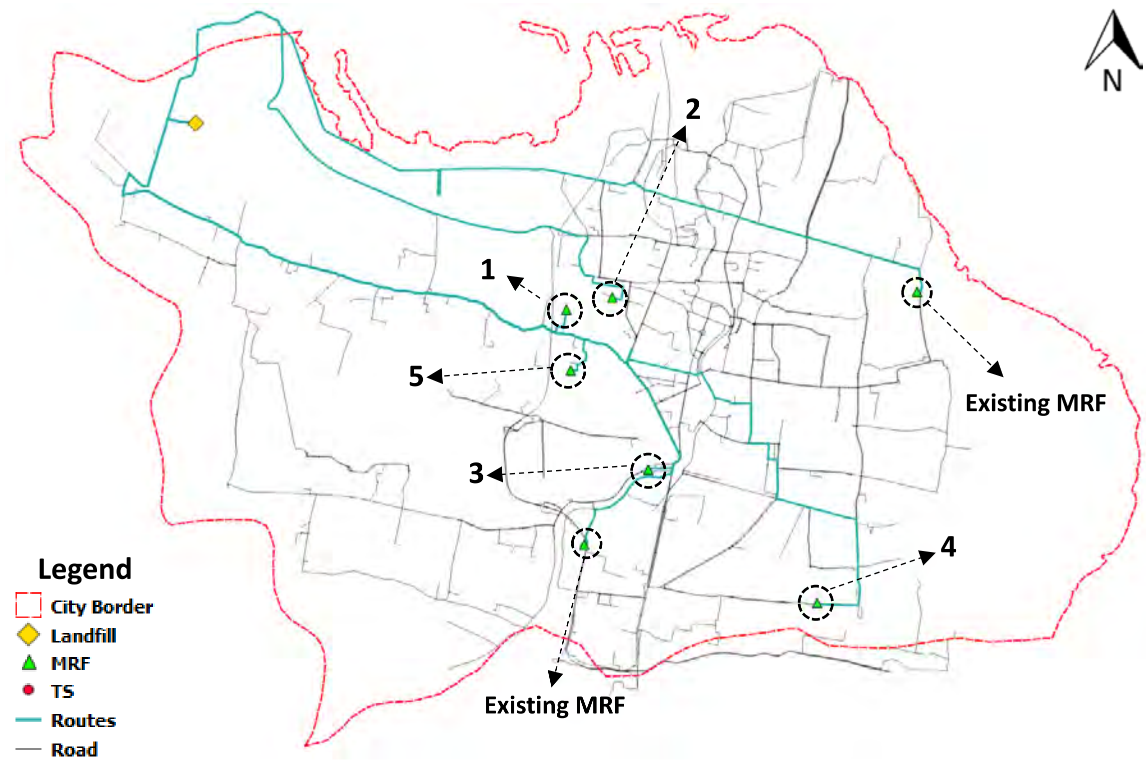

Figure 5. Scenario 3: Existing MRFs and Distributed MRF System

Table 2. Scenario 0 and 3: Waste Recovered, Trip and Fuel Cost per Year

	MRF	Scenario 0			Scenario 3		
		Recovered/Year (ton)	Trip/Year	Fuel Cost/Year (in thousand)	Recovered/Year (ton)	Trip/Year	Fuel Cost/Year (in thousand)
1	Simo Rukun	199.69	1080	Rp188,113	3757.52	391	Rp68,116
2	Bukit Barisan	199.69	1080	Rp199,855	3757.52	391	Rp72,367
3	Joyoboyo	266.25	1440	Rp286,873	5010.02	521	Rp103,877
4	Rungkut Kidul	266.25	1440	Rp323,877	5010.02	521	Rp117,276
5	Makam Mataram	299.53	1620	Rp286,974	5636.28	587	Rp103,913

affect the truck fuel cost to be decreased which saves up to IDR820,143,542 (USD54,676.24).

CONCLUSION

By far, Scenario 3 with distributed MRF system answers the main purpose of reducing the total waste to be disposed to landfill and at the same time reducing the fuel cost of the solid waste transportation truck. Scenario 1 with less waste transportation trip frequency reduces the fuel cost by 18.74% while Scenario 3 with an escalated waste recovery and less trip was able to surpass it by 36.21%.

However, for further research, sensitivity analysis is required to perceive how many units of MRF is actually needed to reach economically affordable condition.

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QUESTIONNAIRE SURVEY ON RESIDENTS' BEHAVIOR AND RECOGNITION OF SEPARATION OF KITCHEN WASTE AND RECYCLABLES AT SOURCE: A CASE STUDY IN TSUCHIURA CITY

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ABSTRACT

The final aim of this study is to verify whether providing information about the need and effectiveness of separation of recyclables and waste at source changes residents' behavior and recognition, in particular as regards kitchen waste. This paper reports the results of a preliminary questionnaire survey for the whole area of Tsuchiura City. There were 2,000 households selected for questioning by random sampling and the number of responses was 1,053. The survey included two parts, with questions on recyclables and kitchen waste; the same questions were designed to compare residents' behavior and recognition as regards separation of recyclables and kitchen waste at source. It was found that people did not have enough knowledge on the reasons for kitchen waste separation and on the effectiveness of kitchen waste recycling, as compared with knowledge on recyclables, such as container and packaging plastics and paper.

Keywords: Kitchen waste, Source separation, Environmental recognition, Questionnaire survey

INTRODUCTION

Kitchen waste recycling for the purpose of producing energy and organic fertilizers by anaerobic digestion or composting, can reduce greenhouse gas (GHG) emissions and landfill waste. For this reason, the residents' cooperation in separating kitchen waste at source is indispensable. In general, it is difficult for people to recall environmental problems in their daily life, which is one of the reasons for not acting in a manner that is environmentally considerate. In particular, most people know how to separate recyclables. However, they do not know why they should do it, how the separated recyclables are used, and what is the effectiveness of separation at source.

Thus, people have difficulty considering source separation in relation to actual environmental problems. The final goal of this study is to verify whether providing information about the need for, and the effectiveness of separation at source modifies residents' behavior and recognition of separation of recyclables, in particular kitchen waste, at source. This paper presents the results of a preliminary questionnaire survey for the area of Tsuchiura City, in which the same questions were designed for recyclables and kitchen waste, respectively, to compare residents' behavior and recognition of recyclables and kitchen waste.

METHOD

Target area

The target area in this study was Tsuchiura City in Ibaraki prefecture (Figure 1). The population is 139,450 (August 1, 2018)[1]. The population density is about 1,135/km^2. Tsuchiura City started to separate kitchen waste from combustible waste in April 2015, and a biogas plant managed by a private company treats the separated kitchen waste. Tsuchiura City collects kitchen waste twice a week. The residents have to put kitchen waste into a special bag. Koizumi et al. (2018)[2] conducted a composition analysis of combustible waste and revealed that the percentage of kitchen-to-combustible waste was 13%, meaning that only 40 to 60% of the total kitchen waste, including the actual amount of separated kitchen waste, was separated from combustible waste.

Questionnaire content

Households were selected in every district by random sampling. The total number of selected households was 2,000, which accounts for about 3.4% of the total population in Tsuchiura City.

The contents of the questionnaire are shown in Table 1. The questions were developed based on the Hirose model[3] (Figure 2) using a computer-scored answer sheet. There are two processes for using environmentally considerate behaviors: belief and attitude, and behavioral intention (see Table 1, Contents of questionnaire).

Figure 1 Tsuchiura City in Ibaraki prefecture

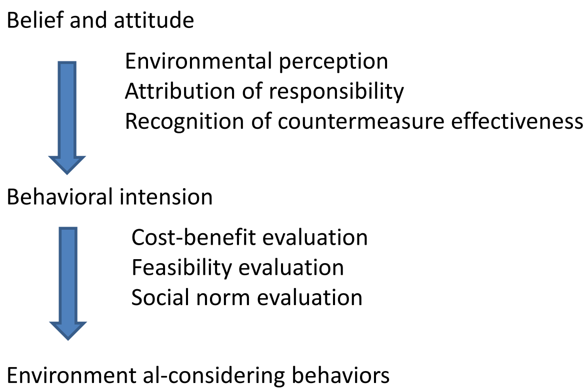

Figure 2 Hirose's model

The attitude is related to environmental risk recognition, attribution of responsibility, and recognition of countermeasure effectiveness.

Table

Factors		Questions
Basic attribute		gender, age, the number of family, address
Basic knowledge on waste separation		Participation to public meetings,
		Knowledge on starting a charging system for garbage from this October
Recyclables		
Belief and attitude		Separating recyclables is a good behavior.
Environmental risk recognition	ERR1	Low recycling ratio in Tsuchiura city is bad.
(ERR)	ERR2	I'm concerned that the landfill site in Tsuchiura city will be full because of low recycling ratio.
Attribution of responsibility	AR1	Low recycling ratio inTuchiura city is my fault.
(AR)	AR2	I do not have to separate recyclables by myself.
Recognition of countermeasure effectiveness	RCE1	Source separation of recyclables is effective for life extention of the landfill site in Tuchiura city.
(RCE)	RCE2	Source separation of recyclables will help solving environmental problems.
Behavioral Intention		Will you separate recyclables?
Cost-benefit evaluation	CBE1	Source separation of recyclables is time and effort.
(CBE)	CBE2	I benefit from source separation of recyclables.
Feasibility evaluation	FE1	I know how to separate recyclables.
(FE)	FE2	I can separate recyclables by myself.
Social norm evaluation	SNE1	I mind the eyes of other people when not separating recyclables.
(SNE)	SNE2	Separating recyclables is a social rule.
Action		Do you separate recyclables, now?
		Which recyclables do you separate?
Kitchen waste		
Belief and attitude		Separating kitchen waste is a good behavior.
Environmental risk recognition	ERR1	Low recycling ratio of kitchen waste in Tsuchiura city is bad.
	ERR2	I'm concerned that the landfill site in Tsuchiura city will be full because of low recycling ratio of kitchen waste.
Attribution of responsibility	AR1	Low recycling ratio of kitchen waste inTuchiura city is my fault.
	AR2	I do not have to separate kitchen waste by myself.
Recognition of countermeasure effectiveness	RCE1	Source separation of kitchen waste is effective for life extention of the landfill site in Tuchiura city.
	RCE2	Source separation of kitchen waste will help solving environmental problems.
Behavioral Intention		Will you separate kitchen waste?
Cost-benefit evaluation	CBE1	Source separation of kitchen waste is time and effort.
	CBE2	I benefit from source separation of kitchen waste.
Feasibility evaluation	FE1	I know how to separate kitchen waste.
	FE2	I can separate kitchen waste by myself.
Social norm evaluation	SNE1	I mind the eyes of other people when not separating kitchen waste.
	SNE2	Separating kitchen waste is a social rule.
Action		What kind of kitchen waste do you separate?

*1 Five-grade evaluation, e.g., 1.I don't know 2. I don't know much 3. Neither 4. I know a little 5. I know

*2 Multiple choice is possible: Kitchen waste, Packaging and container plastic, Glass bottle/pet bottle/can, Newspaper/plain paper, others

*3 Multiple choice is possible: Kitchen waste during cooking waste, Leftovers, Untouched food, Others

In addition, the behavioral intention is also needed for action and is related to cost–benefit evaluation, feasibility, and social norm.

We sent out the questionnaire on April 7 by mail. The reply deadline by mail was April 30. A reminder mail was sent on April 24 to promote reply.

RESULTS AND DISCUSSION

Basic information on respondents

The number of responses was 1,053. Basic information on the respondents is shown in Figures 2–4. Most respondents were female and over 40 years old. The number of respondents who live alone was small. The answer to the question "Which recyclables do you separate?" is shown in Table 2. The percentages of kitchen waste, packaging and container plastics, and newspaper/plain paper were smaller than those of glass bottles/PET bottles/cans.

The answer to the question "What kitchen waste do you separate?" is shown in Table 3; 53% of respondents answered that they do not separate untouched food.

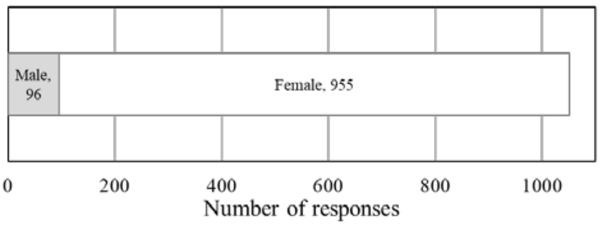

Figure 3 Gender of respondents

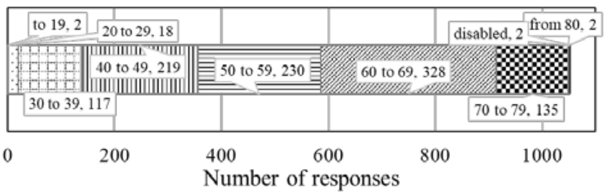

Figure 4 Age of respondents

The answer to the question "Do you separate recyclables now?" is shown in Figure 5. Most of the respondents answered "Usually, all the time" and "All the time."

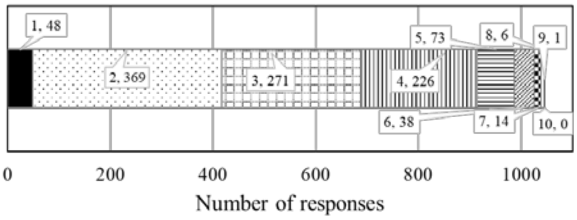

Figure 5 Member of household

Table 2 Which recyclables do you separate?

Recyclables	Responses	Percentage
Kitchen waste	836	80.5%
Packaging and container plastics	801	77.1%
Glass bottle/PET bottle/can	976	94.0%
Newspaper/plain paper	815	78.5%
Others	201	19.3%

Table 3 What kitchen waste do you separate?

Kitchen waste	Responses	Percentage
Kitchen waste during cooking	825	80%
Leftovers	818	80%
Untouched food	479	47%
Others	62	6%

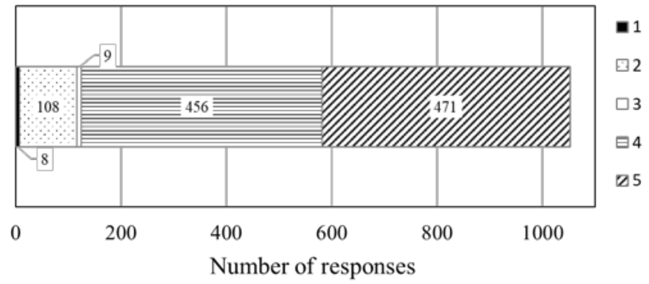

Figure 6 Do you separate recyclables now?

1. Never; 2. Not usually; 3. Neither; 4. Usually; 5 All the time

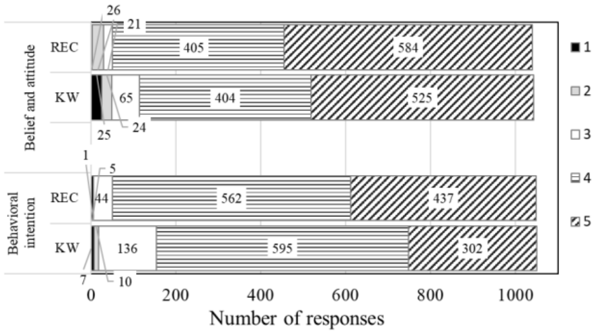

Figure 7 Belief and attitude, and behavioral intention

Belief and attitude: Separating recyclables or kitchen waste is a good behavior.

1. Strongly disagree, 2. Disagree, 3. Neither, 4. Agree, 5. Strongly agree

Behavioral intention: Will you separate recyclables or kitchen waste?

1. I will not, 2. I will not usually do so, 3. Neither, 4. I will usually do so, 5. I will

Belief and attitude, and behavioral intention

The results on the belief and attitude and the behavioral intention for recyclables (REC) and kitchen waste (KW) are shown in Figure 7. Most of the respondents think that "Separating recyclables is a good behavior" or have the will to separate recyclables (Figure 7), however, some of the respondents do not separate recyclables (Figure 6). The number of respondents who answered "Neither" on kitchen waste was larger than on recyclables.

Subfactors related to belief and attitude, and behavioral intention

Like the result on belief and attitude, and behavioral intention in the previous section (Figure 7), the number of respondents who answered "Neither" on kitchen waste was larger than on recyclables, in the result of subfactors (Figure 8).

Separation of recyclables (PET bottle/can) started in 2000, but separation of kitchen waste started in 2015. The necessity of separating kitchen waste and the recycling method used are not known widely, because the publicity from the administration to the residents seems to be insufficient. The respondents could not judge whether they agree or not and for this reason they selected "Neither".

Differences in separation of kitchen waste and recyclables at source

Table 4 shows the result of the Mann−Whitney U test on each subfactor to clarify differences in separation of kitchen waste and recyclables at source. In the Mann−Whitney U test[4)], the order relation of the measurement values of two groups was examined, a test statistic of U representing the discrepancy was calculated, and the significance of the difference between the two groups was judged from the magnitude of the discrepancy using the P value. The P value means the probability that the two groups are the same statistically.

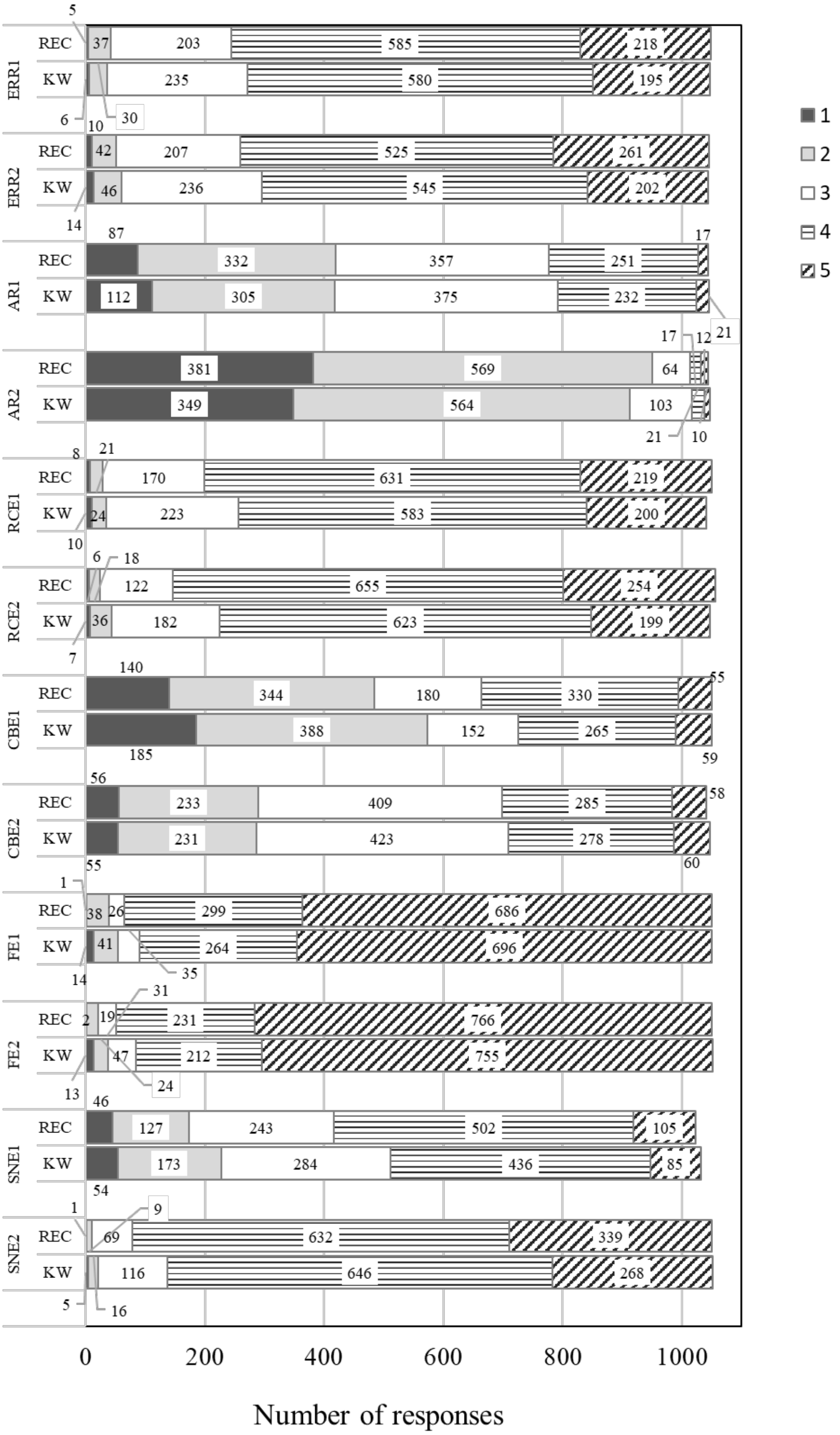

Figure 8 Subfactors related to belief and attitude, and behavioral intention

REC and KW

1. Strongly disagree; 2. Disagree; 3. Neither; 4. Agree; 5. Strongly agree

Table 4 Mann−Whitney U test

(Recyclables and kitchen waste)

Item	P value
ERR1	0.131
ERR2	0.00281
AR1	0.519
AR2	0.0194
RCE1	0.00958
RCE2	3.17E-06
CBE 1	0.000244
CBE2	0.973
FE1	6.01E-05
FE2	4.25E-06
SNE1	0.993
SNE2	0.315

Table 5 Mann−Whitney U test

(Separate and do not separate kitchen waste)

Item	P value
ERR1	1.19E-16
ERR2	7.58E-16
AR1	6.22E-09
AR2	2.19E-18
RCE1	2.74E-13
RCE2	5.00E-12
CBE1	2.73E-28
CBE2	4.79E-08
FE1	1.31E-20
FE2	4.38E-21
SNE1	2.17E-08
SNE2	1.46E-26

The difference in ERR2, RCE1 and 2, CBE1, and FE1 and 2 between kitchen waste and recyclables was statistically significant because their P values were less than 0.01.

In particular, RCE2 was the most critical factor for kitchen waste separation because the P value was the smallest.

Difference in subfactors on kitchen waste between people who separate and people who do not

The results of subfactors on kitchen waste between people who separate and those who do not is shown in Figure 8, where there were significant differences in all subfactors between them. The result of the Mann−Whitney U test also showed statistically a significant difference in all subfactors (Table 5). The ratio of the positive answer to separation of kitchen waste from respondents who do not separate it was smaller than that from respondents who separate kitchen waste. Provision of information on all subfactors is needed to change the residents' behavior and to promote separation of kitchen waste.

At present, we have provided information to some of the residents in Tsuchiura City and measured change in residents' behavior on separating kitchen waste by counting the number of bags for separated kitchen waste at the collection points and through an additional questionnaire survey.

CONCLUSIONS

The following conclusions were drawn from our questionnaire survey.

1) The need for separating kitchen waste and the recycling method are not known widely compared with other recyclables, because the publicity from the administration to residents seems to be insufficient.

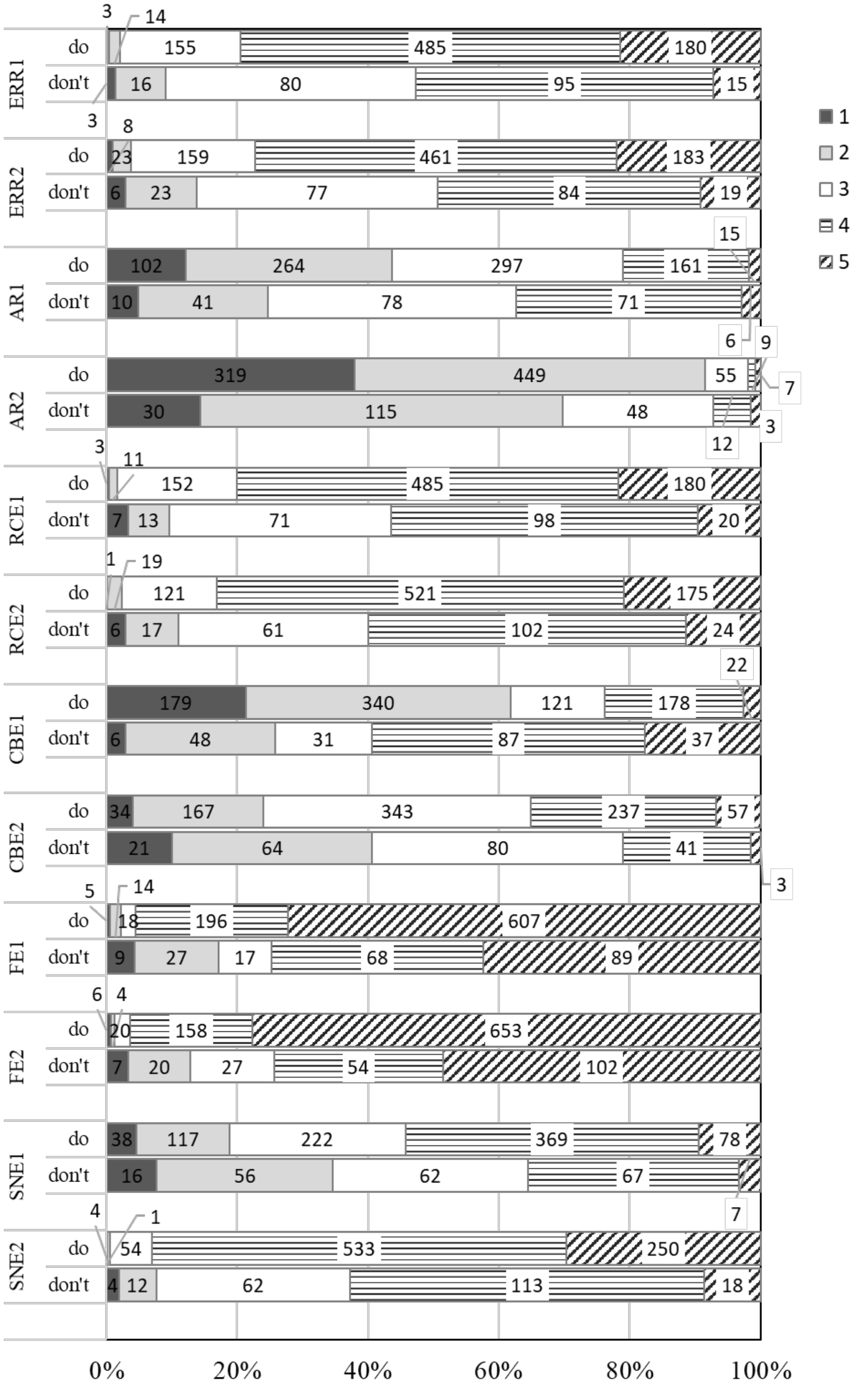

Figure9　Subfactors related to belief and attitude, and behavioral intention

Separate and not separate KW

1. Strongly disagree 2. Disagree 3. Neither 4. Agree 5. Strongly agree

2) There were significant differences in all subfactors between people separating kitchen waste and people who do not. Provision of information on all subfactors is needed to change the residents' behavior and to promote separation of kitchen waste.

ACKNOWLEDGMENT

We would like to thank the residents of Tsuchiura City for answering our questionnaire and the Department of Environmental Sanitation in the Tuchiura municipal office for supporting the questionnaire. This work was supported by Hitachi Cement Co.

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The Integrated Waste Management and Sustainable Landfilling

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ABSTRACT

Waste management, being one of the most important aspects of urban development, is gaining importance among developing nations. Landfills, which were initiated for hazardous waste management and subsequently transformed into sanitary landfills, have been the most widely adapted practice for municipal solid waste management worldwide. The research were conducted over a 9 months period in 3 years on the operational strategy of the larger of the only two sanitary landfills and leachate treatment ponds in NIGERIA and sub-Sahara Africa. The purpose was to examine and evaluate the sanitary landfill and leachate stabilisation ponds against the backdrop of technically sound and sustainable management options. However, the conventional design of landfills not only fails to fulfil the needs of waste management but also fails to target optimal resource recovery and energy generation. In the present study, modified design was proposed for partially engineered landfill system based on theoretical considerations based on integrated and sustainable principles that can deliver environmental, social and economic stability in the nation. furthermore, It was found that the system with modified design could yield 2.157 million tons of landfill gas (2.145 million tons of coal equivalent) out of one year of solid waste. Further, this could recover resource valued at US$16.49 million per year.

Keywords: Sanitary landfills, Sustainable and integrated solid waste management, Leachate stabilization ponds, Lagos, Nigeria and Sub-Saharan Africa, Developing economies

INTRODUCTION

Nigeria, as a developing economy, has had her own share of problems with solid waste disposal. The practice of open dumping has been and still is a dilemma for almost all communities in the cities and towns of the country Open dumps have been of environmental concern with respect to the nuisance they have created and continue to create. Uncontrolled landfilling, as a method of final disposal of solid waste, is environmentally and socially unacceptable as it does little to protect the environment and public health .thus, Open dumps provide very poor living conditions for waste pickers and pose current and future health risks. In addition, the cost of remediating these sites can easily exceed their total lifetime capital and operating cost. They are and have been the source of pollution to the very ground water systems used by most of the citizens. The repercussion of such management practices has been poor health. Sanitation inadequacies contribute to more than fifty percent (50%) of diseases in the country with attendant socio-economic costs. Sanitation related diseases such as malaria, diarrhea, dysentery, intestinal worms and acute upper respiratory tract infections have been among the most frequent health problems reported at outpatient health facilities in the country with seasonal epidemic outbreaks of cholera. Clearly, the practice of open dumping of MSW is neither integrated nor sustainable. It is neither environmentally friendly nor economically viable. The practice has become more challenging in recent times with rapid population growth and diminishing availability of disposal sites especially in urban centers of developing countries. A more sustainable and integrated approach has been the recommendation to phase out uncontrolled disposal and to progress to adopt and implement sanitary landfills in developing countries. In order to reduce environmental degradation and risk posed by uncontrolled solid waste disposal sites, the governments of Nigeria are particularly at risk, because of her bad waste management system and unhealthy disposal practices. Global temperature will continue to increase causing further disruption to climate patterns. Ultimately, all this can only be brought under control by engaging in sustainable waste management practices, and stabilizing greenhouse gases concentrations in the atmosphere. Therefore the research intends to investigate the effect of management practice on waste disposal in Nigeria.

RESEARCH QUESTIONS

1 What constitute solid waste?

2 What is the effect of solid waste in the environment?

3 What constitute the strategy for effective waste management practice?

4 What constitute the management practice of CUDA for effective waste management practice?

WASTE

The federal environmental protection act (1988) does not define “waste”, however Waste as the term implies is any solid, liquid or gaseous substances or materials which being a scrap or being super flows, refuse or reject, is disposed off or required to be disposed as unwanted, this is Environmental law, the term assumes it’s ordinary literal meaning unlike in the real property Law, When “waste” is used as a term of art, having meaning completely different from its ordinary meaning. One of the few statues in Nigeria, which attempts to define waste is the Lagos State Environmental Edicts 1985, there in Section 32, waste is define as follows:

Waste includes:

i.) Waste of all description.

ii.) Any substance, which constitutes scrap materials or an effluent or other unwanted surplus substances arising from the application of any process.

One thing to notice is that none of the above definitions of waste give "value" to the elements considered. There is no suggestion that the items, which constitute a waste, do not have value or is intrinsically useless. The word "unwanted" appears in the definition although it introduces its own problem, does not necessarily, import a value element for a substance or material that may be unwanted notwithstanding that it has some value.

The major effects of waste management on the quality of life Environmental effects

The major environmental effects include air pollution, which includes odor, smoke, noise, dust, etc. Waste pollution - pollution from disposal site via flooding because of blocked drains and land degradation. Health effects: This includes: flies which carry germs on their bodies and legs and also excrete them; mosquitoes breed in stagnant water in blocked drains in favorable location in cans, tyres etc. that collects rain water; Rats: rat's spreads typhoid, salmonella, leptospirosis and other diseases they cause injuries by biting and spoil millions of tons of food. The refuse workers also faces some hazards which includes: parasite infection and infected cuts resulting from skin contact with refuse, other includes hazards on disposal sites; are injuries from glass, razor blades, syringes, tissue damage or infection through respiration, ingestion or skin contact.

Challenges:

Challenges in waste management service delivery include;

? Lack of comprehensive legal framework and enforcement of the existing regulations

? Low investment (private) in infrastructure

? Inadequate human capacity for administrative and technical issues

? Wrong attitude of the public towards solid waste disposal

? Financing –Cost recovery is low in most States and no funding

? Poor Planning – low data management and uncontrolled urbanization

? Uncoordinated institutional functions

? Low academic research and industry linkages

? Lack of political will.

Inadequate vehicles, plant and equipment and tools necessary for waste management Waste disposed or deposited at designated points of collection has to be transported either to the transfer loading station where sorting is done or to the incinerator facility or sanitary landfill or the final disposal point. It was further noted that for effective and efficient collection system, there must be enough and well maintained equipment such as trucks tippers, pay loaders, bulldozers, Int. NGO. J. 176 road sweepers, compactors and others. In Lagos State municipal solid waste transportation, collection and disposal has been epileptic, since the state realized its responsibility to the environment. A lot of problems such as inadequate number of vehicles, lack of spare parts, dearth of fund, poor technical know-how, poor maintenance practices, insufficient funding and lack of motivation has bedeviled the agency responsible for the disposal and collection of waste. The total numbers of vehicles required in the 20 local government area of Lagos state was 757, while the Lagos State Waste Management Authority, just received 100 brands news waste compactors. The heaps and stretch of refuse which adorn our roads pollute the environment and disfigure the landscape are nothing but the result of inefficient waste collection and disposal management method.

WAY FORWARD FOR WASTE MANAGEMENT IN LAGOS STATE TOWARDS SUSTAINTABLE DEVELOPMENT

Some of the major problems confronting and militating against an effective management and sustainable development of waste collection and disposal in Lagos state have been identified in this paper to include among others:

i.) Population growth.
ii.) Waste disposal habit of the people.
iii.) Attitude to work (of those rested with the responsibility of collecting and disposing the waste).
iv.) Lack of adequate equipment and plant and other tools necessary.
v.) Corruption.
vi.) Overlap of function enforcement agents. The entire above highlighted problem cannot allow for effective management and sustainable development. Therefore it is against the background that there is an urgent need to address the effective waste management system to be adopted for a sustainable development and landfilling.

Mitigating Measures

Expanding recycling program can help reduce solid waste pollution but the key to solving severe solid waste problems lies in reducing the amount of waste generated. It was noticed that only the landfill system of waste disposal is being generally adopted in Lagos State. Whereas system that can or may be adopted are:
i.) Recycling
ii.) Bio treatment
iii.) Incinerations
iv.) Neutralization
v.) Secure sanitary landfill
vi.) Composting

What Is Waste?

Waste is any trash, garbage, rubbing refuse, you don't need again you discharge because they can be harmful. Waste comes in various shapes and sizes ranging from an old toothbrush or a scrap the body of a school bus.

Type of waste

Generally was could be liquid or solid waste. Both could be hazardous. Liquid and Solid types can also be group organic, re-useable Here some type of waste outlined as follows:
*Liquid waste: can come in non solid form. Some can also be converted into a liquid form for disposal. It includes point sources and non point source discharges like storm water and waste. A good example liquid waste are water I septic tanks, wash water from homes, liquid used for cleaning in industries and waste detergents.
*Solid Waste: Are waste mostly any form of garbage, refuse or rubbish that we can maybe in our homes and industries. This includes an old car tyres, old newspapers, broken furniture and food waste. They may include any waste that is non liquid.
*Hazardous Waste: Hazardous or harmful are kind of waste that could be inflammable (can easily explode) corrosive (Can easily eat through metal) or toxic (poisonous to human and animals). In most developed countries, it is required by law to involve appropriate authority to supervise the disposal of such hazardous waste such as fire extinguisher, old propane tanks, pesticides, mercury-containing- equipment e.g thermostat and lamp, fluorescent bulb and batteries.

What is Waste Recycling?

Recycling is the processing of used material into a new, useful products, This is done to use of raw materials that would have been used. Recycling also uses less energy and is a great way of controlling air, water and land pollution. An effective recycling starts with the household or the where the waste was created. In most developed countries the authorities helps households with bin bags with label on them. Household then sort out the waste themselves and place them in the right bags for collection. This makes the work much easier.

*Recyclable Waste: Recycling is processing used waste material into a more new and useful end product. This is done to reduce the use of raw materials that have been used. This is waste that can be recycled as the term implies Aluminum product - Soda, milk and tomato cans.

Aluminum recycling process:

1. **Collection**: Local Council provides special can recycling containers (bins) that are clearly marked. This is what helps people know how to place them. Cans include soda, fruit and vegetable cans. Trucks come for these at pick up spot and transports them to the recycling centers. Can may be metal and steel cans. But people do not know the differences.

2. **Preparation**: At the collection center, a huge magnets is rolled over t

hem as they move on the convey belt to pull out the metal and steel cans. Then aluminum can are washed, crushed and condensed into 30pounds briquettes for other companies for further processing The rest is also sorted and sent to the recycling centers.

3. **Melting**: The Crush cans are loaded into a burning furnace, Where all printing designs on the can is removed melted blended with new (Virgin) aluminum. The molten (liquid) aluminum is poured into moulds and made into bars called ingots.

4. **Sheets**: The ingots are then fed into power roller which flattens them into thin sheets of aluminum of about 25.4 thicknesses. These things sheets are rolled into coils and sold or sent to an can making factories. They use aluminum coils to prepare cans and containers for other foods and drink manufacturers.

It is estimated that can collected and recycled takes up to 60days to appear in the shops again as new cans. Plastic grocery shopping bag, plastic bottles, Glass Materials, Wine and beer bottles, broken glass.

Glass Recycling Processing.

1. **Collection**: Many cities have collection spots. Trucks may also pick them also from your home or you might need to take them to a point in your town. In all cases try to do what the waste recycling representative suggested. So be sure you know the various kinds of glass collected from your home. Always wash and separate into the required grades for collection

2. **Cleaning and Crushing**: The glass is transported the processing plants where contaminants such as metal caps and plastic sleeves are removed Different grades are treated separately. Clean glass is then crushed into small pieces called. Cullet is high in demand from glass manufacturers. It melts at lower temperature and is cheaper than raw glass materials.

3. **Ready for use**: The Cullet then transport to glass making factories. Here it is mixed with sand soda ash and limestone. It is heated at a very high temperature and melted into liquid glass. This liquid is poured into moulds and it gives the glass its shape. Glass is used for many things depending on what grade they were recycled glass include fiber - glass, counteracts, bottles and jars. -Paper Materials: used envelopes, newspapers, magazines, car boxes

Paper recycling process:

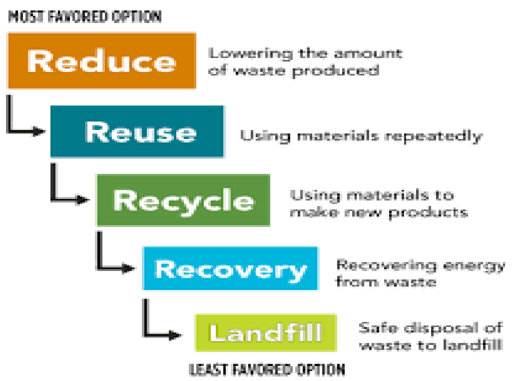
1. **Collection**: The biggest task for paper recycling companies is probably the collection and transportation. This is because we always add paper to other waste item and they get contaminated with food, plastic and metals. Sometimes collected paper is sent back to the landfill because they are too contaminated for use. Try to keep waste paper in separate grades at home or in the office. For example do not mix newspaper and corrupted boxes up. All paper recovered is sent to the recycling center where it is packed, graded put into bales and sent to paper mill the paper is stored in a warehouse until it is needed.

2. **Repulping and Screening**: These waste materials being collected from the shelves, they are moved into the a big paper grinding machine known as a vat (pulper) where the paper is chopped into tiny pieces mixed water and chemical and heated up to turn them into organic plants material called fiber. After it it's screened to remove contaminants such bits of plastic and globs of glue.

3. **Deinking**: This involves 'washing' the pulp with chemical to remove printing ink and glue residue. Sometimes a process called flotation is applied to further remove stubborn stains and stickies. Flotation involves the use of chemical and air to create bubbles which absorb the stickies in the pulp.

4. **Refining Bleaching Color Stripping**: Refining involves beating the recycled paper to make them ideal for making. After refining additional chemical are added to remove any dyes from the paper. It is then bleached to white and brighten it up.

5. **Paper Making**: This stage, the pulp is ready to use for paper. Sometimes new pulp (Virgin pulp) is added to give it extra strength smoothness water added to pulp and spray onto a large metal screen in continuous mode. The water is drained on the screen and fibers begin to bond with each other. As it through the paper making machines press roller squeeze out more water, heat them dry and coat them up. They are then finished into rolls.



Recycling is the process of converting waste materials into reusable objects to prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, energy usage, air pollution (from incineration) and water pollution (from landfilling) by decreasing the need for "conventional" waste disposal.

URGENT TIPS TO ATTAIN BEST PRACTICES

i.) In term of population, there is an urgent need for action plans and education in order to monitor and control waste expected in the state. There should also be a room for international co-operation towards achieving the action plans.

ii.) Expanding recycling programs through the activities of scavengers among others (Waste-to-wealth).

iii.) Land fills management and control; Waste-to-energy programs can be generated through the land fills (Generation of Methane Gas).

iv.) There is need for purchase of updated equipment; there is an urgent need for well trained staff, vehicles, trucks, tipper, pay loaders, bulldozer and road sweeper, which must be backed up with well stocked maintenance store provided for spare parts for all equipment.

v.) There is a need for an organised refuse collection both from residential and industrial estates. There must be a disposal site in each street and avenue nearest to the sources of waste, which must be accessible by everyone and the collection should be daily and regularly.

vi.) The support of private sector and NGO's is also required most especially in the area of organising maintenance workshops and enlightened programs, which should include grassroots participation and input.

vii.) The Federal and State Government should properly fund the various agencies responsible for effective and safe waste management and make it the pivot of the agency in the various states to be responsible for collection and disposal of all types of wastes.

viii.) There is a need for at least one domestic waste incineration plants in each local government council constructed with a daily waste treatment capacity of at least 3000 tons, which can generate electricity through incineration so as to recover the energy out of the waste.

ix.) There is need for more effective and up to date domestic waste transfer stations.

CONCLUSIONS

Landfill scenario has been changing over time. With increase in waste generation rates, Scarcity of land availability and global warming issues, there is a great need for modifications to the existing landfill designs targeting at energy generation from waste and with less requirement of area. Modified design was proposed based on theoretical considerations and also the levels of waste generation. In a case study it was found that there is a possibility of generating energy worth of Rs.115.84 million (with FRIN harvested equivalent to 0.145 million tons of coal). Manifold land saving has been possible on account of these cells. Design by the new approach as they would require only a fixed area of land whereas the conventional designs would need land on a continuous basis because the waste takes more than 20 years to fully get composted and settle in the case of landfill designed as per the existing design procedures. Thus, LFSGR based on the newly proposed landfill design would prove better both on counts of land saving as well as energy generation.

ECONOMIC POTENTIAL OF BY-PRODUCTS AND BIOENERGY COMING FROM BIOMASS ANALYZED IN DIFFERENT COUNTRIES

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ABSTRACT

Biomass energy has become a versatile trend in various countries around the world. The energy generation scenario is an excellent experience to explore new alternatives and provide a base as a better structure for developing countries. Wastes and residues from agriculture, forests, related industries and biodegradable fraction from industrial and municipal wastes, have been used as biomass for renewable energy. The biomass covers a range of by-products, including agricultural by-products like straw, peanut shells, sunflower shells, animal manure, etc., industrial by-products such as residues from food and also sewage sludge and organic fraction of agro-livestock solid waste. Moreover, the possibility of using the above mentioned products and wastes as biomass feedstock enables the production of huge quantities of energy resulting in benefits for the environment e.g. reduction of landfilling and dumps.

This article aims to evaluate the technology development enabling advancements on the circular economy, and the diffusion of best sustainable agricultural practices. Last but not least, this article will discuss alternatives for a sustainable use of residues, waste from bioenergy and it will also present a benchmarking on international cooperation to promote sustainable biomass production systems and their practices in diverse countries.

This paper is a collaborative work carried out by different authors to prepare a report of diverse experiences in some countries in Latin America, Italy and The Republic of Fiji.

Keywords: biomass, bioenergy, wastes, sustainability, circular economy.

INTRODUCTION

The concern for the availability of resources and the quality of the environment gave birth to the concept of sustainable development in the last decades of the twentieth century. It was understood that sustainability was achieved by combining three dimensions: economic, social and environmental.

In parallel, society, companies and governments have addressed sustainability as an objective with different industrial models and from a linear perspective. Nevertheless, it is essential to activate the transition towards a new productive model that reduces the pressure on the environment, and that is capable of generating economic and social development. In this scenario, the concept of circular economy is an alternative to the linear model.

The circular economy replaces the linear model of "take – manufacture – consume - eliminate" with the alternative of reuse, recycling and recovery of materials during the production, distribution and consumption processes. The circular system uses recycled materials to produce goods. The production and supply of goods are designed to minimize waste and, after consumption, return materials to manufacturers for reuse.

The main objective of the circular economy is to maintain the value of products and resources for as long as possible, in order to minimize waste to the point of not generating it. As a result, no additional natural resources are needed to produce materials, and discarded products no longer become waste. The transition to circular economy needs to occur at different levels: products, companies and consumers; eco-industrial parks; cities, countries. (Kirchherr et al., 2017).

There are several circularity strategies to reduce the consumption of materials and natural resources, and minimize wastes. The model presented in Figure 1, defines the hierarchical levels between linear and circular economy (Potting et al., 2016). The lowest level is 'recovery' and describes the linear economy. The highest level is 'reject' and describes the circular economy: the products become redundant or are replaced by a completely different product.

This paper is a collaborative work carried out by different authors to prepare a report of diverse experiences in some countries in Latin America, Italy and The Republic of Fiji.

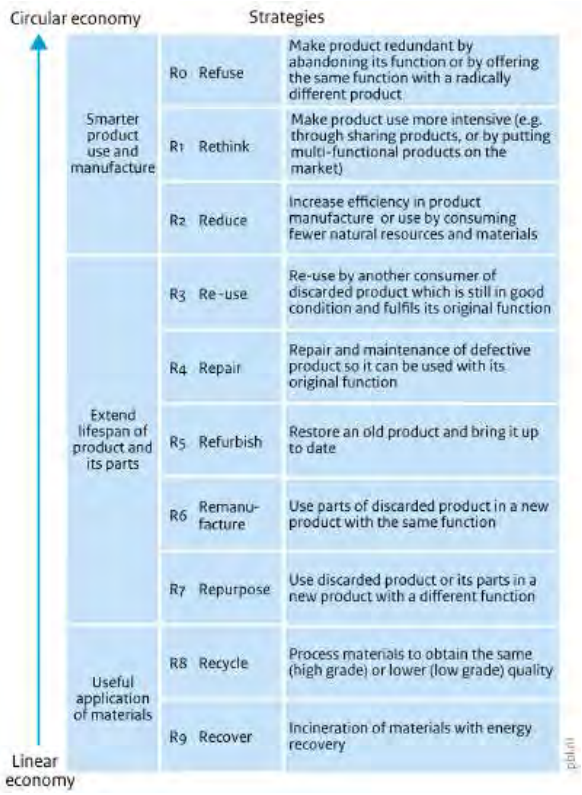

Figure 1. From linear to circular economy

EXPERIENCES IN DIFFERENT COUNTRIES

Figures 2 to 4 show some economic parameters of the countries mentioned in this work: population, gross domestic product (GDP) per capita, oil and electricity generation and consumption.

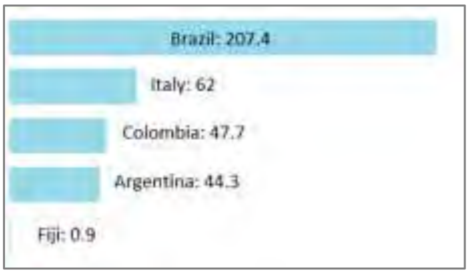

Figure 2. Population [millions of inhabitants]

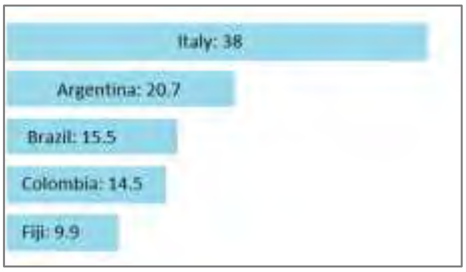

Figure 3. GDP per capita [thousands of dollars]

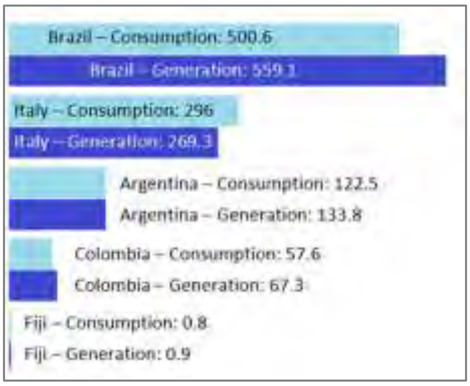

Figure 4. Electricity generation and consumption [thousands of millions of kWh]

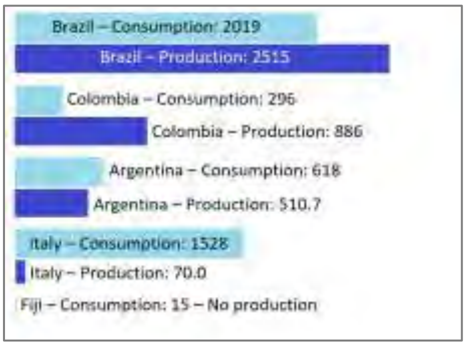

Figure 5. Oil production and consumption [thousands of barrels per day]

Argentina

In Argentina, different programs have been created to stimulate the rational and efficient use of energy and the development of projects with renewable energies, such as the PROBIOMASA Program for the Promotion of Energy Derived from Biomass, created in 2011.

This program aims to "increase the production of energy derived from biomass at local, provincial and national levels to ensure society a growing supply of renewable, clean, reliable and competitive energy, while opening new opportunities for the development of the country's agricultural, forestry and agroindustrial sector". According to a survey carried out by FAO (Food and Agricultural Organization, USA) and financed by the PROBIOMASA Program, in 2009 in Argentina bioenergy projects were developed by industrial sectors with high availability of biomass. According to the region, they were linked to the forestry industry in the Litoral area, with the sugar and citrus industry in the Argentine northwest area, and with livestock activity (production systems in confinement) in the Pampean region. Following the terminology proposed by FAO, these materials can be classified according to their characteristics as woody biomass, tree biomass, fruit and seeds biomass and others. The Ministry of Agribusiness, in order to give continuity to the activities developed in this Program, has created new alternatives that consist of obtaining chemical energy (methane gas, biodiesel or bioethanol, etc.), from animal or vegetable materials, in order to increase the participation of these generation sources in the energy matrix.

Recently, new projects have been signed for the supply of electric power from biomass, which will be carried out in different provinces. They are:

- A project for generating biogas, in the town of Pérez Millán, will add 1.5 MWh. The inputs that will be used will be liquid and solid waste from the process of a beef slaughtering plant.
- In the town of Rojas, corncob, corn husk and sorghum will be used to produce 7 MWh.
- A project of biogas, in the town of Ensanche Coloñia Caroya, department of Colón will use residues from chicken slaughter, animal slurry, bovine manure, oils, fruit residues, sludge, substrates of animal origin to produce 2.4 MWh.
- A project of biogas, in the town of Alcira Gigena. will use effluents from intensive pig farming and will add 1 MWh.
- Using peanut shell in the town of Las Junturas 0.5 MWh will be added.
- With bagasse as an input, in the town of Leales, Tucumán, 2 MWh will be added.

As energy recovery is the lowest level in the circular economies, in the next section other applications will be discussed, in particular for peanut shells.

The peanut industry: Peanuts are a legume from South America, currently spread throughout the world. Despite being a legume, in international food legislation it is considered a nut. Peanuts are often considered to be oleaginous crops because of their high oil content.

The peanut shells, represent between a fourth and a fifth part of the harvest. The use of these shells for diverse applications has been studied.

✓ **Activated carbon**: Several authors have studied the activated carbon produced from peanut shells (Xu et al., 2017; Georgin et al., 2016; Li et al., 2015; Zhou et al., 2015). Activated carbon is used to remove color, smell and taste from an immense universe of products, so it is used in simple applications such as tank filters and complex industrial processes such as wastewater treatment. In Argentina, a company (Cotagro) produces activated carbon from the shells. This company is capable of producing 1,200 tons of activated carbon per year. Argentina consumes between 4,000 and 4,500 tons annually, being the 80% imported. Until the recent development of Cotagro, domestic production was mainly carried out with the chopping of quebracho. From a contaminating waste Cotagro obtains a product with commercial value.

✓ **Biosorption of heavy metals:** The biosorption process has low cost, since it uses biomaterials without industrial application, such as agricultural waste like husks from rice, orange, lemon and grapefruit, corncob, soy and rice bran, etc. The biosorption of heavy metals on peanut shells has also been studied (Cheng et al., 2016; Taşar et al., 2014).

At Facultad Regional San Nicolás (FRSN), Universidad Tecnológica Nacional, the possibility of the biosorption of copper is currently being studied. In the conditions of the study, the biosorption processes were much more efficient for particle sizes in the range 250µm-88µm. The results of the study showed that peanut shells might be used as a low-cost, eco-friendly and effective biosorbent to remove Cu^{++} ions from aqueous solution (Mazzola et al., 2018)

✓ **Construction materials:** There are some works in the bibliography that study the manufacture of construction materials from this type of discards (Binici and Aksogan, 2017; Akgül and Tozluoğlu, 2008).

At FRSN, the possibility of using peanut shells as raw material for the manufacture of ceramic materials for the civil construction industry was studied (Quaranta et al., 2018). It was concluded that the bricks obtained with 5% and 10% of added residue and treated at 950ºC have good physical and mechanical properties, with acceptable values of porosity, modulus of rupture, permanent volume variation and weight loss on ignition. The porosity of the samples increases as the initial biomass residual content increases. Samples with 15% of biomass treated at 1000ºC also have good characteristics.

Brazil

Brazil is one of the largest food producers in the world, consequently, it is also a residual biomass producer.

Biomass is the third largest energy source in Brazil (EPE, 2016), because developing countries have a large capacity to produce energy, as biogas and biomethane, from agro-industrial waste. However, there is no statistical data on the national biomass potential, requiring estimating it through secondary data, such as for example the livestock census.

The country has the ninth largest economy in the world, mainly for the agricultural production that is responsible for most of the GDP. It is the fifth largest food producer in the world considering milk, pork, chicken and beef (FAOSTAT, 2017).

The growth of this sector is evident, especially in the State of Paraná, since it is the largest animal protein producer, responsible for 20% of national production. Considering the breeding of poultry, pigs and cattle, no other State records results, in tons, higher than Paraná (IPARDES, 2016). The data presented in Tables 1 and 2 (Adapted from SEAB, 2016), shows the comparisons between the national agricultural sector and the state of Paraná.

Table 1. Effective of the herd (heads), 2015

Type of breeding	Brazil	Paraná	Ranking (º)
Bovines	212,343,932	9,181,577	10
Pigs	37,929,357	6,394,330	1
Dairy cattle	23,064,495	1,723,996	4
Broiler	5,790,922,484	1,772,546,336	1

Table 2. Products of animal origin, 2015

Product	Brazil	Paraná	Ranking (º)
Milk (thousand liters)	35,174,271	4,532,614	3
Chicken eggs (thousand dozen)	3,734,257	377,452	2

The influence of this sector in the western region of the State of Paraná is strongly affected by agroindustrial cooperatives, because the nine largest cooperatives in Brazil are in this state and six of them in the West region, as Lar, Frimesa, Copragril, BRF, Friela and Globoaves. These cooperatives account for 40 thousand producers, generate 35 thousand direct jobs and have an annual revenue of 50 billion BRL.

The circular economy begins to make sense just over the last 10 years, when the biogas market was strongly influenced by the national energy scenario, since agribusiness products are commodities and generate narrow economies. This does not mean that the biogas or biofertilizer (digestate) generated financial return, but direct and indirect economy return from the energy and fertilizer saved. At this stage the farmer who has their own energy production was not more susceptible to the loss of production due to rural energy failures. For bioenergy producers, biogas impacts on avoiding costs, such as:

- With biofertilizer in partial or total replacement to the mineral fertilizer
- Generation of electric energy by means of a motor generator
- Generation of thermal energy in substitution of firewood
- As fuel by systems of biogas purification, called biomethane

There are 127 biogas plants in operation, of which 54% apply biogas in the generation of thermal energy, 44% in electric energy and 2% in the production of vehicular fuel. The national biogas production potential is around 409 TWh.year^{-1}, equivalent to 78% of national energy demand (CIBIOGÁS, 2016a; EPE, 2016; FIEP, 2016).

Brazil is recognized as one of the market and technology leaders in the production of sugarcane, which has led to the conquest of the international market with the use of bioethanol as an energetic alternative.

Searching for renewable energy sources to substitute the fossil fuels use is growing, due to a great concern worldwide for global warming and climate change. The use of bioethanol, when compared to fossil fuels, reduces the emission of carbon dioxide in the atmosphere by up to 90% (IEA, 2007). The search for sustainable solutions with the intention of taking advantage of the lignocellulosic residues for the alcoholic fermentation and generation of energy results in a more efficient energy process.

Sugarcane, when processed, generates by-products such as bagasse and sugarcane straw. In relation to sugarcane bagasse, this is produced in high quantities and in Brazil it is generally burned to produce steam in the process of heating boilers and / or generate electricity for own consumption as well as for sale.

Each ton of sugarcane, about 140 kg of straw is generated, however, it is necessary to keep a portion of that straw on the surface of the soil, about 50%, for bringing benefits to the cane such as nutrient cycling, reduction of the greenhouse gas emissions and increase of sugarcane yield (Galdos et al., 2010). Consequently, not all straw produced in the crop can be used in industry, either for steam generation or second generation ethanol production.

More than 500 million tons of bagasse are generated annually, Brazil being the largest producer with 40% followed by India with 19% (Sun et al. 2013). The proportion of bagasse produced per ton of sugarcane is

240 to 280 kg (with 50% moisture content), resulting from sugarcane crushing (Canilha et al., 2012)).

Sugarcane cultivation occupies an area of approximately 8.7 million hectares in Brazil, corresponding to a total production in the 2017/18 crop of 633 million tons, generating around 37 million tons of sugar and 28 billion tons of sugar liters of ethanol in the same period (CONAB, 2018).

It is worth emphasizing that the use of sugarcane bagasse and straw present in the field is adding value to this production once the bagasse is already in the mill and the straw is already produced, necessitating only new equipment and the operational cost collecting and transporting the straw.

Colombia

Colombia is a highly privileged country by its geographical position (Ospino, 2010). Being in the equatorial zone, it receives constant radiation in some regions, mainly the Atlantic region, particularly, in the states of San Andrés, Magdalena and the peninsula of Guajira, in which the average radiation is around 4.5 kWh m^{-2} $year^{-1}$. In other regions such as Orinoquia, Amazônia, Pacifica and Andina the average radiation is, respectively, 1,643, 1,551, 1,278 and 1,643 kWh m^{-2} $year^{-1}$ (IDEAM, 2015).

Due to these solar radiation rates, agriculture occupies an important line in the economy of this nation with a share of GDP of 7.0% in the year 2016. On the other hand, the use of this radiation in the generation of electricity "clean and renewable" using solar panels is envisaged.

Colombia is a country that points to the diversification of energy sources compatible with sustainable development, mainly oriented to environmental, economic and social factors.

Within this context of clean energy generation, biomass as an energy source in this nation has relevant importance, mainly by policies adopted by Colombia. So for example, the Ministry of Mines and Energy established different resolutions aimed at encouraging the production of biodiesel. In 2007, the resolution N°18-2142 established that all fossil diesel marketed in the country had to contain 5% biodiesel, which stimulated and increased exponentially the production of this energy source, mainly, obtained from palm oil. The behavior of biodiesel production as well as their crops is presented in Figure 6 (Fedebiocombustibles, 2018). It should be noted that in 2007, in Colombia, biodiesel production was 22,730 tons and in 2015 its production reached 513,354 tons.

The panorama is more and more encouraging because in 2018 the resolution N° 40-184 of the Ministry of Mines and Energy established that diesel should contain 10% of biodiesel obtained from biomass, with which it can be predicted that biodiesel production will have a significant increase.

Another important energy source in Colombia obtained from biomass is the fuel alcohol. This fuel in the country is mainly obtained from sugarcane and is not used directly as fuel but as a gasoline oxygenator. According to the country's energy-planning unit, in 2008, 64% of the gasoline was being oxygenated with 10% ethanol (UPME, 2009). In the year 2011, all gasoline marketed in the country was oxygenated with 10% of alcohol, which increased its production. The behavior of the production of alcohol obtained from sugarcane and their crops is shown in Figure 7 (Fedebiocombustibles, 2018).

In Colombia, the generation of energy from biomass residues is also being encouraged. In 2014, the Law N°1715 was approved, in which the participation of non-conventional renewable energies in the national energy system was regulated. In this context, the sugarcane bagasse is the first residue being used in the generation of electric energy.

According to the industrial sector of the cane (ASOCANA, 2018) 1,420 GWh were generated from bagasse in 2016. This energy can meet the needs of approximately 1 million people.

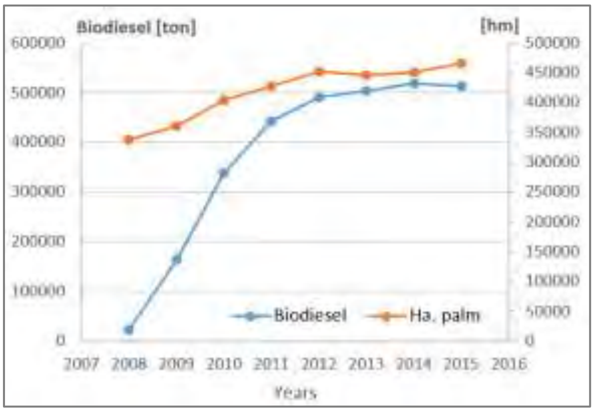

Figure 6. Variation in biodiesel production and palm plantations in Colombia.

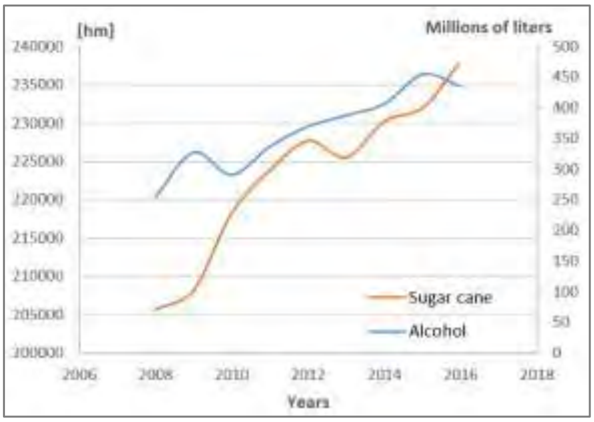

Figure 7. Variation in alcohol production and sugarcane plantations in Colombia.

The circular economy in Colombia took on a great importance in 2014 after the approval of the law of regulation of renewable energies. At present there are many projects directed to generate energy from different types of wastes. Poultry and pig farming companies are adapting their systems to harness animal manure as substrates for methane production. The Incubator Santander generates approximately 4.4 MWh, from the dung of the chickens, waste that formerly caused high impacts on the environment by the release of methane (Amon et al., 2006; Sandars et al., 2003). Domestic solid waste in Colombia to generate methane is also being studied. The organic wastes generated in Palmira-Colombia, a city with a population of approximately 350,000 people, can generate 3,295 MWh (Cadavid-Rodriguez & Bolaños-Valencia, 2015). That is why landfills are being adapted for the burning of the gases with the consequent generation of electric energy. In addition, the treatment plants of domestic sewage in the city of Medellín are used for the generation of gas from these effluents. In this way, in a circular economy those by-products, that do not have a significant value in the process in which they were generated, are used as substrates for the generation of energy with the consequent reduction in the level of pollution.

Italy

In Italy the bio-based economy, including the production of energy from biomasses and bio-fuels, is one of the main pillars of the implementation of the circular economy (EC, 2015). In 2016 the share of the contribution of renewable energy to the whole national electrical energy consumption was about 34%. Bio-energies represent the 18% of this value (GSE, 2016).

Concerning thermal energy bio-energies represent about 68% of the about 10,540 ktoe from renewable energies consumed in the 2016 whereas in the transport sector the amount of energy supplied by biodiesel, bioethanol and bio-ETBE was of about 1,039 ktoe. Such high level of implementation of renewable energies were a consequence of more than 15 years of continuous application of a reliable economic, legal and political supporting scheme for this sector.

Table 3 shows the current and potentially available Italian residual biomasses (ENAMA, 2011).

A big gap still remains between the two figures indicating the high potential of this substrates in contribution to the implementation of circular economy in Italy.

Sri Lanka and Fiji

Circular Economy is the way forward for the Island nations. The island nations are characterized by their small land mass as such need to consider circular economy as their way forward. One of the prime features of the Island nations is the fact that the major proportion of their waste (70-80%) consists of biodegradable material, which can be composted, or converted into biogas.

The solid waste management policy of Sri Lanka and the waste management strategy of Fiji Islands do consider biomass conversion to energy as an appropriate technology. The lack of skills, and of financial resource has led to dumping waste into mountains of garbage.

In 2017 one such garbage mountain in Colombo, Sri Lanka collapsed damaging many houses and injuring people. Since then the Government has been seeking appropriate technology to combat the garbage issue.

Very few data are available in Fiji with regard to the contribution of biomass to sustainable energy supply.

Table 3. Availability and energetic content in TOE of residual biomasses for Italy (2011)

	Availability tonnes on dry basis		Energetic content TOE	
Sector	**Potential**	**Current**	**Potential**	**Current**
Agriculture				
Herbaceous	9,357,000	3,753,000	3,368,520	1,351,080
Arboreal	3,447,000	1,655,000	1,344,330	645,450
Forest				
Copse	1,185,000	486,700	497,700	204,414
Stem	1,838,000	358,100	808,720	157,564
Zootechnical				
Biogas generation [tonnes/year of biogas]	1,817,553,602	1,137,879,631	999,654	625,834
Other				
Agroindustry	1,420,000	1,130,000	511,200	406,800
Wood industry	4,400,000	1,800,000	1,936,000	792,000
Wood recycling	8,000,000	4,000,000	3,360,000	1,680,000

Chandra and Hemstock (2015) has analyzed the above ground biomass production and its utilization during the years 2003 to 2012. The results have shown that the total biomass production was approximately 72.67 PJ, originating 24% from food, 44% as agricultural residues, 10% from dung and 22% from Forestry. According to the mentioned authors, only 11% of the total biomass produced was utilized as fuel, whereas 12% was used as industrial wood and only 24% as food. The unutilized biomass has resulted in the loss of 38.5PJ of energy, which amounts to 53% of the biomass resources. In 2015, a US$35 million (FJ$72 million) Biomass Power Plant commenced in Nabou, Nadroga in Fiji. This renewable energy project has been possible through a joint venture partnership between Tropik Wood Industries Limited and a consortium of three Korean firms. The three Korean companies are GS Power, GIMCO and Korean Development Bank. The project included a 12 MW Biomass Power Plant and a pellet manufacturing project.

The project on utilization technology in Biomass Energy Conversion Systems of Sri Lanka (http://www.biomassenergy.lk/) established in 2016 states that the utilization of biomass for energy by the Sri Lankan industry has increased by 61% from 2001 to 2013. This project which is funded by UNDP (United Nations Development Project) reveals that the main reason for this affinity towards the Bio-mass Conversion systems is the escalating fuel prices, which showed a six -fold increase during the same period of time. A case study carried out in the tea plantations in 2013 recommends that if one decides to promote enhanced use of biomass in the tea industries then it needs to provide the companies that achieve self-sufficiency in energy requirement with sufficient incentives (Dassanayake, 2013). The project Promoting Sustainable Biomass Energy Production and Modern Bio-Energy Technologies in Sri Lanka which commenced in 2013 is funded by UNDP and has the following key components: Policy-Institutional support for effective fuel-switching using fuel wood, barrier removal for sustainable fuel wood production, enabling environment for fuel wood suppliers, wood-based energy technology development. This project which commenced in 2013 was scheduled to be completed in 2017.

The land area for large-scale projects in Fiji as well as Sri Lanka are primarily available in the rural sector, whereas the land available in the urban sector is fast shrinking. At present both in Fiji and in Sri Lanka the common households continue to compost their wastes. Composting is much more an effective technology in Sri Lanka than in Fiji. Fiji as a nation earns more through the sugar industry, and thus has not found a viable solution to the waste from the sugar industry. Chandra and Hemstock, (2016) have published that sugarcane has the potential to produce 129.25 million liters of ethanol. This was revealed when data on Biomass production, utilization and losses from 1993 to 2012 were analyzed in Fiji. According to the paper, bagasse has the potential to generate 8.2 PJ of energy in Fiji (Chandra and Hemstock, 2016).

As developing nations both Fiji and Sri Lanka are faced with the challenge of embarking on large scale waste to energy projects. With a better understanding of the technology and an increase in people with technological literacy and skills, it can be possible to open doors for these countries to commence viable biomass to energy projects. Without the ability of the island nations to be committed to circular economy with added producer responsibility the waste management will remain a tiresome exercise. Collaborations with effective economical win-win partnerships will be the way forwards. The paper will seek to develop a sustainable framework for introducing economical biomass utilization projects to Sri Lanka and Fiji.

FINAL REMARKS

This collaborative work is the product of a combined effort of professionals in solid waste from economically developing, transitional and developed countries. This paper presents some experiences on biomass energy, carried out in some countries of Latin America, Italy and The Republic of Fiji.

Although the economy parameters of the countries mentioned in this work are very different, in all of them, there are many governmental policies tending to stimulate the use of regional biomasses to generate energy.

The concept of circular economy is a common topic, in line with the tendency of most of countries of the world.

In the case of biomass-energy processes, it would be at the lowest level of circularity, that is, in linear economy, but nothing is mentioned about the new waste generated, the residual ash from this process. If the energy production from biomass is analyzed as the main industrial process, that is, considering energy as the product obtained, and new applications or uses of the ashes are sought instead of being sent to final disposal, it would also be increasing the circularity of the economy. In addition, it will get closer to the concept of "zero waste" of Sustainable Development, and contained in the "Principles of Green Chemistry".

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Design Preference of Combustible Trash Bin in Japan Using Pairwise Comparison

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ABSTRACT

Trash bin placed in waste generation and collection processes of waste management as waste collecting tool. In fact, trash bin was very important in source segregation that meant trash bins could not been rejected from waste management system. Good designed trash bins could affect to waste more efficiency. However, only few researches were concerned about trash bin design. In Japan, usually there are three kinds of trash bin including trash bin for combustible waste, incombustible waste and recyclable waste. Combustible waste is the majority waste in Japan with 70.8% (2010), which classified as kitchen waste, scrap paper, sanitary products, unrecyclable plastics, rubber and leather items, and clothing. The authors focused on design trash bin for the major of waste as combustible. This study designed a total of seven trash bin designs varying between the slot positions, visibility, and lid attachment. This research included survey questionnaires and statistical analysis, which analyzed different designed trash bins to find out the best in terms of psychological preference. Psychological preferences of trash bin arrangement were scaled by web questionnaires using pairwise comparison method with Thurstone's law of comparative judgement. Web questionnaires were conducted in Mar. 2018 for 3,090 people. Therefore, a total of 3,090 data was collected in the study. Gender of respondents was balanced equally. The ages of respondents were from 20's to 60's and also balanced equally with 10-year interval. The results showed the best preference design was slope slot position with visibility and worst preference was trash bin with lid attachment. High preference score designs might encourage waste segregation.

Keywords: Designed trash bin, Combustible waste, Waste segregation, Slot position

INTRODUCTION

Solid waste management become a major environmental problem in future with the national average is expected reaching to 2.23 kg/capita by 2024 (Saeed, M. O. et al., 2009). In Japan, the government is interested in solving the waste management problem with the strategies (Ministry of the Environment Government of Japan, 2016). Waste management in Japan is always improving with greatly increasing of recycling rate from 5.3% in 1991 to 20.4% in 2012. However, the recycling rate in Japan is not so high when compare with another developed countries. For example; 60% recycling rate in Korea (Lee, M. et al., 2017), 40% in Italy (Crociata, A. et al., 2016), and 33% in Sweden (Stoeva, K. and S. Alriksson, 2017).

Municipal solid waste which was collected from designed trash bin in good separation before transfer to MSW sorting plant make more efficiency not only in sorting process, but also recycling process. Waste separation become the key of waste management solution because waste separation can reduce cost of waste management service by 26% (Chifari, R. et al., 2017). Furthermore, good waste separation reduces cost of sorting/recycling process in MSW sorting plant (Gundupalli, S. P. et al., 2017).

Solid waste is collected by trash bins/trash containers. Trash bins was designed to encourage people separate wastes. However, only few researches concerned trash bin design. From the review of knowledge, the authors found design physical structure of trash bins may impact waste separation efficiency of recycling waste (Andrews, A. et al., 2013). For the reason, design analysis of trash bins can be one of the solutions for improving waste separation efficiency.

In this study, the authors focus on combustible waste trash bin designs because combustible waste is the major waste in Japan at 70.8% by weight (Chifari, R. et al., 2017). Good designed trash bins need to concern what human preference. Seven designed trash bins are analyzed by preference score from 3,090 respondents.

Objective of design

The authors focused on design trash bin for the major of waste as combustible. This study designed a total of seven trash bin designs varying between the slot positions, visibility, and lid attachment. This research included survey questionnaires and statistical analysis, which analyzed different designed trash bins to find out the best in terms of psychological preference.

MATERIAL and METHODS

This study includes two sections of trash bin design: Design Preference and Preference analysis.

Firstly, Design Preference is the section of design model that refers to many different designs of trash bins such as slot shape, size of bin, separated slots in one bin, indicator (letter/illustration) and position of slot, direction above throwing slot, and colors of bin. To find out the best one of designed trash bin to suite with human preference.

Secondary, Preference analysis is the key of this study to evaluate with selection ratio data set to quantify the unwillingness using Thurston law of comparative judgment (Thurstone, L. L., 1927) by binary pairwise comparison method.

Design Preference

In previous research found out the preference color of combustible trash bin was red and slot shape was rectangle. This study focuses on seven designed trash bins (see Figure 2) which were different in terms of slot position, visibility, and lid attachment. Lid of bin was also one important factor to concerned because Sean Duffy's report presented specialized lids increased recycling compliance rate by 34% (Duffy, S. and M. Verges, 2009). Design of trash bins from TB-01 to TB-07 following; (1) top slot position, letter and illustration indicators in front, and visibility (2) slope slot position, letter and illustration indicators in front, and visibility (3) front slot position, letter and illustration indicators on top, and visibility (4) top slot position, letter and illustration indicators in front, and invisibility (5) slope slot position, letter and illustration indicators in front, and invisibility (6) front slot position, letter and illustration indicators on top, and invisibility (7) top slot position with lid attachment, letter and illustration indicators in front, and visibility. All designs used for web-questionnaires on one by one selected questionnaire that mean vary seven design of trash bins provided 21 questions in one data set of web-survey.

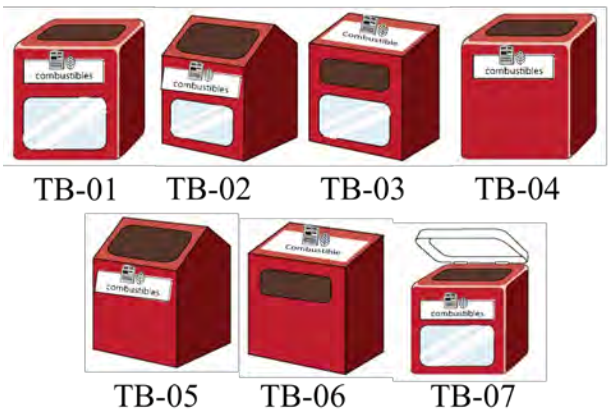

Figure 2 Designed trash bins for combustible waste

Preference analysis

Pairwise comparison matrices are frequently applied in multi-criteria decision making (Bozóki, S. and J. Fülöp, 2016), preference analysis of trash bins is also the one of multi-criteria decision to find out the best among any designs. Binary pairwise comparison method was using to find out the best designed trash bin in statistical preference. Psychological preferences of trash bin arrangement were scaled by web questionnaires using pairwise comparison method with Thurstone's law of comparative judgement. Web questionnaires were conducted in Mar. 2018 for 3,090 people. Therefore, a total of 3,090 data was collected in the study. Gender of respondents was balanced equally. The ages of respondents were from 20's to 60's and also balanced equally with 10-year interval.

1) Check coefficient of agreement. If $P<0.05$ (significant level at 95%) that meant the number of respondents was not too low, statistically useful.
2) Using Pairwise comparison to arrange ranking of each designed trash bin.
3) Using Binomial's test to find out significant different between ranking of results.

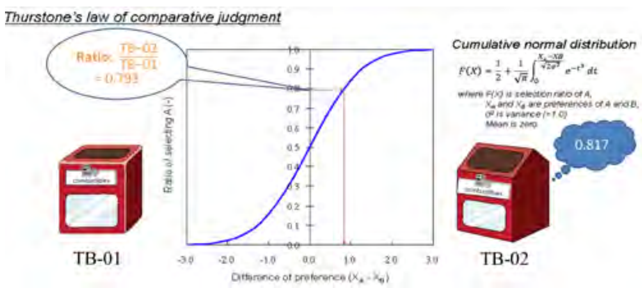

Figure 3 Thurstone's law of comparative judgment

RESULTS and DISCUSSION

First at all, the result of coefficient of agreement showed P value is 0, which is meant statistically useful. After knowing that the data was statistically useful, then evaluate psychological preference using pairwise comparison.

From pairwise comparison, the results showed respondents prefer slope slot (TB-02 and TB-05), top slot (TB-01 and TB-04), and front slot (TB-03 and TB-06) respectively and they also prefer visibility trash bin (TB-01 to TB-03) rather than invisibility one (TB-04 to TB-06) of the same slot position design. Furthermore, respondents not prefer trash bin with lid attached (TB-07) (see Figure 4).

Moreover, the authors also considered psychological preference on each gender and ages. The results showed both of gender and most of ages range were the same ranking of preference score as overall result (see Table 1). However, only 60's people prefer TB-07 rather than TB-06.

There are not significant different between group for all ages and both genders. From Binomial distribution test, there are not any single probability between ranking greater than 0.05, which is all of ranking are significantly different at significant level 95%.

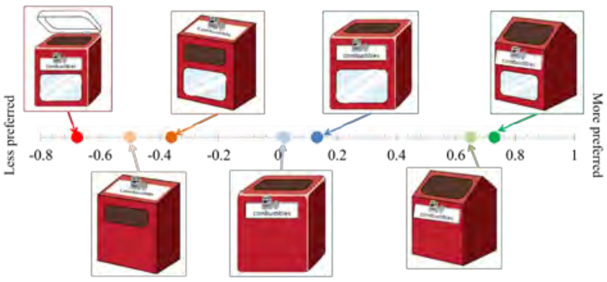

Figure 4 Overall design preference

CONCLUSIONS

This study was designed on only one kind of trash bins that using in Japan. In future, we are being able to continuous design on another kind of trash bins to make waste management better. From background data of waste collection, authors are looking for possibility to make future research about education effect of human behavior. Limited of seasoning collecting waste generation in lab-scale cannot say the best of human behavior in term of seasonal effect, future research is looking forward to collect all seasoning waste generated data.

1) The results showed the best preference design was slope slot position with visibility and worst preference was trash bin with lid attachment. High preference score designs might encourage waste segregation.
2) We concluded slot position, visibility, and lid attached affected to preference scores significantly.
3) For 60's ages people, lid attachment was not impact to made them unlike it when compared with front slot position.
4) Trash bin with lid attachment was not preference, it might be people do not want to touch the lid while dispose waste.

Table 1 Summary of design preference

Overall			Gender				Ages											
			Male		Female		20's		30's		40's		50's		60's	
Rank	CODE	Z score	CODE	Z score	CODE	Z score	CODE	Z score	CODE	Z score	CODE	Z score	CODE	Z score	CODE	Z score
1	TB-02	0.73	TB-02	0.68	TB-02	0.78	TB-02	0.75	TB-02	0.78	TB-02	0.74	TB-02	0.72	TB-02	0.68
2	TB-05	0.65	TB-05	0.59	TB-05	0.72	TB-05	0.70	TB-05	0.71	TB-05	0.65	TB-05	0.62	TB-05	0.60
3	TB-01	0.13	TB-01	0.13	TB-01	0.13	TB-01	0.05	TB-01	0.06	TB-01	0.15	TB-01	0.25	TB-01	0.16
4	TB-04	0.02	TB-04	0.01	TB-04	0.04	TB-04	-0.07	TB-04	-0.03	TB-04	0.04	TB-04	0.08	TB-04	0.10
5	TB-03	-0.36	TB-03	-0.32	TB-03	-0.40	TB-03	-0.23	TB-03	-0.31	TB-03	-0.39	TB-03	-0.44	TB-03	-0.42
6	TB-06	-0.50	TB-06	-0.47	TB-06	-0.54	TB-06	-0.36	TB-06	-0.43	TB-06	-0.51	TB-06	-0.61	TB-07	-0.50
7	TB-07	-0.68	TB-07	-0.62	TB-07	-0.74	TB-07	-0.84	TB-07	-0.77	TB-07	-0.68	TB-07	-0.63	TB-06	-0.61

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STUDY ON MSW MANAGEMENT IN TUNIS, TUNISIA

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ABSTRACT:

In Tunis, the major waste treatment is landfilling which represents 70%, only one landfill is serving the 4 states of Grand Tunis, the capacity of this landfill is almost full, and if the trend continues the landfill will not be able meet to the increasing needs and the landfill will be full in 2 years. Besides, the number of open dumps is increasing, and 21% of the MSW are claimed to be disposed in illegal dumps. This improper waste disposal represents severe threats on both the living environment and the public health. Therefore, an alternative waste treatment must be implemented as soon as possible. Mechanical biological treatment (MBT) seems to be a suitable solution for Tunis, yet a study on municipal solid waste (MSW) management is needed.

The final goal of this study is to evaluate technical and economic feasibility of introducing MBT to reduce landfilled waste. For that, this paper reports: 1) the current situation of MSW management in Grand Tunis, considering roles of stakeholders related to MSW management; 2) comparison of several options to reduce waste for landfilling from several points of views: source separation, incineration, MBT; and 3) discussion on several scenarios for implementing MBT facilities in Grand Tunis.

Key words: Waste management, MBT, waste reduction, landfilling, recycling

INTRODUCTION:

In recent years, the generation of municipal solid waste (MSW) has been increasing drastically with the demographic increase and the economic growth. Since then, the disposal of MSW started to represent a serious threat. Until this moment, many developing countries including Tunisia are still suffering from environmental issues caused by the improper treatment of waste such as open dumping or landfill. To improve the actual MSW management system, a deep understanding of the current situation and the MSW supply chain are required. After diagnosis and analysis of the actual system, a proper and an integrated MSW management can be implemented to reduce landfill and sustainably explore the resources potentiality in MSW.

There are a wide variety of alternative waste management options and strategies available for dealing with MSW to limit the residual amount left for disposal to landfill.

One alternative to deal with waste in a proper way is recycling. Recycling is the process of converting disposed waste into useful materials. It is an alternative to waste landfilling that can save land, material and contribute to reduce greenhouse gas emission. Recycling can prevent the waste of potentially useful materials and reduce the consumption of natural raw materials, thereby reducing: energy usage, air and water pollution.

Source separation seems to be the essential key for recycling. However, Tunisian government couldn't manage to implement source separation law and citizen were not educated for waste separation by themselves.

Mechanical biological treatment (MBT) plays an important role in waste separation and facilitate recycling process afterwards. In general, MBT consists of a mechanical separation of recyclable materials and a biological degradation of organic matter. The implementation of the MBT facility can drastically improve the MSW management system. It is necessary to investigate the current situation of MSW management in Tunisia and Grand Tunis to figure out the possibility of installing the MBT into current system.

The final goal of this study is to evaluate technical and economic feasibility of installing the MBT for reduce to be landfilled waste. The purpose of this report is to introduce the current situation of MSW management in Grand Tunis, considering roles of stakeholders. Additionally, the possibility of installing the MBT into current MSW management system in Grand Tunis was evaluated based on some scenarios.

METODOLOGY:

Investigation of MSW management in Tunis

The investigating of the current situation of MSW management in Tunis was carried out based on interviews and literature research. The data of MSW in Grand Tunis was supplied by interview with staff of the National Agency of Waste Management (ANGeD). Field investigation was to visit the transfer stations and the landfill site in Grand Tunis.

Evaluation of the possibility of installing the MBT

Proposing model MBT as an alternative treatment of waste in Tunis was based on previous studies. Figure 1 shows the waste flow of model MBT facility with the recovery rate and the residue rate. The model MBT was referred to Rambøll, Ficthner,PM, Interdevelopment, Master Plan 2008-2038 for integrated solid waste system in Neamt County, Bucharest et. al., 2008. Initial waste preparation may take the form of simple removal (manual separation) of contrary objects, such as bulky waste, which could cause problems with processing equipment down-stream.

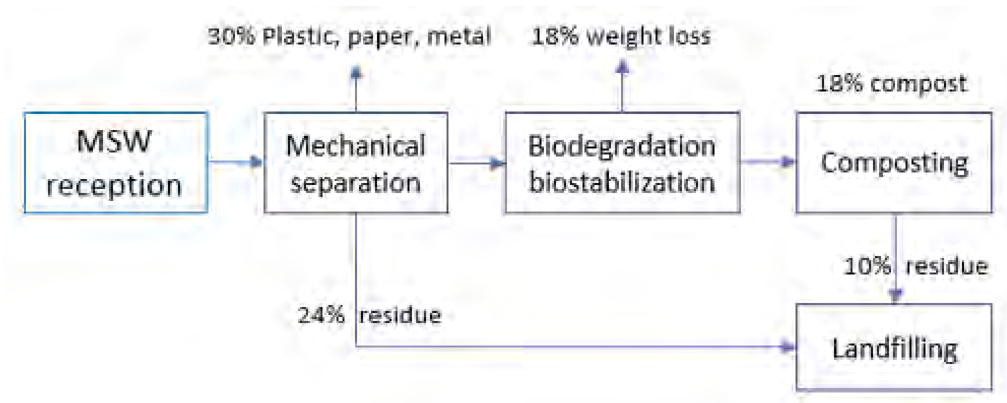

Figure 1 Waste treatment flowchart of model MBT

MBT technology exploit various properties of the different materials in the waste. These properties include the size, density, weight, magnetism, and electrical conductivity. First, MSW shredded into smaller particles to ease to separation afterwards.

The model MBT installing scenarios were designed as from Figure 2 to Figure 5. Figure 2 shows the current situation of MSW management in Tunis. MSW is collected and transported to three transfer stations (TS). After gathered the MSW in each TS, the waste is landfilled without pretreatment.

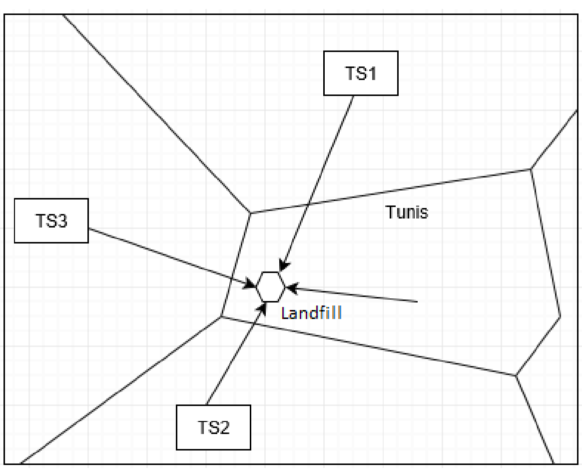

Figure 2: Scenario 0 (Current situation)

First scenario: Transform TS to MBT facility. Since the buildings are already existing, only the equipment need to be installed, therefore the initial cost is relatively low, on the other hand, there is no TS or MBT in Tunis, so the coverage rate is expected to be low also almost half of landfilled waste come from Tunis, so the recovery rate is also low.

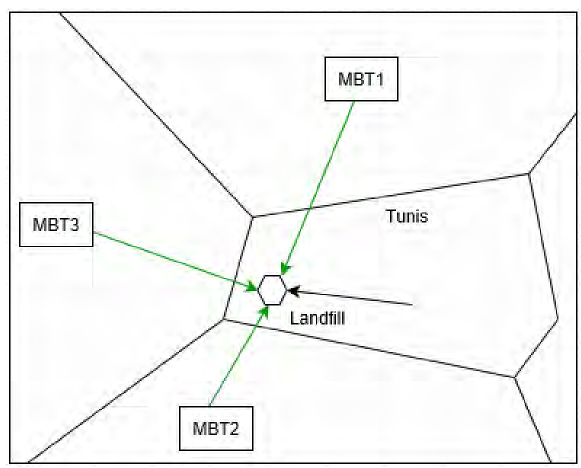

Figure 3: First scenario

Second scenario: Transform TS to MBT and implement 2 new MBT, 2 MBT must be implemented in Tunis, in addition to 3 MBT in other states, that means that the coverage rate as well as the recovery rate will be relatively high, but the purchase of equipment and the construction of 2 new MBT facilities will make the initial cost extremely high.

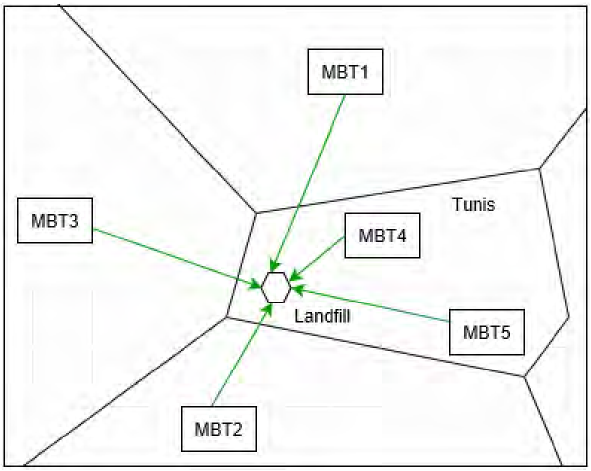

Figure 4: Second scenario

Third scenario: Implement 2 new MBT facilities in Tunis, both facilities will coexist, the initial cost will be only for the construction and the purchase of equipment for the 2 new MBT facilities, in other words, the initial cost will be lower than the one of the second scenario, the coverage rate will be high.

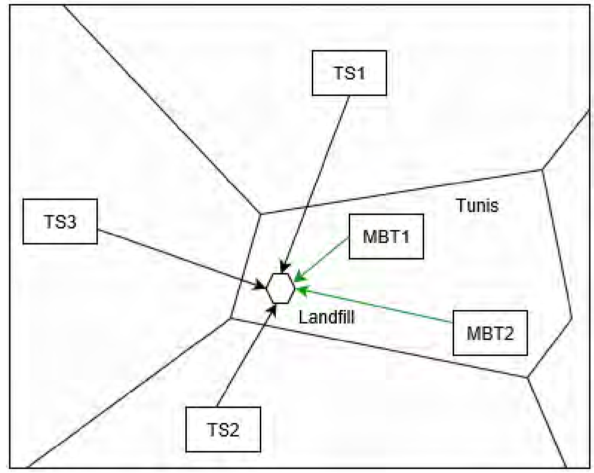

Figure 5: Third scenario

Based on previous data about waste generation in Grand Tunis, 2 MBT facilities need to be implemented in the state of Tunis with a capacity of 200,000 tpa, for the other 3 states, 3 MBT facilities can substitute the 3 existing TS (depends on the scenario) with different capacity (100,000; 120,000 and 200,000)

Table 1 helps to estimate the investment cost depending on the capacity of the MBT facility. In order to compare between different scenarios, in the following paragraph we will use the investment cost from this table.

Table 1: Capacity and cost of MBT facility

Capacity, tpa	Investment Cost, m€	Investment Cost, €/tpa	Operational Cost, €/ton
25.000	12.2	488	24 - 81
60.000	13.5	225	24 - 81
100.000	56	560	
120.000	42	350	55
200.000	40.5	203	24 - 81

RESULTS AND DISCUSSION

Amount and composition of MSW in Tunisia and Grand Tunis

Figure 6 shows the waste composition in Tunisia in 2007 (not yet updated), in Tunis the waste composition is slightly different but there is no such information about it. Tunisian MSW is characterized by a big portion of biodegradable organic matter with a share of 68% from the total waste. The moisture content of MSW is about 65%. People in Tunis generate about 0.925 kg of MSW per day, and the amount of MSW in Tunis is estimated to increase by 2.5% every year.

MSW is collected by the municipality to be transferred to the transfer station where it is compressed and then it is directly sent to the landfill. In Grand Tunis, there are 3 transfer stations in 3 states, and one landfill which receives 2400 tons per day. The landfill and these 3 transfer centers are managed by private companies and the whole MSW supply chain is managed by the National Agency of Waste Management (ANGeD)

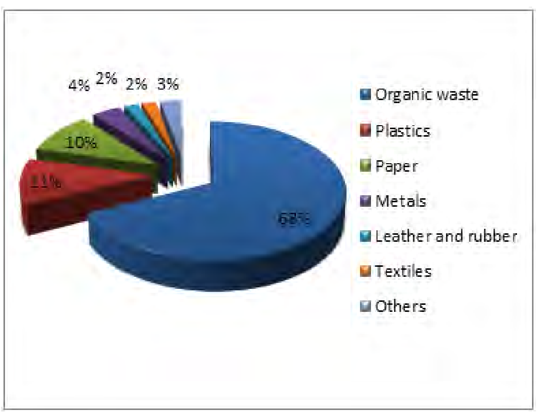

Figure 6: Waste composition in Tunisia

Waste collection and transportation

The amount and composition of MSW produced by Tunisian cities varies widely with the location of cities and income level in one city. Collection systems are almost the same with slight difference depending on the city location (coastal or not), municipalities revenues, and the available infrastructure. MSW is collected on behalf of the municipality, since source separation is not yet applied, collected MSW is mixed together and in most of cases, it is transported to the nearest transfer station. Waste is collected and transported by a variety of vehicles (Packer trucks, trucks, pick-up, and tractors). The variation of equipment is related to the GDP level of the served zone.

According to the statistics giving by the municipalities, the collection coverage was and still near 80% (about 90% in Tunis). The collection covered between 60% and 90% of served householders. The efficiency of collection depends on the demographic and geographic factors, besides the living level of the habitants, as well.

Waste treatment

Waste disposal and treatment remains a problem in all the cities even for the Grand Tunis and coastal cities. For instance, in Tunis, MSW is mainly dumped without any preliminary treatment. According to the statistics, during the last five years, around 70% of waste is dumped in controlled landfills and the other 21% to the inappropriate disposal sites, only 9% count for recycling and composting.

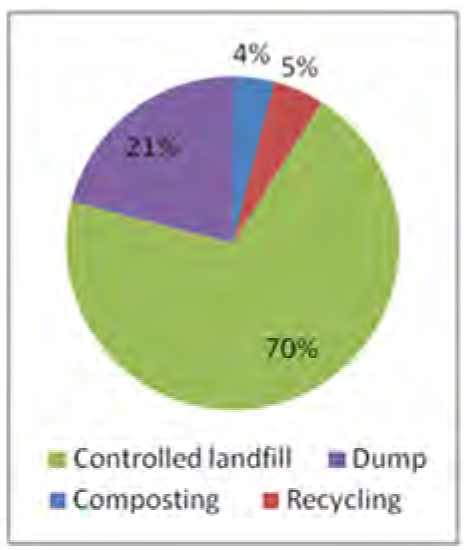

Figure 7: Waste treatment in Tunis

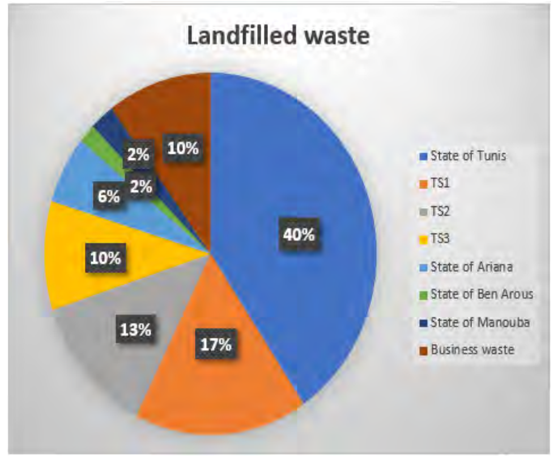

Figure 8: Landfilled waste in Tunis

<u>Landfilling</u>

The first controlled landfill was built in 1999 at the Jebel Chekir (Grand Tunis) with 3 transfer centers. Jebel Chekir is located in the state of Tunis about 10 km southwest of Tunis city. The landfill covers an area of 123 hectares and its current capacity is about 2400 tons per day (2016).

This landfill was built to replace the landfill of Henchir El Yahoudia and other open dumps.

Figure 8 shows that about 40% of landfilled waste are coming from transfer stations, and other 40% are collected only in the state of Tunis and sent directly to the landfill.

<u>Case study of installing the MBT facility</u>

The balance of the cost and benefit

Table 2: Cost and benefit

	Scenario0	Scenario1	Scenario2	Scenario3
Facilities	3 TS	3 MBT	5 MBT	3TS + 2MBT
Investment cost (€/tpa)	-	1113	1519	406
Recyclable material (ton)	0	288	720	432
Compost (ton)	0	172.8	432	259.2
Residue (ton)	2400	1939.2	816	1708.8

The new proposed MBT model has an impact on the reduction of landfilled waste and the recovery of recyclable materials and compost.

As a conclusion from Table 2, there are reduction of 20%, 66% and 29% respectively for senario1, 2 and 3. The estimated waste reduction varies between 460 ton/day and 1580 ton/day depending on the capacity of the MBT facility.

As mentioned before, the 3 TS receive less than what is generated in Tunis. Then, the treated waste by MBT in the first scenario is less than the one of third scenario, on the other hand, the investment cost much higher.

The emission of greenhouse gas will be reduced as well since the landfilled waste is reduced.

Among the 3 scenarios, the third scenario seems to be suitable for Tunis since it has a competitive cost and relatively high recovery rate.

Barriers against the implementation of MBT facility:

Although, results have shown great improvements, the model can face some barriers due to several factors. MBT may look like complex technology and requires high initial cost and maintenance cost.

Also, it might face resistance from some stockholders since it is the first MBT that will be implemented in Tunis.

Resistance from competitors can represent another barrier, mainly private companies running the landfill or the transfer stations

The efficiency of MBT and quality of the output highly depends on the waste composition.

Uncertainty risk is relatively high due to the inaccuracy or lack of some information; therefore, it is difficult to make an accurate estimation about the capacity of the facility and the benefits.

CONCLUSION

Developing countries that have their industrial and social activities growing rapidly have the duty to deal with the fast increase of waste amount since MSW is becoming one of the major global worming factors. Therefore, the implementation of a sound MSW management system is a necessity.

This study presented a new way to treat MSW, and a possibility to implement a MBT facility in Tunis. Since the efficiency of a MBT highly depends on the waste composition, an investigation about MSW in Tunis is needed

MBT seems to be promoting solution in the case of Tunis, but there are some barriers that can be an obstacle in front of the implementation of a MBT facility, such as the financial resource and expenses also local government.

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LANDFILL LEACHATE CHARACTERIZATION IN HANOI CITY

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ABSTRACT

Land filling is still one of the most common methods of solid waste disposal in Vietnam. However, only 17 out of 92 landfills in the country are sanitary which were constructed mainly from ODA funding, the rest are dumping sites. As Vietnam is still not applied waste classification at source, thus leachate composition of domestic landfill are very complicated. It contains not only in organic substances but also soluble organic substances, heavy metals. This review paper provides an insight into heavy metals compound and it association with organic matter in landfill leachate of main landfill sites in Ha Noi, Hai Phong, Hue and Ho Chi Minh city. The results showed that the leachate's composition could be categorized into two groups. Young landfill leachates has low pH (6-7), high concentration of COD (40,000-60,000 mg/L), high BOD/COD ratio (0.7-0.8), high heavy metal concentration and nutrients contents. Contrary, old landfill leachate is characterized by high pH (7.9-8.2), low BOD/COD ratio, low heavy and nutrient contents. Further, heavy metals in leachates were mainly found in the forms of dissolved inorganics or complexes with humic substances (humic acid and fulvic acid). In Nam Son landfill, the combination of dissolved organic matters and Fe, Ni, Cu were very significant. Understand speciation and behavior of heavy metals and its combination with organic matter will elucidate the transport of leachate in the environment. Further, the results of landfill leachate characterization will also help to improve treatment efficiency then minimize the adverse impact on the environment.

Key words: Landfill leachates, heavy metals, organic matter, Hanoi City.

INTRODUCTION

Generally, one of the most prevalent technique of handling municipal solid wastes in developing nations have been landfill due to the fact that it offers the higher capacity, and lower capital and operation cost than the other waste management ways [1]. In 2015, the volume of domestic solid waste was 38,000 ton/day, from 2011 to 2015 the trend was increasing around 12%/year [2]. There have been three common methods for municipal waste management: landfill, composing and incinerating. Landfilling is still one of the most common methods of solid waste disposal in Vietnam. According to the report of MOC, there are totally 657 operated landfill sites in Vietnam with the total area of 4,900 hectares, 31% of the number can be certificated sanitary ones. The daily municipal waste generated in Hanoi was estimated approximately 6,240 tons [3]. There have been 4 sanitary high capacity landfill sites in Hanoi namely Nam Son, Kieu Ky, Xuan Son and Nui Thong. It was estimated that the volume of daily generated solid waste in 2020, 2030 and 2050 were 14,150, 18,900 and 25,380 tons respectively. Hanoi capital set a plan to operate 17 solid waste disposal complexes, including 8 existing zones, which are upgraded and expanded, and 9 new ones [4]. As Vietnam is still not applied waste classification at source, thus leachate composition of domestic landfill are very complicated. It contains not only in organic substances but also soluble organic substances, heavy metals. This review paper provides an insight into heavy metals compound and it association with organic matter in landfill leachate of main landfill sites in Viet Nam and Hanoi city.

LEACHATE GENERATION AND CHARACTERIZATION

Landfill - a carefully designed structure built into or on top of the ground in which trash/waste is isolated from the surrounding environment (groundwater, air, rain). This isolation is accomplished with a bottom liner and daily covering of soil. A sanitary landfill uses a clay liner and a municipal solid waste (MSW) landfill uses a synthetic (plastic) to isolate the trash and leachate from the environment.

Landfill leachate is still widely considered as a complex naturally occurring hazardous liquid. It contains various organic materials (biodegradable and non-biodegradable carbon, humic acids and fulvic acids) and the inorganic material such as colloidal, heavy metals and non-organic salts like sodium, calcium, sulfate, ammonia and high concentration toxics [5].

The composition of landfill leachate, the amount generated and the extraction of potential pollutants from the waste depend upon several factors, including solid waste composition, degree of compaction, absorptive capacity of the waste and waste age, seasonal weather variations, levels of precipitation, Landfill temperature, size, hydrogeological conditions in the vicinity of the landfill site, engineering and operational factors of the landfill, pH, landfill chemical and biological activities [6].

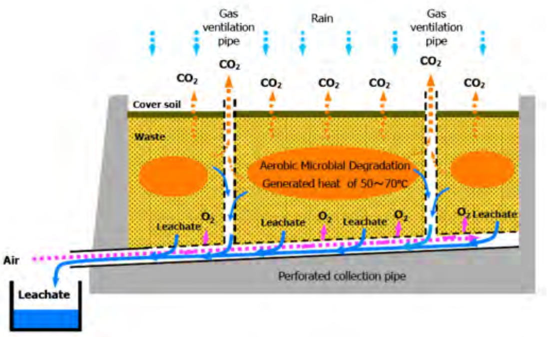

Figure 1. Semi – aerobic landfill mechanism [7]

Three main groups of landfills are classified based on the operated period, such as young (less than 2 years), intermediate (2-10 years), and old or stabilized (more than 10 years). Table 1 summarizes the typical characteristics of leachate according to age of landfill.

In terms of the young landfill sites, they showed the high concentration of organic pollutants. The value of BOD5 varied from 2,000 to 30,000 mg/L, COD ranged from 6,000 to 60,000 mg/L, TOC in the range of 1,500 – 20,000, the ratio of BOD5/COD > 0.5, the ratio of TOC/COD < 0.3. In addition, the concentration of biodegradable organic compounds was far higher than the non-degradable one. Regarding the higher-2-year-operated landfill sites, they witnessed the decrease of biodegradable organic compound concentration. As a result, the ratio of BOD5/COD dropped to 0.5 and less than 0.1 for intermediate and mature landfill sites respectively. Conversely, the ratio of TOC/COD rosed to 0.3 – 0.5 and higher than 0.5 for intermediate and mature landfill sites respectively. The concentration of heavy metal in leachate was relatively high. While the intermediate landfill sites underwent the figure, which was higher than 2 mg/L, it fell to below 2 mg/L for mature landfill sites. In addition, the content of nitrogen compounds namely Total Kjeldahl, ammonia and organic nitrogen showed the huge fluctuation, ranged from hundreds to thousands mg/L.

Table 1 Summarized typical characteristics of leachate according to age of landfill [5]

No.	Parameter (mg/L) *No unit for pH, BOD5/COD and TOC/COD	Landfill age (years)		
		< 2	2–10	> 10
1	Stabilization status	Young (fresh)	Intermediate	Mature (stabilized)
2	BOD5	2,000–30,000	NA	100–200
3	COD	3,000–60,000	3,000–15,000	100–2,800
4	TOC	1500–20,000	NA	80–160
5	BOD5/COD	0.5–1.0	0.06–0.5	< 0.1
6	TOC/COD	< 0.3	0.3–0.5	> 0.5
7	Total Kjeldahl nitrogen	100–2,000	NA	NA
8	Ammoniacal-nitrogen	10–800	30–1800	20–900
9	Organic nitrogen	10–800	NA	80–120
10	Nitrate	5–40	NA	5–10
11	pH	4.5–7.5	6.5–7.5	6.6–7.5
12	Alkalinity as CaCO3	1,000–10,000	NA	200–1,000
13	Total hardness as CaCO3	300–10,000	NA	200–500
14	Total suspended solids	200–2,000	NA	100–400
15	Heavy metals	> 2.0	< 2.0	< 2.0
16	Total phosphorus	5–100	NA	5–10
17	Orthophosphate	4–80	NA	4–8
18	Calcium	200–3,000	NA	100–400
19	Magnesium	50–1,500	NA	50–200
20	Potassium	200–1,000	NA	50–400
21	Sodium	200–2,500	NA	100–200
22	Chloride	200–3,000	NA	100–400
23	Sulphate	50–1,000	NA	20–50
24	Total iron	50–1,200	NA	20–200
Note: NA: not available				

LEACHATE CHARACTERIZATION IN VIET NAM

In Vietnam, the classification of municipal waste has not been required in households, resulting in the fact that the content of leachate in landfill sites was variable and complicated. It can be changeable based on the sampling period (dry or rain season), design criteria, operation conditions and others.. It can be seen from Table 2 that there were differences and complexes in the content of various landfill sites in big cities in Vietnam. It is worth noting that BOD_5, COD were relatively high and variable based on operation periods. According to the operated timescale, Trang Cat landfill can be classified into young landfill sites, while for the other, they are either intermediate or mature ones. However, the value of COD and BOD_5 were lower than that of the other landfill sites. Additionally, the ratio of BOD_5/COD in Thuy Phuong was lowest, ranging from 0.163 to 0.234, indicating that the concentration of biodegradable compound was low as compared to non-biodegradable one. Also, there was a presence of heavy metal ions in the leachate in the low quantity.

Table 2 Summarized typical characteristics of leachate in some cities of Viet Nam

Parameter	Unit	Nam Son Landfill	Xuan Son Landfill	Go Cat Landfill	Thuy Phuong Landfill	Trang Cat
City, Year		Ha Noi, 2013	Ha Noi, 2012	Ho Chi Minh, 2007	Hue, 2009	Hai Phong, 2013
pH		6.81 – 7.98	7.7	7.4 – 7.6	7.7 – 8.5	6.5 – 8.22
TDS	mg/l	6,913 – 19,875	-	-	-	4.47 – 9.24
TSS	mg/l	120 – 2,240	986	700 – 2020	42 – 84	21 – 78
COD	mg/l	1,020 – 22,783	3,540	13,655 – 16,814	623 – 2442	327 – 1,001
BOD_5	mg/l	495 – 12,302	2,150	6,272 – 9,200	148 – 398	120 – 465
BOD_5/COD		0.485 – 0.540	0.607	0.459 – 0.547	0.163 – 0.234	0.370 – 0.465
TN	mg/l	423 – 2253	62	1,821 – 2,887	-	179 – 507
$N\text{-}NH_4^+$	mg/l	-	17.2	1,680 – 2,427	184 – 643	-
$N\text{-}NO_2^-$	mg/l	-	12.5	0 – 6.2	-	-
TP	mg/l	6.51 – 24.80	4.31	10.3 – 19.8	-	3.92 – 8.562
Total Hardness	mg $CaCO_3$/l	-	-	-	1,419 – 4,874	-
Cl-	mg/l	-	-	-	518 – 1199	-
As	mg/l	0.001 – 0.003	0.2	-	-	0.047 – 0.086
Pb	mg/l	0.050 – 0.086	0.34	-	-	<0.05
Cd	mg/l	0.010 – 0.025	0.14	-	-	<0.01
Hg	mg/l	0.0001 – 0.0009	-	-	-	0.0001
Ages	year	7	10	7	9	2
Source		[8]	[9]	[10]	[11]	[8]

NAM SON LANDFILL LEACHATE CHARACTERIZATION

Nam Son solid waste treatment complex is located 45 km far from the central of Hanoi, to the North. It has been operated since 1999 with the area of nearly 85 hectares, the capacity of 4,200 tons per day. The sanitary area accounted for 55.99 hectares with 10 landfill places. It is reported that Nam Son is the biggest landfill site in Hanoi. In 2015, more than 600,000 m^3 leachate was collected in the biological bonds and was still untreated in Nam Son [12].

Figure 2. Nam Son landfill
(Source: Google earth)

Table 3. Summarized typical characteristics of Nam Son landfill leachate from 2013 to 2018

Parameter	Unit	2013	Mar, 2017	Jun, 2017	Sep, 2017	Dec, 2017	Sep, 2017 - Mar, 2018	QCVN 40/2015 BTNMT
Temperature	^oC	NA	21.5	28.2	32.9	20.1	NA	40
pH		6.81 – 7.98	7.8	8.4	9.8	8.6	8.4 – 8.7	5.5 – 9
BOD_5	mg/l	495 – 12,302	3,810	686	720	2700	330 – 960	50
COD	mg/l	1,020 – 22,783	7,840	1,520	1,680	5,520	1,400 – 2,000	150
BOD_5/COD		0.485 – 0.540	0.486	0.451	0.464	0.489	0.40 – 0.46	-
SS	mg/l	120 – 2,240	270	167	160	960	NA	100
As	mg/l	0.001 – 0.003	0.239	0.144	0.126	0.038	0.02 – 0.16	0.1
Cd	mg/l	0.010 – 0.025	0.0012	0.001	0.0009	0.0005	NA	0.1
Cr^{3+}	mg/l	NA	0.097	0.136	0.085	0.04	NA	1
Ca	mg/l	NA	NA	NA	NA	NA	52 – 265	-
Al	mg/l	NA	NA	NA	NA	NA	0.6 – 3.5	-
Mg	mg/l	NA	NA	NA	NA	NA	188 – 230	-
Cu	mg/l	NA	0.019	0.035	0.016	0.007	0.01	2
Fe	mg/l	NA	8.45	6.44	6.38	4.13	5.4 – 12	5
Hg	mg/l	0.0001 – 0.0009	0.0061	0.0005	0.001	0.0006	NA	0.01
Mn	mg/l	NA	0.405	0.216	0.225	0.561	0.01 – 0.12	1
Ni	mg/l	NA	0.319	0.214	0.129	0.069	0.02 – 0.16	0.5
Pb	mg/l	0.050 – 0.086	0.023	0.04	0.013	0.024	NA	0.5
Zn	mg/l	NA	0.283	1.05	0.33	0.108	NA	3
Cr^{4+}	mg/l	NA	<0.01	<0.01	<0.01	<0.01	NA	0.1
CN^-	mg/l	NA	<0.004	0.019	0.028	0.034	NA	0.1
Phenol	mg/l	NA	1.43	0.216	0.246	0.495	NA	0.5
S^{2-}	mg/l	NA	15.9	20.9	5.4	17.4	NA	0.5
F^-	mg/l	NA	10.6	11.3	6.35	4.25	NA	10
$N\text{-}NH_4^+$	mg/l	NA	1,235	633	762	1,002	59 – 80	10
TN	mg/l	423 – 2,253	1,306	1,551	1,555	1,377	460 – 560	40
TP	mg/l	6.51 – 24.80	9.73	0.74	13.06	3.1	15.1 – 15.3	6
Cl^-	mg/l	NA	1,839	1,505	1,520	1,620	NA	1,000
Coliform	MPN/100 ml	NA	$47x10^6$	$36x10^6$	$75x10^6$	$43x10^6$	NA	5,000
Source		[8]	[13]				[14]	[15]
NA: not available								

It is obvious from Table 3, the landfill leachate in Nam Son could be classified into intermediate (2013 – 2017) and mature type (2017 – 2018). The pH reached the high value (6.81 – 9.80), the recent sampling showed the result higher than 8. There was a high concentration of organic matters, BOD_5 ranged from 330 to 12,302 mg/L, COD varied from 1,020 to 22,783 mg/L, the ratio of BOD_5/ COD from 0.40 to 0.54. It was noted that the organic content underwent the decrease. The highest concentration of BOD_5 and COD in 2013 reached 12,302 and 22,783 respectively, while for 03/2018, they were 960 and 2,000 mg/L. The BOD_5/ COD ratio also dropped from the highest level in 2013 from 0.485-0.540, down to 0.40-0.46 in 2018. This accurately reflects the conversion in the landfill, as the age of the landfill increases. Observing the data for 2017, it could be seen that the seasonally adjusted leachate content was relatively marked. In the dry season (March & December) the composition of pollutants was much higher than in the rainy season (June and September). The values recorded of COD, BOD_5, TN and Ammonium exceed the permissible limits of the national technical regulation for industrial wastewater QCVN40 - MT: 2015 / BTNMT.

There were various metals and heavy metals in Nam Son landfill leachate, the highest value was Ca (52 – 265 mg/l), and followed by Mg (188 -230 mg/l), Fe (4.13 – 12 mg/l), Al (0.6 – 3.5 mg/l), Mn (0.01 – 0.561), Ni (0.02 – 0.319 mg/l), As (0.001 – 0.239 mg/l). The concentration of As and Fe exceeded the Vietnamese regulation standard QCVN 40.

According to Ngoc's study [14], the most of the metals were concentrated in the dissolved inorganic matter, it is shown in Fig. 3 Average percentages of the metals in the different fractions. The percentage of the dissolved inorganic fraction of most elements was high accounting for 30 to 98% total concentration, in which Mg in dissolved inorganic fraction was most dominant compared to other metal. For complexation between the metal with the dissolved organic matter, the highest proportion of dissolved organic was for Ni (38%) and followed by Fe (22%), Cu (20%) and As (14%). Most of Al fraction presented in particle fraction 62% on average. The percentage of the particulate fraction in Fe, Mn, Cu were 18 – 39%.

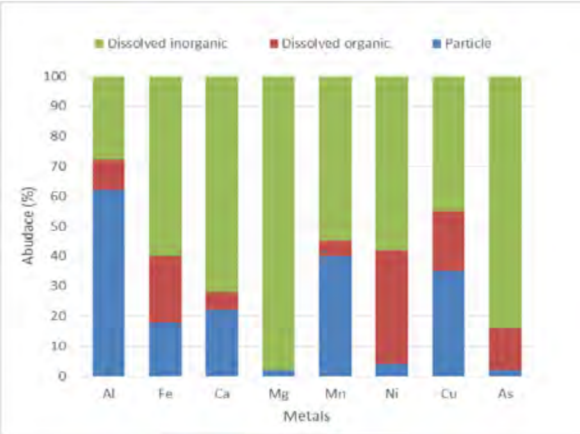

Figure 3. Average percentages of the metals in the different fractions [14]

The average percentages of dissolved organic and dissolved inorganic fractions are shown in Fig. 4. Dissolved inorganic fraction constitutes more than 60% of the dissolved fraction of the metals. Fe, Ni, Cu, Al are found in the association with organic matter in 26 – 40% of the dissolved fractions. It is followed by As, Mn around 15%. The proportions of the dissolved organic fraction are low in Ca and Mg under 10%.

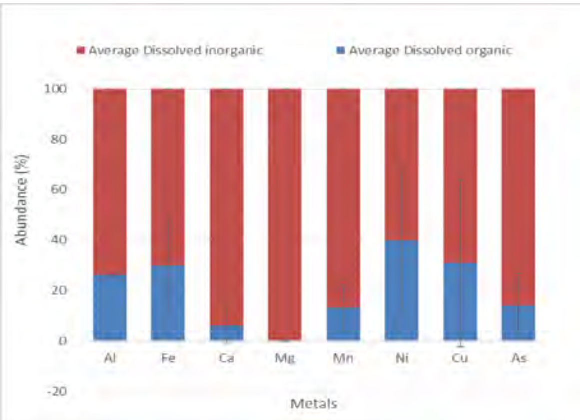

Figure 4. Average percentages of dissolved inorganic and organic fractions [14]

Leachate organic matter is composed mainly of humic and fulvic acids [16]. Humic substances (HS) are products of the degradation of organic matter in the environment. They are highly complex molecules with numerous different functional groups and highly aromatic structures. HS are usually divided into humic acids (HA) that are soluble in pH above 2, fulvic acids (FA) that are soluble in any pH and insoluble humins. In environmental terms, HS are highly relevant in landfill leachate. Since HS are refractory against biological degradation, they are unlikely to cause problems related to rapid degradation. They also act as ligands for heavy metals [17]. The main parts of the heavy metals in landfill leachate were dissolved inorganic fraction and/or complexes with humic substances, including humic acid and fulvic acid.

CONCLUSION

As Vietnam is still not applied waste classification at source, thus leachate composition of domestic landfill are very complicated. It contains not only in organic substances but also soluble organic substances, heavy metals.

The concentration of pollutants in landfill leachate in Nam Son was variable based on operation period and age of the landfill, and season. Currently, Nam Son landfill leachate showed the characteristics of mature one with the ratio of BOD_5/COD < 0.5.

Nam Son landfill leachate contains metals, heavy metals. The concentration of As and Fe exceeded the Vietnamese regulation standard. The main parts of the heavy metals in landfill leachate were dissolved inorganic fraction and/or complexes with humic substances, including humic acid and fulvic acid.

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ON-SITE SURVEY OF TRASH CONTAINERS COLLECTABILITY DURING FIRE WORK EVENTS IN JAPAN

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ABSTRACT

In Japan, there are lots annual firework events in summer. Thousands people will join the firework events, at same time, and tons of waste will be generated. To collect the waste and keep event place sanitary, temporary trash bins should be set to collect the waste. In order to maximize effectiveness of trash containers, management of the temporary trash containers is very important. In the other hand, even the Japanese people are already acquainted with the waste separation and resource recycle rules, during such social activities, people's behavior could be different from the normal time. Therefore, the management of trash containers should consider events situation and human behavior. During the summer in 2015 and 2018 , more than 10 firework events were chosen to investigate the management of trash containers. Trash container characteristics, setting conditions, and waste collection efficiencies were researched. Many trash containers with small volume is not efficient to collect wastes. Because each trash containers became full soon, it causes uncollected wastes around trash containers. Even though the number of trash containers is limited, larger volume is more efficient to prevent from waste scattering.

Keywords: firework events, trash bin, setting condition, management

INTRODUCTION

In Japan, a signature summer event is fireworks displays. There is fireworks show somewhere in Japan every weekend during July and August. Usually, there is Japanese festival for selling food and drink near the event's location. Thousands of people will join the events, at the same time, tons of waste will be produced. The waste including combustible waste, incombustible waste and lots drink containers like PET bottle, can and glass. Temporary trash bins should be set to collect and separate the waste and keep event place sanitary. In order to maximize the effectiveness of trash containers, management of the temporary trash containers is very important. On the other hand, even the Japanese people are already acquainted with waste separation and resource recycling rules, their behavior can be changed when loose supervision. Therefore, the management of trash containers should consider events situation and human behavior. In this study, Trash container of several firework events was researched and the characteristics, setting conditions, waste collection efficiencies and cost of trash containers will be discussed.

METHODOLOGY

First investigation

In 2015, six annual firework events held in Kanto region were chosen to investigate the situation of temporary trash bins. The six firework events were chosen by its scale. The number of fireworks was fixed before the events and the number of participants was predicted by last year's data. In these six firework events, three in Tokyo and three in the other cities. Table 1 shows the situation of firework events in six different places. According to the number of fireworks and the number of participants. The six places can be divided into three types: large size, middle size, and small size. The six firework events are arranged by using the number of participants as the priority order and a number of fireworks as second order. Therefore, the three firework events types are shown as follows.

Large size: Sumitakawa firework event and Edokawa firework event. The number of participants was around 900000 and the number of fireworks was over 10000.

Middle size: Kotoku firework events and Kanazawa firework events. The number of participants was around 300000 and the number of fireworks was around 3500.

Small size: Kawagoe firework events and Numata firework events. The number of participants was less than 100000 and the number of fireworks is around 10000. The size and number of trash containers were recorded and situations of trash containers and waste collection were recorded by photos.

Table 1. Situation of firework events in six different places (first investigation)

	1	2	3	4	5	6
	Sumitakawa	Edokawa	Kotouku	Kanazawa	Kawagoe	Numata
Number of Participants	950000	900,000	350,000	280,000	900,00	47,000
Number of fire works	20000	14000	4000	3,500	8000	10,000

Second investigation

According to the results from 2015, In 2018, three fireworks were chosen to investigate the management of trash containers. Two big sizes (Adachi and Edokawa) and one middle size(Kamakura). The situation of the three fireworks is shown in table 2.

Table 2. Situation of firework events in three different places (second investigation)

	1	2	3
	Adachi	Edokawa	Kamakura
Number of Participants	660,000	900,000	150,000
Number of fire works	13600	14000	4000

TRASH CONTAINER BEFORE THE FIREWORK EVENTS

Trash bin design: color material and slot shape

Unlike the existing trash bins we used every day, the design of the trash container for firework events are simple: single color and no special design. Figure 1 shows the trash containers in the nine fireworks events. The temporary trash containers are all made of recyclable materials. The trash containers in Simitakawa and Edokawa are made of card papers. In Koutoku firework event, the organizers use the paper carton and plastic box to collect waste. In Kanazawa and Kamakura firework events, trash containers made by plank. In Kawagoe, Numata, and Adachi, the trash containers are made of metal stick. Only in Simitakawa, the trash containers for PET bottle, can and glass bottle use circle disposal slot shape.

Figure 1. Trash containers in eight firework events

Separation rule

There are three normal waste types in our daily life: combustible, incombustible, recyclable waste (PET

Table 3. Situation of trash containers in eight firework events

	Sumitakawa	Edokawa	Kotouku	Kanazawa	Kawagoe	Numata	Adachi	Kamakura
Location number of trash bin	8	52	19	4	14	3	16	6
Total volume of trash bin/L	34992	22000	8729	73445	20760	5499	171346	74338
Personal volume/L	0.037	0.024	0.025	0.262	0.231	0.117	0.260	0.496

bottle, can and bin). See figure 1, the separation rules are basically based on the 3 types of waste. Simitakwa and Kanazawa use one container for recyclable waste. In Koutoku firework event, the trash containers only separate into combustibles and incombustibles, can and bin are collected in incombustible waste container. Kotoku and Edokawa have no container and instruction about how to dispose of the PET bottles. Kawagoe firework events separate waste into combustible, can, bin and PET bottles. Numata firework events have the most complex separation of waste. They set the containers for the can, PET bottle, and glass bottle, respectively, and has the container for the cap of PET bottle, They also prepare a plastic bucket special for the remaining drink.

Trash bin management

Table 3 shows the situation of trash containers of eight firework events, Kamakura firework event has the largest volume of trash containers, more than twice of the second one(Kanazawa). Numata firework event has the smallest volume of trash containers, following by Kotoku firework event. For the personal volume, the largest still the Kamakura firework events, next is Kanazawa. The personal volume in the Kamakura firework events are over 20 times compares with the smallest one (Kotoku). In addition, even the number of trash bin locations in Edokawa firework event is about seven times of the number in Adachi firework event, the total volume of trash bin is quite smaller than Adachi firework event. In Kanazawa firework events, it has the biggest container compare to the others. The organizers only set four such containers, but the total volume of these trash containers is still the second largest in six firework events.

TRASH BIN CONDITION AFTER FIREWORK EVENTS

Large size

After Edokawa firework show, all the temporary trash containers were full of the waste as shown in figure 2. The wastes head up like waste mountains around the trash containers, most of the containers cannot be distinguished any more. The containers lost the function of helping waste separation, all the wastes are mixed together. At the beginning the situation of waste separation was good, wastes were disposed of in the correct container (see figure 3). When the wastes

Figure 2. Situations of trash containers after firework events (large size)

Figure 3. The waste disposal situation at beginning

generated more and more, the generated waste is full of the small trash bins and even over the trash bins. Like the broken window theory, people would not continue to follow the rules when the rules are broken. At last, lots of people disposed their waste in the plastic bag without separation. In addition, the accumulated trash make the trash containers disappeared, results in littering. The material for these temporary making was difficult to recycle because the paper carton got dirty by the waste. In the first and second investigation, the Edokawa use the same trash containers, and the situations after fireworks are same. Sumitakawa has totally different site situation with Edokawa, and the trash bin only set in a small part of the area, the special slot shape design had no use for the recyclable waste disposal. Adachi's situation was better than Edokawa because the total volume is bigger than Edokawa. Adachi firework has the same surrounding situation with Edokawa, but different from Edokawa, Adachi only set the containers on the main road, not on the grassland where people gather for watching firework show. Even the container is not enough for the waste, the littering situation is rarely find in the Adachi.

Middle size

Koutoku and Kawagoe showed the same situation with Edokawa (see figure 4), but another two middle size fireworks (Kanazawa and Kamakura) showed better management of the trash after firework events , the big volumes of containers are not easy to full, it makes the "broken window" comes later. And the big trash

Kotouku Kawagoe

Figure 4. Situations of trash containers after firework events (middle size)

Kamakura Kanazawa

Figure 5. Volunteers in kanazawa and kamakura firework events.

containers like big targets are easy to find, what's more, in the guideline for the fireworks events, the manager put the location of the containers. The separation way in Kanazawa is very easy to understand and Kanazawa and Kamakura firework events had volunteers nearby the trash container help and supervise the waste separation (see figure 5). We can see the clear waste separations after Kanazawa firework show. In Kamakura events, the container for recyclable waste is small, but the volunteers will change the plastic bag when the container got full. So the personal volume for waste is high than our calculation.

Small size

The two small size firework (Kawagoe, Numata) didn't show the good situation as the Kanazawa and Kamakura firework events. The site and participants are smaller than other fireworks events ,the management of waste should be easier as we excepted. According to the situation of the trash container, the main reason is the single trash containers are smaller. And for Numata firework events, the separation rule is too complex for the firework situation.

DISCUSSION AND CONCLUSION

From the successful experience of Kanazawa and Kamakura firework events, three advices can be obtained as follows:

1). The locations of trash containers don't need too much but the trash bin container should as big as the space allowed. When the trash bin can be recognized as a big target, the behavior of waste disposal can be done easier. For the location to set trash container, the road for most people will pass is recommended. And the entrance and exit are also good to choose for bin's setting.

2). Simplify the sorting way of wastes. Different from our daily life, the generated waste during firework events will be disposed of in a short time. A simple sorting way is better for people to understand. For example, can, bin and pet bottle can use one container.

3). Volunteers can help and supervise waste disposal behavior. First, the separation of waste and followed treatment can become easy. Second, the cost for the firework events can be decreased. Last the experience for the volunteers like junior school students is a good education for their eco-friendly consciousness development.

In our expectation, these advices can release the hard management for large size firework events, and maximize the benefits for middle and small size firework events.

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REMOVAL OF TOXIC HEAVY METALS FROM INDUSTRIAL WASTEWATER USING RICE STRAW AND SAWDUST BIOCHAR

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ABSTRACT

This study was evaluated sorption capacity of saw dust and rice straw biochar for the recovery of Arsenic(III), Chromium (III) and Lead(II) from aqueous solutions. Biochar were obtained from pyrolysing at 400◦C. Sorption studies were performed at different pH, particle size, contracting time and different initial metal ion concentration in the batch mode. The efficacy of biochar in heavy metal removal depends on grain size, biochar dose, pH and the initial concentration of the metal ion solution. The optimum adsorption was found to be within 1 h with an adsorbent dose of 1 g/L and initial concentration ∼20 mg/L for metal solutions at a pH range of 5.0–7.0 for Pb(II), Cr(III) and 3 for As(III) ions in the solutions. Two isotherm models were employed to describe the metal ions adsorption on to biochar surfaces. Langmuir isotherm model was a better fit for both biochar materials for Pb(II) and Cr(III) ions. Freundlich model was fitted with AS(III). The separation factors of different biochars indicate a favourable sorption isotherm for Pb(II) and Cr(III) and adsorption or intra-particle diffusion process for As(III) ions.The FTIR spectra indicated that carbonyl, hydroxyl, amine and halides are the main adsorption sites in biochar which complex with metal ions in the aqueous solution. 90%–94% removal of metal ion from aqueous solution could be attained by using saw dust and rice straw biochar.

Keywords: Biochar, Wastewater, Adsorption, Heavy metal

INTRODUCTION

Among many sources of heavy metal pollutions of surface and groundwater, industrial activities are nowadays significant (Wong et al., 1993). Chemical precipitations, conventional adsorption (Amritphale et al., 1999, Prasad and Pandey, 2000) ion exchange (Mier et al., 2001), membrane separation methods (Reddad et al., 2002) and electro-remediation methods are used more commonly to treat industrial wastewater. Although chemical precipitation is the most economical and widely use method for removing heavy metals from industrial effluents it produce large amount of toxic sludge with lower rate of removal toxic metals from aqueous phase (Gunatilakea and Chandrajithb, 2017). Therefore numerous novel approaches have been investigated to develop cost effective and efficient heavy metal adsorption techniques (Kadirvelu et al., 2001, Liu and Zhang, 2009). Most scientists focused on their research on biosorption methods aiming towards the optimizing different physicochemical parameters to obtain the highest removal efficiency while the others were concerned the mechanism (Gunatilake, 2015). Such methods are usually low cost as the absorption materials are mostly by-product of agricultural and other industrial wastes. From among these low cost biosorption materials, application of biochar is becoming extremely popular due to their high sorption capacity and availability of materials in almost unlimited amounts (Gunatilakea and Chandrajithb, 2017). New resources such as hazelnut shell, rice husk, pecan shells, jackfruit, maize cob or husk, rice straw, rice husk, coconut shell etc can be used as an adsorbent for heavy metal uptake after chemical modification or conversion by heating into activated carbon or biochar (Bansode et al., 2003). They found that the maximum metal removal occurred by those biomass due to containing of cellulose, lignin, carbohydrate and silica in their adsorbent. Biochar, that pyrolyzed from biomass under no or very low oxygen condition are mostly stable and having a superior ability to retain heavy metals. Therefore such materials are beneficial in decreasing the bioavailability of pollutants and mitigate their ecological toxicities replacing costly chemisorption methods (Gunatilakea and Chandrajithb, 2017).

This study was aimed to investigate the efficiency of different bio residues to remove toxic heavy metals such as Pb(II), Cr(III), As(III) from contaminated water. Biochar that produced from sawdust and rice straw were used as the adsorptive material in this study. Pyrolyzing temperature was selected as 400°C since it considered as an optimal condition that producing biochar for effective sorbent.

MATERIALS AND METHODS

The biochars used in this work were obtained from rice straw (Oryza sativa L.) and from saw dust (Artocarpus heterophyllus). Rice straw was collected from the field and then chopped into small pieces (< 2mm). Saw dust was collected from wood mills. All materials were then dried in air for 48 hours. The pyrolysis was performed in a small stainless steel pyrolyser vessel (1200 cm^3) with a screw tight lid that fixed with 2 mm diameter steel tube. Pyrolyser was filled with material and flushed with nitrogen gas prior to plug the lid. The pyrolyser was kept inside a pre-heated (100 ± 5 °C) muffle furnace (Thermolyne- type 6000). Pyrolysis temperature was raised to 400 °C at a rate of approximately 20 °C min-1 and held constant for four hours. After heating for 4 hour at 400 ±5 °C, the pyrolyser was quickly taken out from the muffle furnace and was rapidly quenched in a distilled water bath at room temperature.

Pyrolyzed materials were then washed thoroughly with deionized water in order to remove any remaining dirt. Dried material were then grounded and mechanically sieved to a particle size of <0.125 mm that were used for the adsorption experiments. Adsorption experiments were carried out by using batch technique to obtain equilibrium data that were performed at different pH, contacting time and initial concentrations to obtain equilibrium isotherms for known concentrations of different metal solutions. A stock solution of 1000 mg/L of Pb(II), CR(III) and As(III) were used to prepare various initial experimental concentrations. The experimental procedure was done as follows: 0.1 g of the powdered samples was shaken with 100 ml of a metal ion solution whose concentration was 5 mg/L for each metal. All adsorption experiments were performed at room temperature (27±1.0°C) and 0.1 g of biochar were added to 250-ml Stoppard flasks containing 100 ml different solutions and agitated at 600 rpm. All batch isotherm tests were replicated three times and all the observations were recorded in triplicate and average values are reported. The solutions were then filtered using 0.45 µm nylon fiber membrane filters and the total metal ions concentrations in solutions were determined by atomic absorption spectrophotometer.

To observe the effect of pH for the adsorption, the solution pH were changed from 3.0 to 9.0 using either 0.1 M NaOH or 0.1M HCl. Initial concentrations of solution were set from 5 mg/L to 30 mg/L in order to evaluate the effect of initial concentration for the adsorption on to biochar.

The most suitable particle size biochar for the optimum adsorption was found to be <0.125 mm. This was possibly due to the biochars having a large surface area and therefore higher numbers of metal binding sites hence further experiments were performed using this size fraction.

After selecting the optimum conditions, the amount of different metal ions removed or adsorbed and the removal percentages (%) of metal ions were calculated using the mass balance equations given below:

$$q = \frac{(c_i - c_f)V}{m} \quad (1)$$

$$\text{Removal percentange}(\%) = \frac{(c_i - c_f) * 100}{c_i} \quad (2)$$

where q is the amount mg/g of metal ions adsorbed, C_i and C_f are the initial and final concentrations of metal ions (mg/L), respectively, V is the volume of solution and m is the weight of the biochar used for the experiment. All materials were characterized by Fourier Transformation Infrared Spectroscopy (FTIR) using a Thermo Scientific Nicolet iS-10 spectrometer between 400 and 4,000 cm^{-1} in which samples were mounted onto a transparent polyethylene film.

RESULTS AND DISCUSSIONS

Effect of pH for metal ions adsorption

The percent removal of Pb(II) at initial pH of 3.0, 4.0, 5.0, 7.0 and 9.0 on rice straw biochar was 51%, 82%, 83%, 83%, 83% and for saw dust it was 6.5%, 54%, 90%, 89%, 94%. The adsorption of Pb(II) was 90% at pH 5.0 for saw dust biochar. Previous studies indicated that almost 92% of Pb(II) adsorption was obtained with the same type of biochar at this pH (Naiya et al., 2009). As indicated in their study Pb(II) adsorption was followed by a pseudo-second order kinetics in which adsorbent dosage was 5 g/L with the equilibrium time of 1 h. When the pH was increased to 9.0, the maximum Pb(II) adsorption was achieved by the saw dust biochar (94%), whereas rice straw biochar reached its maximum adsorption of Pb(II) as 83% (Figure 1).

The results revealed that As(III) adsorption by biochars were highly pH-dependent. The amount of As(III) adsorption on to rice straw biochar was increased with decreased in pH values. The effect of pH values on As(III) adsorption was more evident when rice straw biochar was used as adsorbent compared to that of sawdust (Figure 1). For instance, As(III) removal percentage (%) for rice straw biochar was 53 at the pH of 3 and decreased to 17 at the pH of 7 when initial concentration was 10.55ppb, whereas for sawdust the values were 35 at the pH of 2.5 and increased upto 59.9 at the pH of 7. For the As (III), the sorptions were 53% and 59% for biochars from rice straw and sawdust respectively. When pH close to 5, the binding sites of sawdust biochar became negatively charged due to presence of amino groups on the surface hence, the higher removal was recorded.

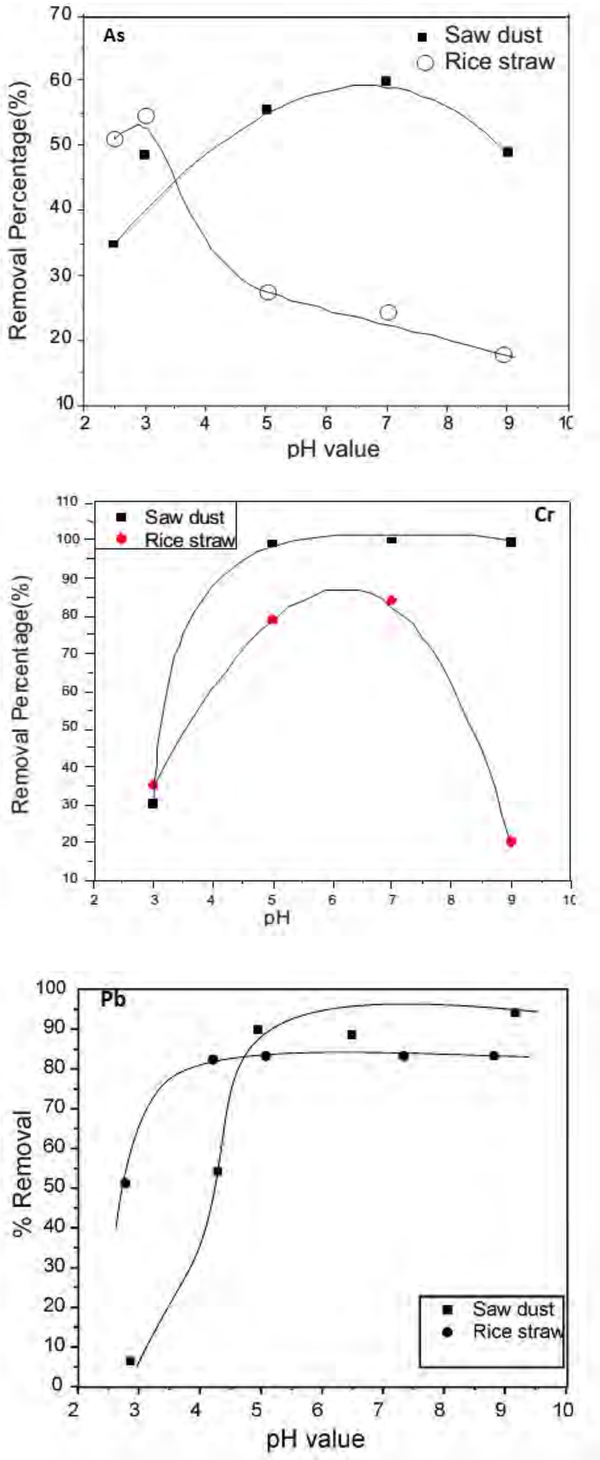

Figure 1 Variation of Removal % with pH

Higher adsorption of As(III) ions onto rice straw biochar at lower pH may be due to attracting AsO_3^{3-} ion onto higher positively charged metal binding sites.

The amount of Cr(III) adsorption increased with the increase in pH from 3 to 6 and then gradually decreased with increased of pH (Figure 1). The effect of pH values on Cr(III) adsorption was more evident when rice straw biochar was used as adsorbent. For instances, Cr(III) removal percentage (%) for rice straw biochar increased from 35% at the pH value of 3 to 87% at the pH valu e of 6 and then decreased to 19 at the pH 9 when initial Cr(III) concentration was 6.5 mg/L, whereas Cr(III) removal percentage (%) for saw dust biochar had a slight increase from 30% to 99% in the above pH range from 3 to 6 and decreased as rice straw biochar upto 76%. At lower pH, excess proton can compete with Cr(III) reducing the adsorption of Cr(III) ions on to biochar surface. Cr(III) produced Cr^{2+} , Cr_2^{+} ions in the solution due to excess proton which can compete with Cr(III)(Mohan and Pittman Jr, 2006)). When metal binding sites on biochar became positively charged and adsorption was low due to repelling Cr(III) cations. Removal of Cr(III) ions was optimum when pH increases above 5 for both sawdust and rice straw biochar. When pH is increased above 6, Cr(III) is precipitated. Since more hydroxyl groups are in rice straw biochar surface when pH higher than 7, adsorption was reduced due to production of polynuclear ((Mohan and Pittman Jr, 2006).

Effect of removal % of metal ions with contact time

The influence of contact time for the adsorption of metal ions on the biochars was investigated by successively increasing the contact time from 1 to 9 h using different size fractions. It was found that adsorption of all metal ions occurs within the first hour and then reached equilibrium. Higher adsorption of As(III) ions onto rice straw biochar at lower pH may be due to attracting AsO_3^{3-} ion onto higher positively charged metal binding sites.

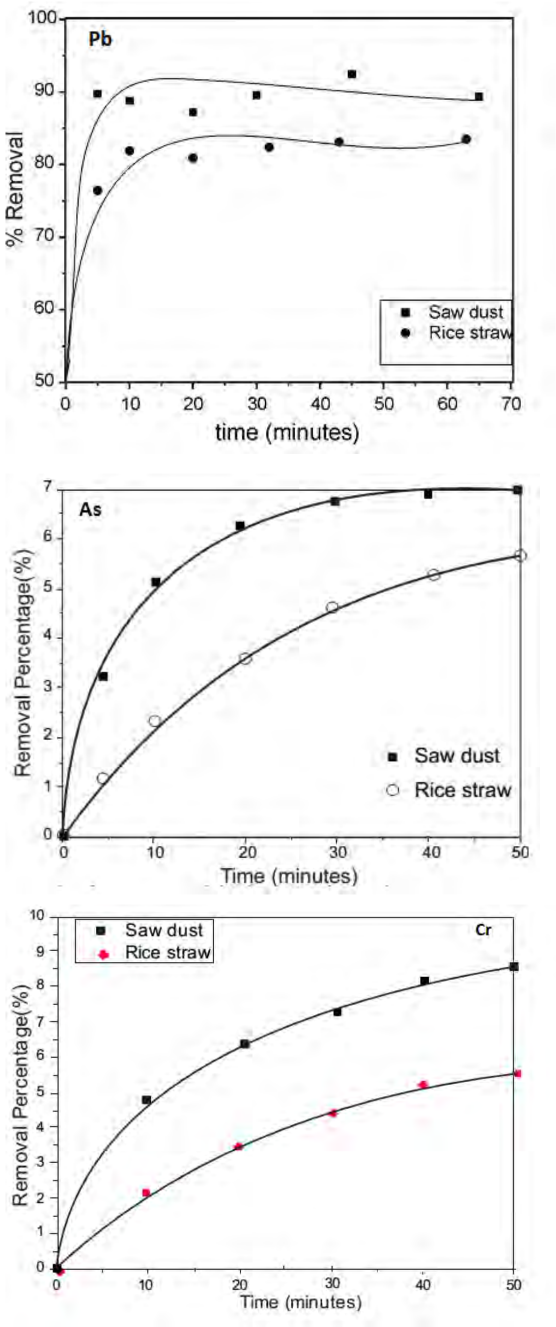

Figure 2 Variation of Removal % with contact time

Higher adsorption of As(III) ions onto rice straw biochar at lower pH may be due to attracting AsO_3^{3-} ion onto higher positively charged metal binding sites.

Saw dust shows over 90% of adsorption within the first 10 min for Pb(II) (Figure 2). The higher rate of adsorption in the first 10 min could be attributed to the availability of a higher concentration of adsorption sites in the saw dust biochar surface. It was observed that adsorption capacity about 6.8 mg/g of As(III) ion from saw dust biochar was attained in first 35 minutes and concentration became almost constant after 40 minutes (Figure 2). Adsorption of arsenic onto rice straw biochar was optimum around 50 minutes duration and adsorption capacity was 5.7mg/g. Chromium adsorption capacity with contact time was higher with saw dust biochar (8.5 mg/g) while 5.5mg/g adsorption capacity was achieved by rice straw biochar (Figure 2)

Effect of removal % of metal ions with intial concentration

Adsorption experiments were carried out using different initial Pb(II) concentrations. This showed that higher initial concentrations tend to be adsorbed more onto biochar. This indicates that the over 90% of Pb(II) ions readily adsorbed onto the biochar surface; however, saw dust biochar shows slightly higher adsorption of Pb(II) from the aqueous solution. This may be due to the high probability of collision between metal ions with the biochar surface and high rate of metal ions diffusion onto biosorbent surface. The ratio of metal ions to active sites is low at low initial metal concentration and relatively high at higher initial metal concentrations. Removals percentages of arsenic ions onto saw dust and rice straw biochar were gradually increased with increased initial concentration of the metal solution. It was observed as a general trend that there is a decrease of the removal percentage with increase in initial concentration from 22 mg/L. Highest removal was observed at low concentrations of chromium ion solution. At the first 15 minutes it was observed rapid uptake of chromium ions by both biochar and then gradually decreased with time. These results may be explained on the basis that the increase in the number of ions competing for the available binding sites and also because of the lack of active sites on the adsorbent at higher concentrations.

The adsorption isotherms of metal ions

Adsorption equilibrium measurements are used to determine the maximum adsorption capacity. There are six models of adsorption isotherms that are used to describe the metal adsorption on to solid surfaces (Rahman and Haseen, 2014, Mohan et al., 2005) From these, Langmuir and Freundlich isotherms were considered in this study as they have been widely used to describe the interaction between metal ions in solution and adsorbents. Langmuir isotherm (linear form) is expressed as follows(Langmuir, 1918):

$$\frac{C_e}{q_e} = \frac{1}{Q_0 b} + \frac{C_e}{Q_0} \quad (3)$$

Essential features of the Langmuir isotherm was expressed in terms of a dimensionless constant separation factor R_L(equilibrium parameters) that is given by

$$R_L = \frac{1}{1+bC_i} \quad (4)$$

in which q_e is the amount mg/g of metal ions adsorbed at equilibrium state, Q_0 is the maximum adsorption capacity, C_e and C_i are the equilibrium and initial concentrations of metal ions (mg/L) and bis the Langmuir constant.

The Freundlich isotherm model is widely used to describe adsorption characteristics for the heterogeneous surfaces (Freundlich, 1906)) and assumes a monolayer capacity, but is accompanied by interaction between the adsorbed molecules. The Freundlich equation (linear form) is given as follows:

$$Log\, q_e = Log\, K_F + \frac{1}{n} Log\, C_e \quad (5)$$

where K_F is a constant related to the adsorption capacity of the adsorbent and the constant 1/n indicates the intensity of the adsorption.

The maximum adsorption capacities (Q_0) estimated from the Langmuir isotherm model for Pb(II) was observed for saw dust biochar. The separation factor for saw dust and rice straw biochars were 0.234 and 0.128 that indicates a favourable sorption isotherm for Pb(II). Therefore, the results show that saw dust and rice straw biochars have the potential as good sorbents for Pb(II) ions that follow monolayer adsorption isotherms.

The Freundlich model was chosen to estimate the adsorption intensity of the sorbent towards the sorbate. The 1/n obtain for saw dust, rice biochar were 1.27, 1.65 respectively, and indicates the cooperative sorption of Pb(II). The values indicated the affinity of the sorbent towards the uptake of Pb(II) ions and the adsorption of metal ions was favourable.

Maximum adsorption capacities were showed by saw dust biochar for Cr(III) ions. The Langmuir isotherm assumes monolayer adsorption onto a surface containing a finite number of adsorption sites. Monolayer adsorption is distinguished by the fact that the amount adsorbed reaches a maximum value at a moderate concentration; this corresponds to complete coverage of the adsorbent surface by a monomolecular layer of adsorbate (Khraisheh et al., 2004)) . The separation factors for saw dust and rice straw biochars were 0.991 and 0.069 for Cr(III) ions and Freundlich isotherm model was well fitted with As(III) ions.

The FTIR spectra obtained for biochar from byproducts of biomass that were pyrolyzed in moderate temperature of 400°C, are characteristics of different oxygen containing surface groups of C–O; C=O and C–OH and other lingo cellulose materials since the materials were pyrolyzed at a lower temperature. The FTIR spectra of two biomass indicated that Pb(II) metal can be adsorbed by the biochars specifically through the formation of surface complexes between Pb(II) and the functional groups on the biochars surface. It also revealed that As(III) and Cr(III) metal ions bound to active sites of the biosorbents in different biochars through either electrostatic attraction or complexation mechanism. These results indicated that carbonyl, hydroxyl, amine and halides are the main adsorption sites in saw dust and rice straw biochar and these functional groups complexed with metal ionss in the aqueous solution and changed the chemical environment of the functional groups in the biochar.

CONCLUSIONS

This study reveals that the percentage removal of metal ions is dependent on the dose of the adsorbent, pH of the solution contact time and the initial metal concentration. The contact time necessary for maximum adsorption was found to be less than an hour. The optimum pH range for Pb(II) and Cr(III) adsorption was 5.0–7.0 while As(III) was 3.0. Langmuir isotherm model was a better fit for both biochar materials for Pb(II) and Cr(III) ions. Freundlich model was fitted with AS(III). The separation factors of different biochars indicate a favourable sorption isotherm for Pb(II) and Cr(III) and adsorption or intra-particle diffusion process for As(III) ions. The FTIR spectra indicated that carbonyl, hydroxyl, amine and halides are the main adsorption sites in biochar which complex with metal ions in the aqueous solution. 90%–94% removal of metal ion from aqueous solution could be attained by using saw dust and rice straw biochar. Adsorbent materials derived from low-cost agricultural wastes can therefore be used as an effective removal and recovery of lead ions from wastewater.

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CHARACTERISTICS OF WOOD PELLETS MIXED WITH TORREFIED RICE STRAW AS AN ENERGY UTILIZATION

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ABSTRACT

Utilization of rice straw as an alternative fuel source to fossil fuel has been considered. However, properties such as water content, low heating value, less grindability, high bulk density, and high ash content are problems in such a biomass fuel supply chain. This study attempted to produce wood pellets mixed with torrefied rice straw (WPTRS) to solve the problems related to using rice straw as fuel. For that, preferred torrefaction conditions, such as torrefaction temperature and holding time, were determined by indicators of the grindability, energy loss, and heating value. As a result, the preferred grindability was found at torrefaction temperatures of over 220°C. In terms of energy, we derived two viewpoints: i.e., if minimum energy loss is prioritized, the preferred torrefaction temperature is 220°C, and for an increase in the heating value of rice straw, 280°C was preferred.

Keywords: agriculture biomass, torrefaction, wood pellets mixed with torrefied rice straw

INTRODUCTION

Renewable and sustainable energy is of global interest because fossil fuels have been exhausted and greenhouse gases are being emitted. The European Commission compiled a new policy framework for climate and energy for the period from 2020 to 2030, in which a target in the share of renewable energy consumption is at least 27%, and in the electricity sector in particular, the share must be at least 45% (EU Commission, 2014).

In Japan, solar and wind power generation and electricity saving have been promoted by the feed-in tariff scheme. However, the share of biomass energy in electricity and heat is still low (IEA, 2016), although the number of power generation plants using wood chip and palm kernel shell (PKS) has been increasing. Fossil fuels for heating should be replaced by biomass as an activity of local production for local consumption, especially in colder regions, such as northern European and Hokkaido.

There is an abundance of agricultural residues, such as rice straw, rice husk and wheat straw in Japan, including in Hokkaido. However, most of the agricultural residue is returned into the soil as organic matter to enrich the soil (Yagi and Minami, 1990), which means that the utilization ratio of agricultural residue, except for the straw return, is only 30% (Ministry of Agriculture, Forestry and Fisheries, 2016).

Under this background, various areas have been begun researching the use of agricultural residue for local energy. Though biomass fuel is an attractive energy source that can replace fossil fuel in terms of carbon neutrality, utilization of agricultural residues has many shortcomings, such as high moisture content, low bulk density, low heating value, high ash content, hygroscopic nature, low energy density, and poor grindability (Werther et al, 2000; Acharya et al., 2015). For example, the low bulk density means that large spaces are required to store agricultural residues, and poor grindability and high moisture content needs pretreatment processes, such as shredding and drying, before producing biomass fuel. Therefore, it is difficult to build a cost-effective supply-chain system of biomass fuels using agricultural residues, considering all related processes such as collection, transportation, storage, pretreatment, production, delivery and utilization of the biomass fuel.

Rice straw is one of the most widely available agricultural residues in the world. Most of it is available in rural areas. A specific problem of utilizing rice straw as a biomass fuel is its high ash content, which causes clinkers during a burning process. During 2011, Nanporo was the first town in Hokkaido that started a business to use rice straw pellets. To mitigate the clinker problem, Nanporo introduced a co-combustion process of rice straw pellets and wood pellets in the ratio of 1:1 (Ishii and Furuichi, 2014). The above shortcomings of rice straw for utilization as biomass fuels can be overcome by applying torrefaction, although torrefaction requires energy. Our approach is to produce pellets using both wood and torrefied rice straw. Torrefaction of rice straw as pretreatment before pelletization and production of wood pellets mixed with the torrefied rice straw (WPTRS) would contribute to the wider use of lingocellulosic biomass as fuel for local heat supply, which would benefit the regional economy.

The torrefaction process is a thermal treatment process in an inert atmosphere and in the low temperature range of 200°C to 300°C (van der Stelt et al., 2011). The torrefied product retains a maximum of 90% of its original energy content, while losing a maximum of 30% of its original mass, which is due to a partial loss of the volatile matter and moisture contained in the biomass (Acharya et al., 2015). It depolymerizes the long polysaccharide chains, producing a hydrophobic solid product with an increased energy density (on a mass basis). This process also partially decomposes the hemicellulose in the biomass fiber (Koppejan et al., 2012). As a result, much less energy is required to grind the torrefied biomass (Bridgeman et al., 2008; van der Stelt et al., 2011). Moreover, pelletizing is a process applying a mechanical force to compact biomass residues into uniformly sized solid particles. The objectives of pelletization are to increase the volumetric energy density (Werther et al, 2000). Therefore, combining torrefaction and pelletization can solve the above shortcomings related to transport, handling, and storage (Chen et al., 2015).

Regarding usage of pellets using torrefied agricultural residues, no studies were found related to the use of them, especially in small and/or middle scale of biomass boilers in public facilities or greenhouses and biomass stoves in houses. And it appears that no studies on pelletization of both wood and torrefied rice straw have been done. Fundamental data on torrefaction conditions (temperature and holding time) for rice straw to produce WPTRS should be obtained.

Therefore, this study focused on WPTRS to improve the problems related to the supply chain for biomass fuels using rice straw. In particular, the effectiveness of torrefaction of rice straw on the quality of WPTRS was analyzed from an energy balance perspective.

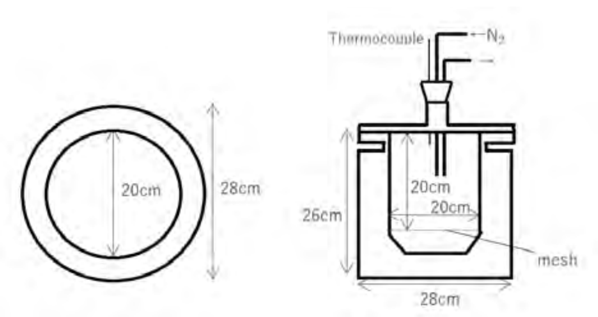
MATERIALS AND METHOD

Rice straw

The rice straw used in this study was collected in November 2014 from the town of Nanporo in Hokkaido, Japan. The collected rice straw was stored at room temperature, in the order of 20 - 25°C, in the laboratory of Hokkaido University. Our experiments were conducted in the winter of 2016. The moisture content was 6.5%, and the ash content was 18.0%.

Torrefaction method

The rice straw was torrefied in a stainless-steel reactor placed in an electric drying oven. The plan and side views of the reactor are shown in Figure 1. The raw rice straw was put in the reactor, which was sealed and placed into the electric drying oven. The reactor was heated to the designated temperature (190 to 280°C) under a nonoxygen environment made up by flowing nitrogen gas. The temperature inside the reactor was increased by 1°C /min up to 40°C, and by 2°C /min up to 200°C (Figure 2). As the temperature increased further, the temperature rises gradually became slower. After the temperature reached the designated temperature (i.e., the torrefaction temperature), the temperature was maintained for a designated holding time (0 to 120 minutes). The reactor was then cooled down naturally to room temperature. The torrefied rice straw was weighed and shredded with a continuous mill (IKA MF10 basic, Germany). The shredded rice straw was discharged through a 3 mm mesh. The torrefaction conditions, such as the torrefaction temperature and holding time are shown in Table 1.



Plan view (with the lid off) Side view

Figure 1 Plan and side views of the reactor

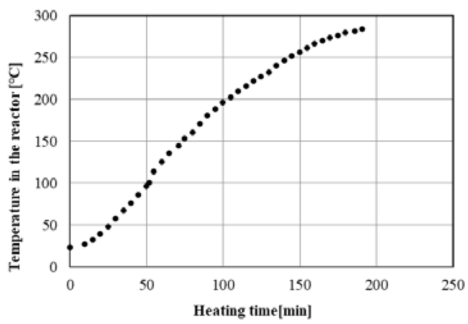


Figure 2 Change in the reactor's internal temperature (the torrefaction temperature was 280°C)

Table 1 Torrefaction conditions

		Holding time [min]					
		0	10	30	60	90	120
Torrefaction temperature [˚C]	190	✔			✔		
	220	✔			✔		✔
	250	✔			✔		✔
	280		✔	✔	✔	✔	

Analysis method

Higher heating value (HHV): In accordance with the Japanese Industrial Standards M 8814 (1993), the higher heating values (HHV) of the samples were measured using a bomb calorimeter (C7000, IKA, Germany). One mass of approximately 0.5 g of shredded samples was analyzed and it was repeated four times.

Hydrogen content and lower heating value (LHV): Hydrogen content was measured using an elemental analyzer (Elementar Vario EL; Elementar Analyzer System, Germany). Each run was repeated four times. The lower heating values (LHV) were calculated from their HHV and hydrogen content by using Eq. (1).

$$\mathrm{LHV} = \mathrm{HHV} - \mathrm{r} \times (\mathrm{U} + 9\mathrm{H}) \quad (1)$$

where, LHV and HHV are the lower and higher heating values (MJ/kg), respectively, r is the evaporative latent heat (2500 kJ/kg), U is the moisture content (kg/kg) and H is the hydrogen content (kg/kg).

Remaining heating value rate: Torrefaction increases the heating value per weight of rice straw. However, some energy is lost because volatile matter is thermally decomposed. To evaluate the energy loss during torrefaction, the remaining heating value rate (RHVR) was calculated from Eq. (2). This indicator is also called the energy yield (Chen et al., 2015).

RHVR= (LHV for torrefied rice straw ×weight of torrefied rice straw)/(LHV for dried rice straw ×weight of dried rice straw) (2)

Thermogravimetric analysis (TG) and differential thermal analysis (DTA): Dried and shredded rice straw was heated to 300°C with a simultaneous thermogravimetric analyzer (STA7300; Hitachi, Japan), and the thermal weight and differential heat were measured twice. The heating program was then set as follows, based on the temperature rise in this experiment and as described in Torrefaction method.

(1) From room temperature to 40°C at 1°C /min
(2) From 40℃to 200°C at 2°C /min
(3) From 200℃to 260°C at 1°C /min
(4) From 260℃to 280°C at 0.5°C /min
(5) From 280℃to 300°C at 0.2°C /min

Particle size distribution: Particle size distribution was measured to evaluate the grindability of torrefied rice straw, by using seven types of test sieves, whose mesh sizes were 0.075, 0.125, 0.25, 0.5, 1.0, 2.0 and 5.6 mm.

RESULTS AND DISCUSSION

Heating value and remaining heat value rate

The relationships among the torrefaction temperature, LHV, and RHVR are shown in Figure 4. The LHV of torrefied rice straw increased with the torrefaction temperature because the reduction in weight of the rice straw accompanied by torrefaction was larger than the decrease in the volatile content of the rice straw. Figure 5 shows the results of the TG-DTA for the dried rice straw under the same condition of temperature increase rate in this experiment, although the final temperature was set to 300°C. Hemicellulose and cellulose in the rice straw appeared to be mainly decomposed. The decomposition temperatures for hemicellulose and cellulose are 200-260°C and 240-350°C (Mohan, 2006), respectively. The drying process was seen up to 100°C because of a water content increase during storage (Figure 5). Reduction in the weight of the rice straw started and radiation of the heat started when the temperature exceeded 200°C, which means that decomposition of hemicellulose started. When the temperature exceeded 250°C, the weight was further reduced significantly and the radiation of heat continued. Cellulose was decomposed during this temperature range around 250°C. At the temperature of 300°C, the decomposition seemed to end. The increase in the LHV of torrefied rice straw (Figure 4) had the same tendency as the result of the TG-DTA. The LHV of rice straw at the torrefaction temperature of 280°C was over 19 MJ/kg, which was higher than for wood pellets with an LHV of 16.9 MJ/kg (García-Maraver et al., 2011). Therefore, torrefaction contributes to an increase in the LHV of rice straw.

Although torrefaction increased the heating value per unit weight of rice straw, a part of the energy in the dried rice straw was lost. In addition, the ash content increased relatively due to the reduction of volatile matter. To evaluate torrefaction from the viewpoint of energy loss, the RHVR is also shown in Figure 4. The definition of RHVR, as shown in Eq. (2), means that the RHVR is 1.0 when the torrefaction temperature is 100°C (just drying). The RHVR decreased with an increase in the torrefaction temperature because the volatile matter was reduced with an increase in the torrefaction temperature. For torrefaction temperatures less than 220°C, the RHVR was still over 95%. However, the RHVR was significantly decreased at torrefaction temperatures of more than 250°C. When the torrefaction temperature was 280°C, the RHVR was 80%. This means that 20% of energy in the dried rice straw was lost through torrefaction, although the LHV of torrefied rice straw was improved.

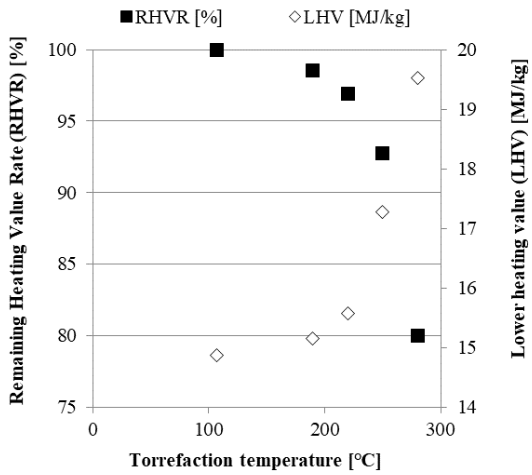


Figure 4 Relationships of LHV and RHVR vs torrefaction temperature

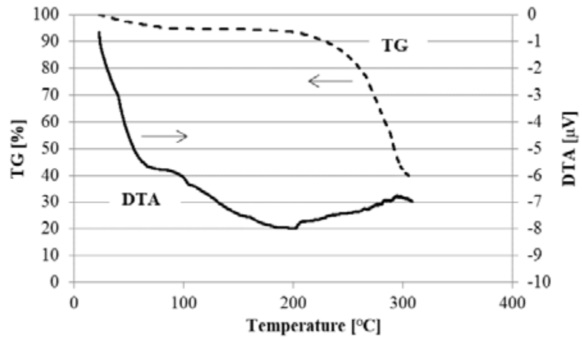


Figure 5 Results of TG-DTA of rice straw

<u>Grindability</u>

The torrefied rice straw was broken easily with one's fingers, especially when the torrefaction temperature was 220°C, 250°C, and 280°C. This was because a part of the hemicellulose and cellulose was decomposed. However, the rice straw torrefied at 190°C could not be broken easily with one's fingers.

The comparison of particle size distribution for shredded torrefied rice straw is shown in Figure 6, where the plots are denoted as X°C -Y min: X indicates the torrefied temperature, and Y indicates the holding time. The particle size of the rice straw torrefied at 190°C, 220°C, and 250°C was smaller than that of the dried rice straw. In particular, and regardless of the holding time, there was no significant difference in particle size for rice straw torrefied at 220°C and 250°C. Therefore, torrefaction at the temperature of over 220°C seemed to be enough to improve the grindability of rice straw. Arias et al. (2008) studied the changes in the grindability characteristics of biomass samples (eucalyptus) when subjected to mild pyrolysis treatment (torrefaction) in the temperature range of 240-280°C.

The difference in the particle size distribution of shredded rice straw for holding times between 0 min and 60 min was small, although the difference at the torrefaction temperature of 190°C was a little bit larger than those at the other temperatures of 220°C and 250°C. In general, there is a significant mass loss initially, which is associated with the decomposition of some reactive components of the hemicellulose. At higher holding times, the mass loss can be attributed to the decomposition of the less reactive components of the hemicellulose. In this study, because a very slow heating rate was used (1-2°C /min), it seemed that reaction had progressed to a certain extent when the temperature reached the designated torrefaction temperature. That is why there was no significant difference in the particle size distribution between 0 min and 60 min in the holding time.

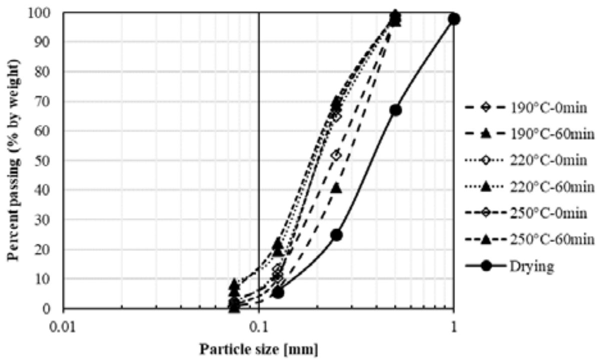


Figure 6 Comparison of particle size distribution for shredded rice straw

Preferred torrefaction conditions from the viewpoint of energy and grindability

As the torrefaction temperature increased, the heating value per weight unit of rice straw increases. However, energy loss occurred in terms of the total energy in the rice straw, as mentioned above. Therefore, the preferred torrefaction conditions can be discussed as follows, considering both the energy loss and grindability.

Minimization of energy loss: The energy required for torrefaction and the energy loss during the torrefaction process should be minimized. From our data on torrefaction of rice straw, the preferred torrefaction temperature is 220°C, because the RHVR was over 95% and the grindability was also improved. Torrefaction temperatures of 250°C and 280°C are not needed because the energy loss is large. It is noted that the holding time should be further investigated because a very slow heating rate was used in this study. Further investigations are needed for faster heating rates.

Improvement of quality of rice straw as fuel: The other viewpoint is to produce biomass fuels with high quality that can be sold at a high price. Considering that the price of biomass energy can be determined by LHV, the preferred torrefaction temperature is 280°C. Longer holding times may increase the heating value, but may decrease the RHVR. Therefore, further investigation into the effects of holding time is needed.

CONCLUSIONS

The following conclusions were drawn from this experimental study.

The grindability of rice straw was improved by torrefaction at temperatures of over 220°C. This study suggested two important viewpoints for torrefaction conditions of rice straw. One viewpoint is minimization of energy loss, where a torrefaction temperature of 220°C and no holding time was preferred. The other viewpoint is improvement of the quality of rice straw as a fuel, where a torrefaction temperature of 280°C and no holding time was preferred.

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RESEARCH OF SOLID FUEL BY TORREFACTION METHODS USING ORGANIC WASTE RESOURCES

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ABSTRACT

This study presents an investigation into a method of processing biomass in torrefaction and converting it into fuel. The experiment was performed by using raw sludge generated from the first sedimentation area among sewage sludge. For torrefaction method, the experiment was performed through 2 methods, which are drying method, oil method. When conducting torrefaction and oil torrefaction experiment, the reaction temperature was 200˘, 215˘ and 230˘ a nd reaction time was 15 minutes, 30 minutes and 45 minutes. The percentage of water content in reactants stared to drop to 10% or lower at the reaction temperature of 230˘ to torrefaction method. Oil torrefaction reactants moist content were 10% or lower at all reaction temperatures. The heating value started to meet the standard of 3,500Kcal/kg for solid fuel products in the Korean at the reaction temperature of 230˘ and reaction time over 30 minutes by torrefaction method. All of products by oil torrefaction method satisfied the Korean standard. Therefore, it was observed that oil torrefaction method for solid fuel production of sewage sludge through torrefaction method shows higher efficiency in terms of removing moisture content and upgrading caloric value.

Keywords : Oil torrefaction , Organic waste, Sewage sludge , Torrefaction

INTRODUCTION

The consumption of fossil fuel including oil is incessantly increasing due to the abrupt demand for energy due to larger global population and development of emerging economies. But development of definite alternative energy source to replace fossil fuel is still unsatisfactory (Yoonkyung Lee., 2013).

Korea is depending most of energy source, raw material and food materials on foreign supply, with self-appropriation ratio of 3% for energy and 26% for food. Among them 97% of energy is imported, of which the majority is oil. For ensuring sustainability of the country, securing the resources has become the social issue recently. In this situation, expanding use of renewable energy such as biomass etc. is one of the important tasks (hyuksoo Kwon et al., 2010).

There has been an increasing concern and effort on reduction of energy and green-house gas in the world. New and renewable energy has been serving as an important role to solve aforementioned two issues. Korea has been also accelerating the development of technology and commercialization based on government-led policies. In the Second Energy Master Plan, it has been set to provide 11% of the renewable energy of the one supplied in the first master plan until 2035. In the Fourth Energy Master Plan, 47.2% of the amount of energy has been produced in wastes and biomass out of the total new and renewable energy until 2035 (Institute for advanced engineering., 2015).

Items produced by using torrefaction technology tend to have hydro-phobic property and a very low percentage of water content. Therefore, they are less likely changed in terms of appearance including decomposition or distortion due to micro-organisms. In addition, they tend to have low cost for delivery in long-distance, outstanding handling property including treatment and preservation, enhancement of pulverization, and high energy density (Sangwoo Pak., 2013, Sunjae Baek., 2015, Gavrila Trif-Tordai and Ioana Ionel., 2011, J.J Chew., 2011, Hyungchul Ahn., 2015).

This study researched on feasibility of solid fuel precess by torrefaction methods by using sewage sludge.

MATERIALS AND METHODS

This study has been conducted to make sewage sludge a source of fuel by using torrefaction. Sewage sludge used in this study was from primary sedimentation pond at ‘S’ management corporation located at Incheon. Physical and chemical characteristics of sewage sludge are as follows in Table 1.

Table 1 Physical and chemical characteristics of sewage sludge

Physical analysis (wt%)	
Moisture	82.19
VM(Volatile matter)+FC(Fixed carbon)	11.92
Ash	5.36
Chemical(elemental) analysis (wt%)	
Carbon	6.48
Hydrogen	10.43
Oxygen	55.44
Surfer	0.17
Nitrogen	1.422

The heat medium used in the oil torrefaction method using waste oil was the waste cooking oil of the ‘S’ university’s restaurant in Nowon-gu, Seoul.
The experimental setup used in this study is shown in Fig 1. The reactor is made of a stainless steel material with a total volume of 1.3 L and the indicator that can confirm the internal temperature of the temperature inside the reactor is located in the control device and reduces the error range of set temperature and actual

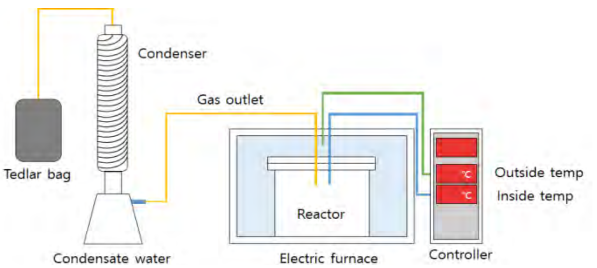

Figure 1 structure of torrefaction reactor

temperature.

Experiment condition

In the experiment, 100 g of sewage sludge was used and 200 mL of waste oil was used for oil torrefaction.
When conducting torrefaction and oil torrefaction experiment, the reaction temperature was 200˜, 215˜ and 230˜ and reaction time was 15, 30 and 45 minutes. Using reactants manufactured, possibility of creating fuel from them has been derived through caloric value analysis, physical and chemical analysis, respectively.

RESULTS AND DISCUSSTION

Torrefaction results of anaerobic condition

As the reaction temperature increased and the reaction time increased, the hardness of the surface increased and the color became darker. Moisture content analysis in torrefaction reactants is indicated in Fig 2.

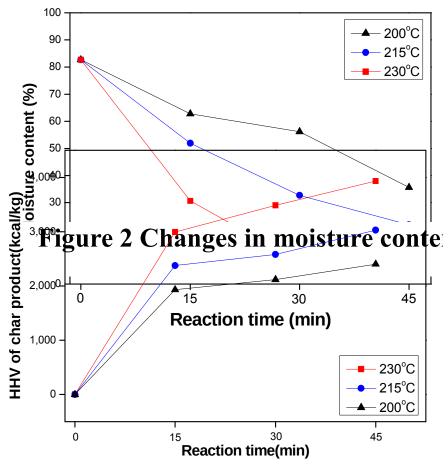

Figure 2 Changes in moisture content

It was found that the dehydration reaction increased as the reaction temperature increased, and the dehydration reaction increased sharply as the reaction temperature 230˜. In the case of calorific value, the products meeting the Korea solid fuel standards were obtained from the reaction temperature of 230˜ for more than 30 minutes. Fig 3.

Torrefaction results of oil condition

Moisture analysis showed that the water content decreased to less than 10% regardless of the reaction temperature and time, because the heat medium oil was more uniformly distributed on the surface of the sludge

Figure 3 Caloric value of reactants of torrefaction

and the heat transfer was more efficiently transmitted. Fig 4. The addition of the heat medium oil in the calorific value measurement resulted in the product in which all the products meet the Korean solid fuel standards. Fig 5.

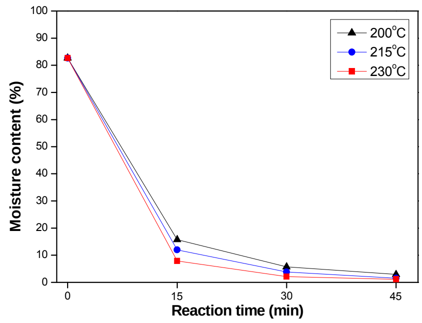

Figure 4 Changes in moisture content of oil torrefaction

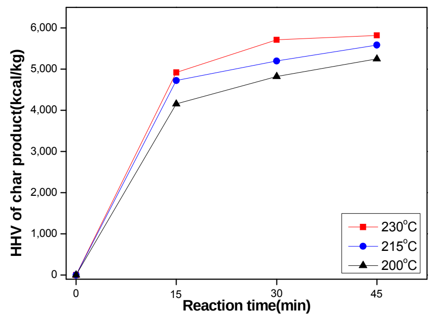

Figure 5 Caloric value of reactants of oil torrefaction

CONCLUSIONS

The following conclusions were obtained in the solidification of fuel through torrefaction reaction using sewage sludge.

1. As the reaction temperature increases, the dehydration reaction becomes bigger during the torrefaction reaction under anorexic condition, and the calorific value is improved.
2. It was found that dehydration reaction and calorific value greatly increased due to the effect of heating oil on the torrefaction.

Lowering the moisture content is considered to be an important issue due to the characteristics of the sewage sludge, and the torrefaction method shows high efficiency in terms of water content removal.

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Clarification on factors of increasing viscosity in anaerobic digestion of food wastes

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ABSTRACT

In this study, actual data from a biogas plant such as solids and dissolved matters in the digestion tank was analyzed to assess factors affecting increase of viscosity in the sludge. As a result, temporal change of viscosity in several months was similar to that of total solid concentration (TS) and the dissolved COD concentration (dissolved COD) of digested residue although some peak of the viscosity occurred without that of TS and dissolved COD. In addition, TS and dissolved COD had a clear correlation with the apparent viscosity of the residue in the anaerobic digestion tank. These results indicated that the factors to increase the viscosity of the digested residue were not only the TS but also the dissolved sticky substances.

Keywords: Anaerobic digestion, Food wastes, Viscosity, Total Solid concentration, Dissolved matters

INTRODUCTION

Anaerobic digestion is one of the effective methods to utilize food wastes. It is important to raise efficiency of contact between substances and bacterium by mixing in a digestion tank in order to make methane yield stable. However, the high viscosity of sludge in a digestion tank leads to non-uniform mixing of it. The homogeneous mixture of sludge with high viscosity needs a lot of energy and costs (Stoyanova, E., et al., 2014). In addition, the high viscosity causes friction head loss in pipe flow of sludge (Murakami H. et.al. 2001) and the inhibition of the sludge flocculation on water treatment processes. Thus, it is necessary to clarify factors affecting viscosity increase so that the viscosity in aerobic digestion can be controlled. The previous studies (Terashima, et.al., 2007, Seyssiecq, et al., 2003, Forster, C., 2003) revealed that the properties such as the size, shape, surface charge and size distribution of grains, concentrations of sewage sludge and adhesion change the viscosity of sludge. Some studies also suggested the model equation for predicting the viscosity of the anaerobic digestion sludge with the solid concentration (Terashima, et.al., 2007, Slatter, P., 1997, Moeller & Torres, 1997). However, the proposed empirical models were different from each other. The other factor might affect on the viscosity. Other factors as the dissolution of the sticky substances, e.g., thickening stabilizer in foods, might affect the viscosity. Therefore, the objective of this study is to clarify factors to increase viscosity. In particular, this study focused solids and dissolved matters in anaerobic digestion of food wastes by analyzing the actual data from a biogas plant.

ANALYSIS OF ACTUAL DATA FROM A BIOGAS PLANT

Description of the biogas plant

The biogas plant targeted in this study treats food wastes of 150 ton/d, including industrial and domestic kitchen-wastes, using an anaerobic digestion process: After shredding food wastes packaged and removing impurities such as plastic bags, , separated food wastes are sent to three tanks for hydrolytic reaction; Then, they are treated in the methane fermentation tank at a temperature of 37 Celsius degree and hydraulic retention time of approximately 27 days; Finally, the digestate drained from the methane fermentation tanks is separated into solid and liquid parts after flocculating.The former are composted, the later are subjected in the water treatment system. The average loading rate of COD_{Cr} to the methane fermentation tank is 5 kg m^{-3} day^{-1} at the normal operation in this plant.

In terms of efficient and stable methane fermentation, the operation of the biogas plant is based on the following analyzed characteristics of slurry in the digestion tank: COD_{Cr}, pH, TS, alkalinity and the concentration of ammonium ion. Packaged wastes discharged from food processing are stored to the stockyard and manually are put in the treating system considering with TS and COD_{Cr} of them. The apparent viscosity of the sludge in the digestion tanks is measured with rotational viscometer to evaluate flocculant of sludge.

Data analysis

Actual data, including the viscosity, CODcr, etc, which were analyzed and recorded from January to May in 2018, were obtained from the biogas plant. Temporal changes of apparent viscosity and TS in the digestion tanks and Spearman rank correlation coefficient between them were compared to assess the effect of the solid in the digestion sludge to the viscosity.

Bacterium secretes extracellular polymeric substances to protect own bodies against the environment. Some of them are considered to be viscous substances. Assuming that change of the environmental conditions for bacterium, such as pH and the concentration of ammonium ion, would effect the bacterial secretion, the temporal changing of environmental conditions and apparent viscosity in the digestion tanks were compared, and Spearman rank correlation coefficient between them were calculated.

The plant does not have actual data for the concentration of thickening stabilizer in the wastes and the digestion tank. Some of the stockyard wastes such as disposed fluid foods, sauces and ice-cream contain thickening agent. The ratio of HRT-cumulated amount of the stockyard wastes to the total input (hereinafter called “the ratio of stockyard waste”) was calculated to represent the amount of the thickening substances in the digestion process.

The cross-correlation functions (CCFs) between the viscosity and the other characteristics in the digested residue were calculated to identify the delay of the viscosity increasing and the correlation.

RESULT

Figure 1 shows the temporal change of the apparent viscosity and TS in the digestion tanks 1 and 2 from 1st January to 4th May in 2018. The apparent viscosity in

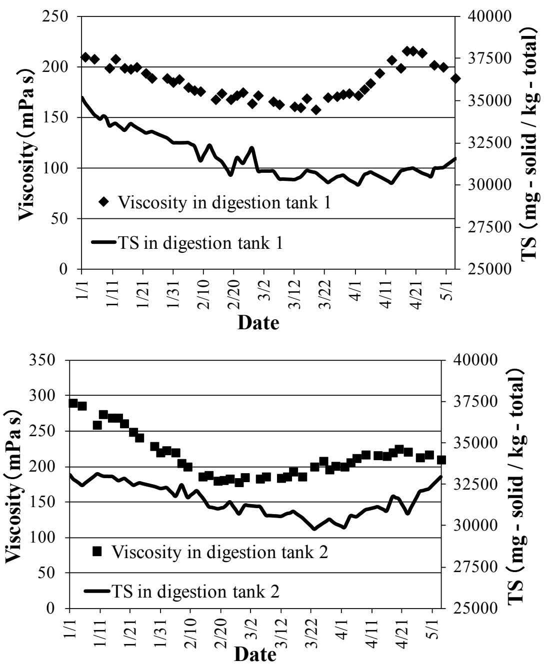

Figure 1 Comparison of temporal change of the apparent viscosity and TS in the digestion tank1 & 2

both tanks was gradually decreased from 1st January to the middle of March, then increased from March to April, again decreased in May. TS in both tanks was also decreased from January to March, however, was slightly decreased until April, then increased in May. The peak of the apparent viscosity in both tanks was observed in April, although that of TS not.

Figure 2 shows the temporal change of the dissolved COD in both tanks during the same term, compared with the apparent viscosity. The dissolved COD was changed up and down during the short time. However, the tendency of decrease from January to March and that of increase from March to April was similar to that of the apparent viscosity.

Figure 3 shows the ratio of the stockyard wastes to total input and the apparent viscosity in the digestion tanks from January to May. The ratio of the stockyard wastes to total input went stable in almost all the time because the input amount of the stockyard wastes was

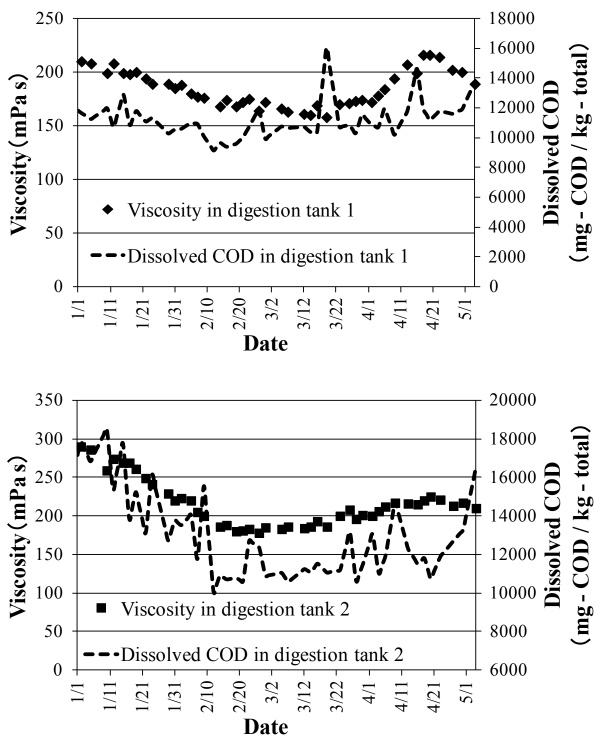

Figure 2 Comparison of temporal change of viscosity and dissolved COD in digestion tank 1 & 2

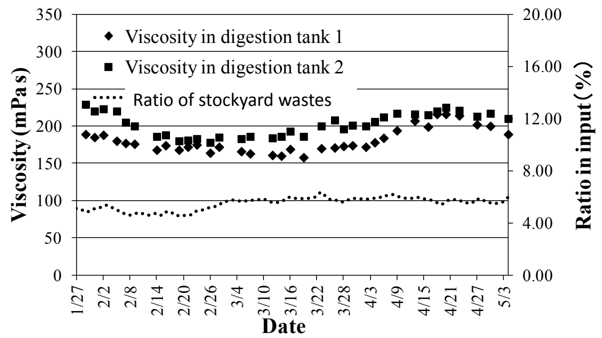

Figure 3 Temporal change of viscosity in digestion tank and ratio of stockyard wastes to input

controlled to adjust TS of digesting waste to less than 10%. All of the stockyard wastes did not contain the thickening agent so that the effect of them on the apparent viscosity was not clearly observed.

Figure 4 shows the relationships of the apparent viscosity and TS or dissolved COD in the digestion tanks. The apparent viscosity was related to TS and

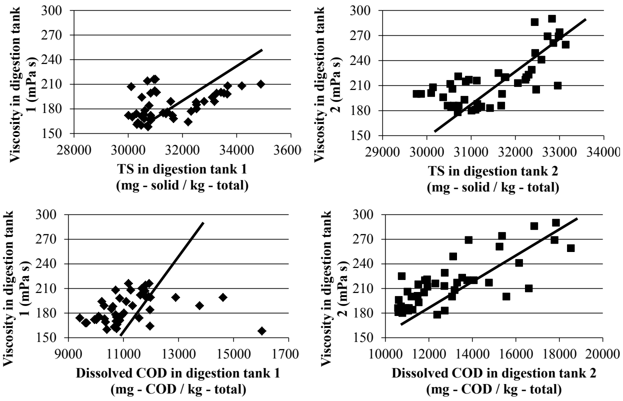

Figure 4 Correlation between the apparent viscosity and TS or dissolved COD in digestion tank 1&2

Table 1 Spearman rank correlation coefficient between the apparent viscosity and the other characteristics in the digestion tanks.

	Tank 1	Tank 2
TS	0.471	0.658
Dissolved COD_{Cr}	0.446	0.714
COD_{Cr}	0.263	0.348
pH	0.267	0.161
Alkalinity	0.191	0.133
NH_3-N	0.237	0.275

dissolved COD. Spearman rank correlation coefficient between the apparent viscosity and TS and dissolved COD were higher than that among the other characteristics (see Table 1).

Figure 5 shows CCFs between the apparent viscosity and TS in the digestion tanks. CCFs showed a maximum value when no delay time. CCFs between the apparent viscosity and TS also had the same result (not shown in the figure). These results mean that the correlation between the apparent viscosity and dissolved COD or TS do not make high even if the time delay were considered.

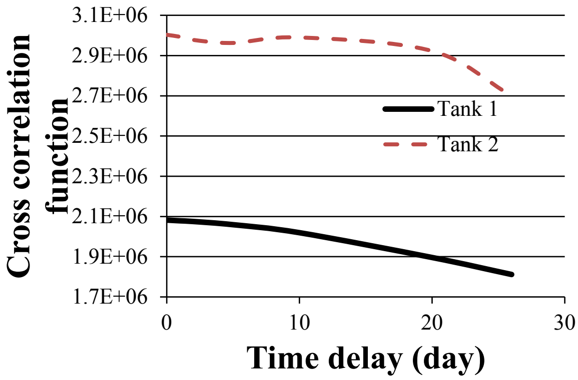

Figure 5 CCFs between the apparent viscosity and dissolved-COD in the digestion tanks

It was considered that the concentration of sludge regarding anaerobic digestion of food waste effect on the viscosity as researchers reported about the sewage sludge. In addition, the correlation of dissolved COD and the apparent viscosity indicated that the dissolved-sticky substances in the digested residue might increase the viscosity of the digested sludge.

CONCLUSION

As a result of analyzing the actual data from a biogas plant treating food wastes, the following facts were obtained.

- The temporal change of the apparent viscosity of the sludge in the anaerobic digestion tank for several months was almost similar to that of TS and dissolved COD.
- Spearman rank correlation coefficient between the apparent viscosity and TS was the highest among the other characteristics, except dissolved COD in the anaerobic digestion tank.
- CCFs between the apparent viscosity and TS or dissolved COD was maximum at the no delay time.

The concentration of sticky substances in the digested residue should be considered to affect the viscosity in the future works.

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BIOPOWER POTENTIAL FROM SUGARCANE BAGASSE COGENERATION IN AFRICA

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ABSTRACT

Africa is reeling under the impact of inadequate access to electricity and other modern energy services to the detriment of socio-economic development. Where electric power is available, there is often a heavy reliance on fossil fuel energy that is imported, too expensive and not environmentally sustainable. Many urban cities experience many days of shutdown time per year due to power outages since installed electric capacity does not meet demand. Africa is endowed with a myriad of renewable energy sources with bagasse being especially important. Sugarcane bagasse is the fibrous residue after sugar cane is crushed and the juice extracted. Bagasse as a by-product of the sugar industries means the logistics and processing structure of this source is already well-established. It is a renewable feedstock and through cogeneration greenhouse gases emissions can be reduced when substituting fossil fuels. The present paper assessed biopower potential from bagasse in African countries using crop statistics and a probability modelling technique with the support of 50,000 Monte Carlo simulations. At a continental level, bagasse could potentially contribute 4,207 – 14,312 GWh of electricity at a 90% confidence interval and a mean of 9,085 GWh/yr. This can substitute roughly 2.1 – 7.2 million Mg/yr of coal and avoid emissions of between 6.0 – 20.6 million Mg/yr of CO_2. The continent can benefit from bagasse energy as it can address climate mitigation and promote sustainable development.

Keywords: Sugarcane bagasse, biopower, Africa, renewable energy, Monte Carlo

INTRODUCTION

Africa still lags behind other regions of the world with regard to electricity access. Electricity is a key element in the socio-economic development of any nation as it addresses three human conditions: poverty, security and diseases (Ingwe, 2014). Low access to electricity still persists in sub-Saharan Africa with at least 590 million people out of a total of almost 1 billion people still living in the dark. Roughly 80% of those deprived of electricity live in rural areas (IEA, 2017; Poloamina and Umoh, 2013). Without access to modern and affordable energy services people are forced to consume a significant amount of time and income on expensive and unhealthy forms of energy. Traditional forms of biomass such as firewood still provide a significant proportion of the total energy needs. As a result of indoor open fire cooking, thick "kitchen smoke" fills most homes. Exposure to particulate matter from this smoke adversely affects health in many ways. Studies have shown that cataract, respiratory and heart diseases are prevalent in those households that use poorly processed biomass compared to those that are not exposed to indoor air pollution (Mishra et al., 1999). Almost 600,000 deaths occur in Africa due to indoor air pollution every year (Owili et al., 2017). Energy plays a pivotal role in enhancing food security. Communities in rural areas can have a better chance to achieve food security when connected to the grid and provided with technologies for irrigation and water pumping to improve agricultural output (Johansson et al., 2012).

Despite the aforementioned problems, Africa is richly endowed with renewable energy resources and could benefit from harnessing them. There is a plethora of opportunities afforded by embracing renewable energy sources such as contributing to economic growth through the creation of jobs to alleviating the effects of climate change and improving access to electricity in rural areas. The economic development of sub-Saharan Africa is strongly tied to the agricultural sector which accounts for up to half of the GDP in some of the nations in the region. Agro-food industries already use energy for the processing of crops into refined products and the logistics and processing structure of crops are already well-established. Thus, agro-food industries have the potential to serve as catalysts for greater power generation by supplying waste biomass for biofuel production (To et al., 2018).

Biofuels are considered a promising alternative source of energy because they are produced from sustainable energy crops or waste biomass and they can play a crucial role in bolstering Africa's energy security; and improve infrastructural development plans within the region (Sekoai and Yoro, 2016). Dedicated energy crops have been largely overlooked in favor of growing food crops whereas waste now presents itself as an attractive renewable resource. Bagasse is the fibrous residue of sugar cane after crushing and extraction of juice. The excess bagasse accumulation and inappropriate treatment causes several problems. The indiscriminate disposal of bagasse leads to air and water pollution. It also leads to the chocking of water bodies and adds to the solid waste going to landfills.

This study set to estimate the quantity of bagasse and electrical energy obtainable therefrom for the African continent. This article uses a probability modelling technique to overcome uncertainty introduced by a lack of reliable data and variability of sugarcane production. Deterministic estimates offer little insight in the electrical output range from bagasse-fired power stations and may erroneously lead to under or over overestimates. For example, the uncertainty and variability bagasse generation would present several challenges including equipment scaling and feedstock supply. On-site processing equipment would need to be accurately scaled to reduce overall production costs. A deterministic approach is only suitable if the nature of the whole system is known.

ESTIMATION METHOD

Bagasse generation was estimated from cane production. Reportedly a sugar mill can produce 0.250 - 0.280 Mg of bagasse per Mg of cane processed and this in turn can be used for the generation of up to 0.500-0.600 Mg of steam per Mg of cane (that is roughly 2Mg steam/ Mg bagasse). One author states that a sugar mill can produce up to 0.320 Mg of bagasse per Mg of cane processed (Birru, 2016). Bagasse production is reported to be 40 % of sugarcane production. The moisture content in bagasse is 50% with 1.0 Mg of bagasse producing 2.0 Mg of steam. 5.0 Mg of steam produces 1.0 MWh electrical power (Isabirye et al., 2013). In this article, an Excel spreadsheet equipped with Palisade's @RISK software was used for the analysis. @RISK usefulness lies in its ability to automatically select the best-fitting model for a set of data and to perform Monte Carlo simulations. Bagasse generation and biopower were estimated using the mathematical model presented in equations 1 and 2. First, historical sugarcane production data (1961 to 2016) reported by the Food and Agriculture Organization of the United Nations were fitted into a probability distribution model for each country using @RISK. The best model was selected based on Akaike's Information Criterion (AIC). Bagasse generation rate and biopower potential was then estimated as sow below:

$$B_{GR_i} = C_{PR_i} \times (1 - m) \times Y \qquad (1)$$

B_{GRi} is the bagasse generation rate for country i in Mg/yr, C_{PRi} is the probability distribution function for annual sugarcane production in Mg/yr for country i and Y is a uniform distribution for the percentage yield of bagasse from sugarcane and m is the uniform distribution for bagasse moisture content

$$P_i = B_{GR_i} \times E \qquad (2$$

Pi electrical energy of bagasse in GWh for county i and E is the uniform distribution function for the electrical energy per Mg of bagasse.

RESULTS AND DISCUSSION

Bagasse generation

Bagasse generation in Africa is estimated to lie in the range of 3.7 – 39.1 million Mg/yr on a dry basis. Roughly 20.9 million Mg/yr are generated on average. At a 90% confidence level about 9.7 – 32.8 million Mg/yr are generated. Figure 1 shows the bagasse generation rate by country, it can be remarked that the relatively higher-income countries generate higher amounts of bagasse with the exception of Nigeria. The major sugar cane producers of sub-Saharan Africa are South Africa, Mozambique and Cameroon. South Africa is the leading generator of bagasse at 2.8-7.7 million Mg/yr at a 90% confidence level. South Africa is followed by Sudan, Kenya and Eswatini (Swaziland) in terms of sugarcane production in sub-Saharan Africa. Nigeria with the highest GDP in Africa in addition to having the largest population generates significantly less sugarcane bagasse compared to other countries. South Africa has the second largest economy in Africa, after Nigeria, and is the biggest generator of bagasse. Egypt is the third largest economy follows South Africa in bagasse generation lying between 1.3 – 5.6 million Mg/yr.

Biopower potential

Bagasse generated in Africa can potentially provide a total of about 4,207 – 14,312 GWh of electricity at a 90% confidence interval and a mean of 9,085 GWh/yr.

This can substitute roughly 2.1 – 7.2 million Mg/yr of coal and avoid emissions of between 6.0 – 20.6 million Mg/yr of CO_2. Total electric energy consumption for Africa in

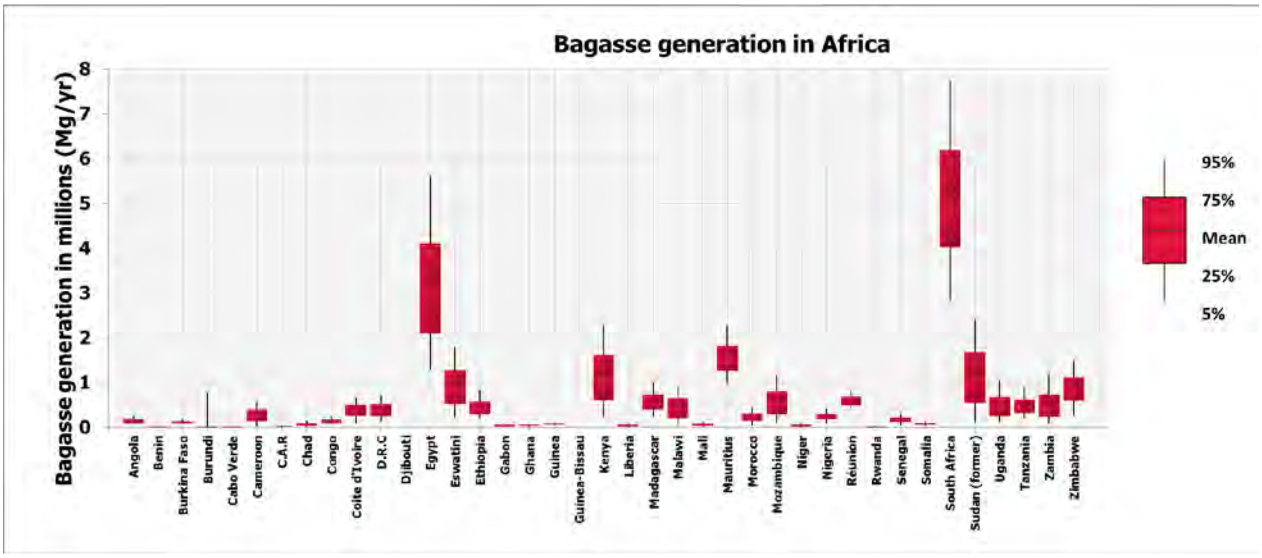

Figure 1 Bagasse generation (dry basis) in Africa

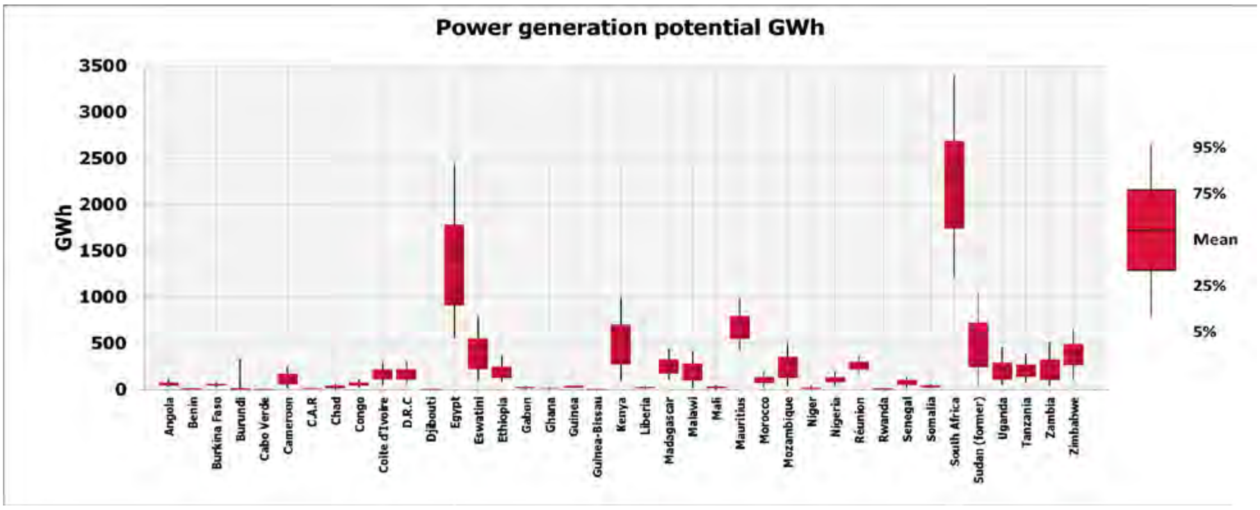

Figure 2 Potential bagasse derived power in Africa

2017 was 675 TWh. Bagasse can contribute about 0.6-2.1% at a 90% confidence level (1.4% on average) of the current electrical energy consumption. Figure 2 shows the biopower potential for African countries. South Africa can benefit from approximately 1,220-3,383 GWh from bagasse. South Africa consumed 209 TWh in 2017, bagasse can potentially supply 0.6 - 1.6% of current consumption levels. Bagasse can play an important role in the supply of electricity in order to meet the growing demand of energy without incurring environmental costs.

CONCLUSIONS

Biopower from bagasse from estimates given in this study suggest there is great potential in this waste biomass. The stochastic model presented here indicates that there are exploitable quantities of bagasse produced particularly in South Africa and Egypt. A 90% confidence interval estimate of the bagasse generation rate in Africa is 9.7 – 32.8 million Mg/yr Mg/yr. From this, 4,207 – 14,312 GWh of electricity at a 90% confidence interval and a mean of 9,085 GWh/yr can be expected. Based on the estimations reported here, we propose that the following:

1) Economic evaluations of potential technologies that can be applied to harness this power must be conducted to assess the financial viability.
2) Research must focus on versatile technologies that can handle different kinds of biomass feedstocks. The variability in bagasse availability can be reduced by introducing other types of feedstock such crop residues or municipal waste.

ACKNOWLEDGMENT

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DEVELOPMENT OF PRETREATMENT FOR BIO-ETHANOL PRODUCTION USING FALLEN LEAVES

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ABSTRACT

The study is to produce bio-ethanol by using fallen leaves, which is biomass, as a fermentation substrate in consideration of situation in Korea. In order to enhance the production efficiency of bioethanol, the study compared the saccharification efficiency of pretreatment method. And Tween-80, nonionic surfactant, was tested to enhance saccharification efficiency by coping with hydrophobicity resulted from torrefaction. In result confirmed the glucose production by the various enzyme, we most obtained fermentable glucose production from cellulase by characteristic of lignocellulosic biomass, also got the glucose high in result of mixed enzymes. And then, saccharification of torrefied biomass conducted by applying best condition obtained by the above result. As a result of this experiment, we could know that conversion of sugar by torrefied biomass was 10% higher than result of chemical pretreatment. And enzyme ratio of 7:3 (cellulase : hemicellulose) had high glucose production. As a result of adding surfactant, sugar conversion was higher when the biomass was saccharified addition of tween-80. It was found torrefaction can be applied as a pretreatment for lignocellulosic biomass and tween-80 is needed to enhance its enzyme saccharification. If the pretreatment method is appropriately applied, it is expected to solve the problem of recycling and progressing about fallen leaves seasonally.

Keywords: Bio-ethanol, Pretreatment, Fallen leaves, Torrefaction, Surfactant

INSTRUCTION

Recently, an interest about renewable resource ha s been increasing to solve the depletion of the foss il fuel and the limitation of the fossil energy in th e world. Bio-ethanol from biomass has been known as an alternative fuel for gasoline.

Bio-ethanol is produced from sugar-based and starch-based crops like a sugar cane, corn, sugar beer, wheat. If we use these food crops continuously, we will encounter food shortage problem. It is not appropriate to use food resources as an energy source. In order to meet the increasing demand for bioethanol as transportation fuel in the future, it is necessary to generate ethanol using non-food biomass, which may be a stable source of bio-energy fuel. Instead of 1st generation bio-material, 2nd generation bioethanol is an excellent alternative for stable supply [1].

For the production of bio-ethanol from lignocellulosic biomass, the saccharification process through hydrolysis is essential. Pretreatment of the biomass have a great effect on saccharification of biomass and ethanol fermentation process. The major components of lignocellulosic matertials include cellulose, hemi-cellulose and lignin. The celluloses and hemicelluloses are tightly tangled together while the lignin firmly wraps them as a protection wall, which makes the structure of lignocellulosic materials very tough to biodegrade.

Table 1 Composition of biomass

Component(%)	**Biomass**
C	49.195
H	5.235
S	0.202
N	0.825
Moisture	6.7015
Combustible	85.9615
Ash	7.337
Carbohydrate	76.04
Crude protein	6.64

Because of the unique compact structure of lignocellulosic materials, a pretreatment is need for bio-ethanol production.

Feedstock pretreatment has been recognized as a necessary for upstream process to remove biomass recalcitrance for downstream microbial and enzymatic processing during ethanol production. A representative pretreatment includes both physical and chemical steps. Physical pretreatment refers to the reduction of physical size of biomass feedstock to increase enzyme-accessible surface areas. Chemical pretreatment refers to the process of using chemicals to remove or modify key chemical components that interfere with biomass cellulose saccharification, mainly hemicelluloses and lignin. Feedstock pretreatment reported in the literature have almost exclusively focused on chemical pretreatments. [1,2,3,4]

In this study, we applied chemical treatment and torrefaction as pretreatment. During the process of torrefaction, the lignocellulosic biomass is broken down into cellulose and lignin in between 250~300℃. In this experiment, fallen leaves are used as a feedstock and saccharified after pretreated by torrefaction. Tween-80, nonionic surfactant, was added to enhance saccharification efficiency to cope with hydrophobicity obtained after torrefaction.[5,6]

MATERIALS AND METHODS

Biomass, fallen leaves were collected at random and dried to be crushed into powder.

The pretreatment process was chemically treated with sodium hydroxide by soaking, biomass torrefied 250-300℃ in the absence of oxygen.

The hydrolytic enzymes were Cellulase (Celluclast 1.5L, Novozymes Korea), Hemicellulase (Viscozyme L, Novozymes Korea). The enzyme hydrolysis was adjusted to pH 5.5 at 50℃ with 0.1 N potassium phosphate buffer in a shaking tank stirred at 200 rpm. Glucose concentration was 2% (v / v) per 50 ml of total liquid and solid. Samples were taken at intervals of 1 hour for 72 hours of reaction and glucose concentration was analyzed using HPLC (Younglin, KOREA). Tween-80 was added at concentrations of 1, 2, 5, and 10%.

RESULT AND DISCUSSION

Basic characteristics of leaves

Table 1 summarizes the compositions of raw bio mass, fallen leaves. The raw biomass consist of ap proximately 50% carbon and 5.2% hydrogen. 86% of the biomass is combustible. Carbohydrate and cr ude protein are 76%, 6.6%, respectively. If a prope r pretreatment process is applied, we can expect to get glucose conversion from the biomass.

Torrefaction as a pretreatment

Torrefaction is applied as a pretreatment to break down the biomass to be accessible by hydrolysis enzyme in this study. Through torrefaction, biomass can be destroyed into small molecules which can be easily attacked by hydrolysis enzyme. The glucose yield from enzymatic hydrolysis of biomass treated by torrefaction was compared with that obtained from alkaline pretreatment. In Figure 1, the glucose yield obtained from biomass pretreated with alkali is about two times higher than control, raw biomass without pretreatment. The conversion of cellulose obtained from saccharification of biomass pretreated by torrefaction at temperature of 250~300℃were compared each other. The conversion of cellulose are higher than 37%. From the result, the torrefaction is an effective pretreatment for enhancing enzymatic saccharification.[8]

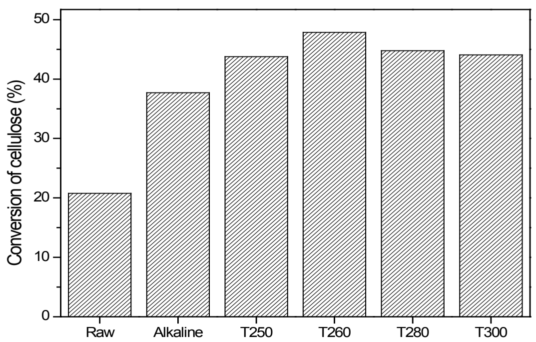

Figure 1 Comparison of alkaline and torrefaction as a pretreatment

Effect of enzyme ratio of cellulase to hemi-cellulase on glucose yield

The lignocellulosic biomass consisted of cellulose and hemi-cellulose. The enzyme ratio of cellulase to hemi-cellulase is an important factor determining the glucose yield from lignocellulosic biomass because they are tightly tangled together. The enzyme ratio was varied from 1/9 to 9 and conversion efficiency was compared each other. The enzyme ratio was tried to be optimized for saccharification and the result is shown in Figure 2.

During the experiment, as the amount of cellulase addition increased, cellulose conversion increased. When the enzyme ratio was 1/9, the conversion rate was about 50%. And as the enzyme ratio increased, the cellulose conversion increased to 90%. When the enzyme ratio was between 7/3 and 9/1, the cellulose conversion was not increased further.

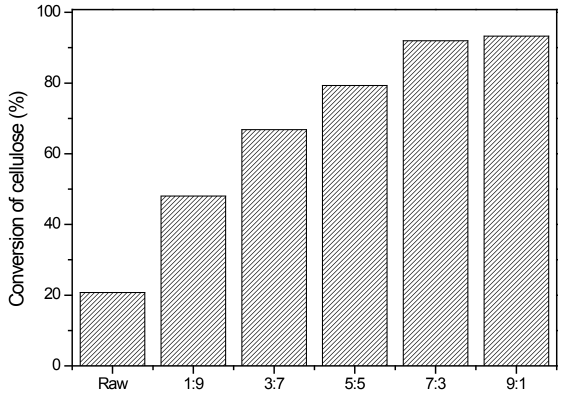

Figure 2 Enzymatic ratio(cellulase : hemi-cellulase) for hydrolysis of torrefied biomass

Glucose yield from torrefied biomass

Torrefied biomass was hydrolyzed with the enzyme mixture of cellulase and hemi-cellulase. After 1 hour of enzyme hydrolysis, the reaction rate was high and the glucose yield was 600 mg glucose/ g biomass. The reaction rate became slow thereafter. The time course of hydrolysis of torrefied biomas is shown in Fig 3. After 48 hours of reaction, the glucose yield increased to 1200 mg glucose / g biomass.

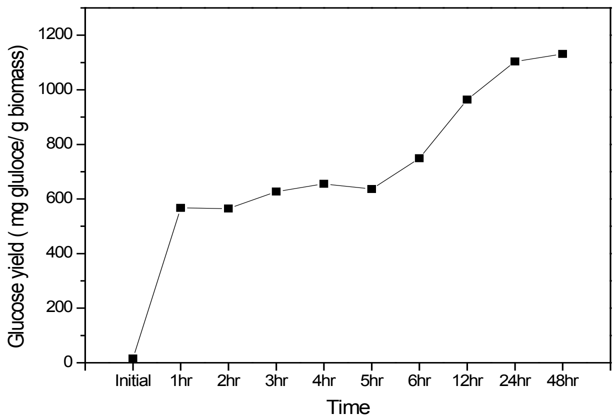

Figure 3 Glucose yield by Time course of hydrolysis of torrefied biomass

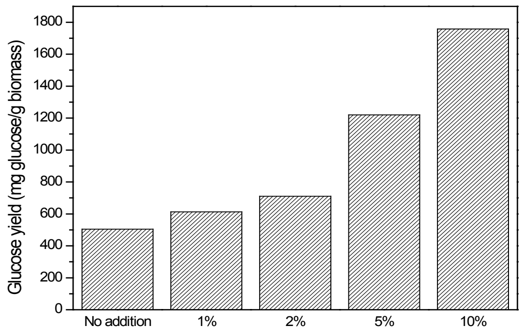

Figure 4 Glucose yield by hydrolysis with Addition of Tween-80

<u>Effect of nonionic surfactant addition on glucose yield</u>

Enhancement of cellulose hydrolysis by adding surfactants to biomass has been reported by several authors. They showed that the higher the crystallinity of the substrate, the more positive was the effect of the added surfactant. Increased hydrolysis by addition of surfactants has also been reported for delignified steam-exploded wood, bagasse, and corn stover. It has been proven that the most effective surfactants are non-ionic and that the surfactant effect is higher at low cellulase concentration. It is believed that surfactants adsorb to the cellulose during hydrolysis. In this study, non-ionic surfactant was added to the torrefied biomass to increase enzymatic hydrolysis. During torrefaction of biomass as a pretreatment, its nature was changed from hydrophilic to hydrophobic by vanishing moisture. Tween 80, nonionic surfactant, was selected for this experiment. As Tween 80 loading increases from 1% to 10%, the glucose yield increased up to 1800 mg glucose/g biomass.[7]

CONCLUSIONS

From this study, it can be concluded that torrefaction is an effective pretreatment compared to other physico-chemical pretreatment like alkaline. When enzymatic hydrolysis is conducted for torrefied biomass, the optimum enzyme ratio of cellulase to hemi-cellulase is 9: 1. Addition of non-ionic surfactant, Tween80, enhances the cellulose conversion when the torrefied fallen leaves. With addition of Tween 80 at 10%, amount of glucose is higher than that without addition of surfactant. Base on this, we expect that high effect will present for saccharification with increasing surfactant, if adjust amount of biomass and surfactant well.

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MODIFICATION OF COAL FLY ASH ON BIODEGRADABLE POROUS COMPOSITES SYNTHESIS

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ABSTRACT

Coal fly ash (FA) is one of the major by-products from coal-fired power generation. Global FA generation is estimated to be 800 million Mg/yr. Huge amounts of FA were disposed at open-air dumping site or landfilling without appropriate utilization. The storage and handling of FA are ongoing challenges in the context of environment impact. New applications of FA are significantly required. Research on recycle and reuse FA as eco-friendly products and engineering composites have been considered since the past decade. Functional polymers are promising candidates in fabrication of high performance composites as they are able to maximize the interaction between filler and polymer matrix. In this study, biodegradable polymer polyvinyl alcohol (PVA) was used as matrix; cellulose was used as the crosslinking holder to form supporting structures of fly ash based porous composites. Scanning Electron Microscope (SEM) observed the morphology of the composites, and the micrograph showed interconnection of the polymer FA composites, which varied with different temperatures in fabrication process. The objective of this study is to develop high strength biodegradable porous FA composites, which will be a potential candidate of FA applications in the industrial fields.

Keywords: coal fly ash, polymer, compression strength, porous composites

INTRODUCTION

Fly ash (FA) is one of the by-products from the coal combustion process of coal-fired power plants. Global FA generation is estimated to be 800 million Mg/yr [1]. Currently, worldwide utilization is only around 50% of total FA produced, though it is vary from country to country. For example, more than 100 million Mg of FA is produced every year in India and only around 38% of FA is utilized. In China, the total annual FA generation is about 500 million Mg and only 60% of FA is utilized **[2-4]**. According to the huge FA generation as described above, FA recycle is still a big social challenge. In worldwide, huge amounts of FA are disposed and accumulated in landfill sites or dumps. It causes severe social and environmental problems due to its occupation of large area for disposal and adverse environmental impacts **[5-7]**. Therefore, new applications of FA are significantly required. Researches on recycling and reusing FA as eco-friendly products and engineering composites have been conducted since the past decades. Functional polymers are promising candidates in fabrication of high performance composites as they are able to maximize the interaction between filler and polymer matrix **[8]**. In this study, polymer polyvinyl alcohol (PVA) was used as matrix; cellulose was used as the crosslinking holder to form supporting structures of fly ash based porous composites. The objective of this study is to develop the properties of FA composites with high FA concentration, such as the compression strength and porosity, which can be a potential candidate of FA applications in the industrial fields.

MATERIALS AND METHODS

Coal fly ash, polyvinyl alcohol, and cellulose

Fly ash particles are generally spherical, powdery and glassy, either solid or hollow. The particle size ranges from 0.5 µm to 300 µm. The specific gravity of fly ash usually ranges from 2.1 to 3.0, and the specific surface area varies from 170 to 1000 m2/kg **[9]**. FA utilized in this study was taken from one coal-fired power plant in Japan. Elemental content of tested FA, analyzed by Energy Dispersive X-Ray Fluorescence spectrometer (EDXRF), is showed in **Table 1**.

Polyvinyl alcohol (PVA) (Mw: 25,000 Da, completely hydrolyzed), cellulose powder (through 38 µm, 400 mesh) are from Wako Pure Chemical Industries, Ltd, Japan.

Preparation of composites materials

The composition of polymer-FA composites in this study is showed in **Table 2**. Quantified amount of FA, cellulose and PVA were mixed in the beaker, and distilled water was added into the mixture (Liquid/Solid (ml/g) =1). The suspension was heated and under vigorous stirring for around 30-40mins when the suspension became into gluey form. The resulting gluey mixtures were poured into the mold, kept at 40°C, 80 °C and 105 °C, respectively in the incubator until dried.

Table 2. The composition of FA composites

The composition of FA composites			
Samples	FA (%)	PVA (%)	Cellulose (%)
1	90	10	0
2	90	5	5
3	80	20	0
4	80	10	10
5	70	30	0
6	70	15	15

Infrared spectroscopy (FTIR) analysis and scanning electron microscope (SEM) observation

The microstructures of the materials and specimens are investigated via SEM observation. The results of the microscopic investigations showed the changes in macro behavior of PVA matrix in FA composites, which compared to different temperatures in fabrication process. FTIR was used to analyze the chemical functional groups in the composites. FTIR spectrum and morphological SEM image of fly ash in unmodified

Table 1. Element content of tested FA

Element	Si	Al	Fe	Ca	K	Mg	S	P	Zn
Content (wt %)	46.9	19.6	15.2	5.85	3.17	1.21	0.504	0.41	0.118
Element	Co	Ni	Cr	Cu	Sn	Ba	Ti	Zr	
Content (wt %)	0.119	0.1	0.093	0.081	0.06	1.44	3.66	0.398	

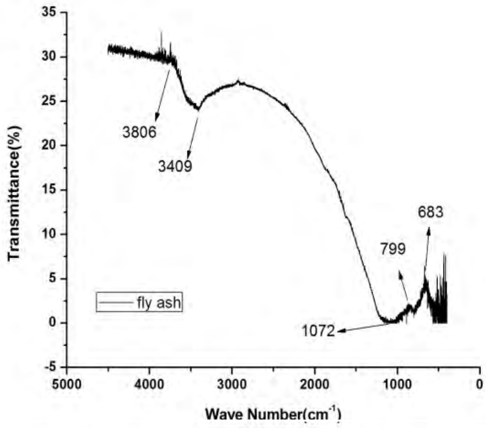


Figure 1. FTIR spectra of unmodified fly ash

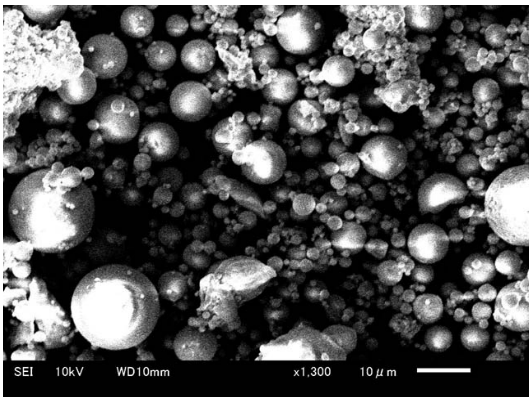
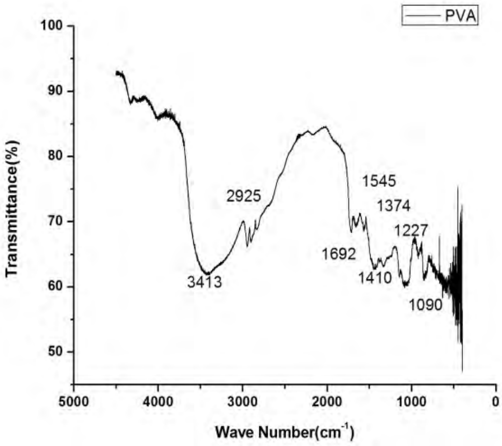


Figure 2. Morphological SEM image of fly ash in unmodified form

form is displayed in **Figure 1-2**. The selected band positions of unmodified FA are summarized in **Table 3**. FTIR spectrums of PVA and cellulose are displayed in **Figure 3-4**.

Table 3. The selected FTIR absorption peaks of unmodified FA

Unmodified FA	Peak position of structural groups in (cm^{-1})			
	Si-O/Al-O	Al-O	Al-O	-OH
	1072	799	683	3409



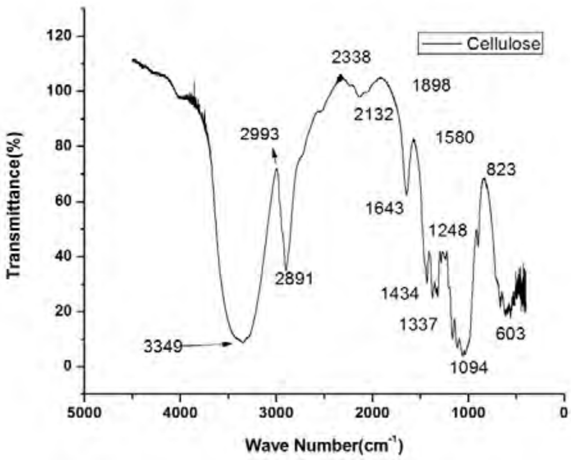


Figure 4. FTIR spectra of Cellulose

__Unconfined compression test__

The sample is placed in an apparatus while the side stress is not applied, and the axial stress increase until failure occurs.

Experiment Procedure

1. The sample will be placed horizontally between bottom plate and a disc shape metal probe (10cm of diameter).

2. The force and displacement data will be recorded using data logger attached to compression tester.

3. The experiment will be carried out at a certain compression rate and stopped after specimen failure.

4. The stress applied to the ends of the sample is computed as follows: $\sigma 1 = F/A$

RESULTS AND DISCUSSION

__Morphology of FA composites observed by SEM__

The representative SEM images of cellulose-PVA modified FA composites dried at 40°C, 80 °C and 105 °C are displayed in **Figure 5**. According to the SEM observation, three-dimensional structure of hexagon, which is a structure in stable state as crystalline with lower energy, was found in the specimen. Cellulose combined FA-aggregates are formed, in which PVA chains facilitated the intimated contact. In the aggregate, cellulose was served as anchor, and PVA was served as adhesive, thus this structure could be reinforced with FA particles stick to the cellulose. In general, most of the unmodified FA particles look like scattered spherical, or some are non-spherical shape (**Figure 2**). In comparison, the polymer modified FA becomes multiple stacked layers with mostly irregular shape, such as the FA particles were dried at 40 °C during the fabrication process. The PVA may coat on the surface of FA particles and give contribution to the superior light reflecting quality of the particles in the SEM. The thin layers may reduce the attraction forces of particle-particle and help to disperse in matrix media. At 80 °C, the entire micrograph shows efficient packing of FA particles by PVA in the composites with a few interstitial voids. In general, at low temperature during the fabrication process, FA particles were finely dispersed and thoroughly encompassed by PVA coating. However, at higher temperature condition (such as at 105°), PVA coating was over extended and FA particles were randomly and largely dispersed in the matrix, thus the inter-connectivity of the composites was reduced, and possibility of crack extension was increased.

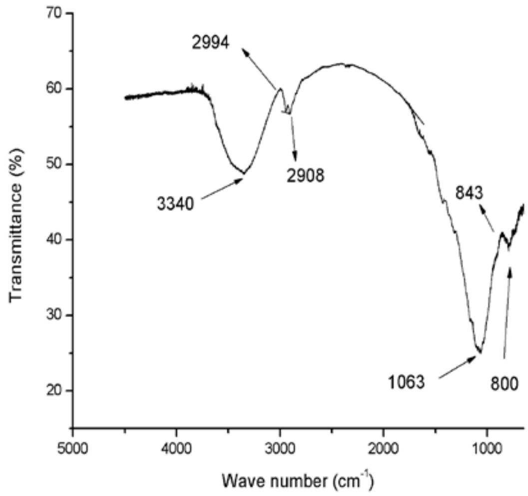


Figure 6. FTIR spectra of PVA-FA composite

Characterization of PVA-cellulose-FA composite investigated by FTIR

The structure configurations of PVA modified FA composites were investigated by FTIR spectroscopy

Table 3. The selected FTIR absorption peaks in PVA, cellulose

Peak position of structural groups in (cm^{-1})							
	OH str	C-H str	C=O str	O-H bend	C-H bend	C-O-C str	C-OH str
PVA	3413	2925/2875	1692	1410	1374	1227	1090
Cellulose	3349	2993/2891	1643	1434	1337	1248	1094

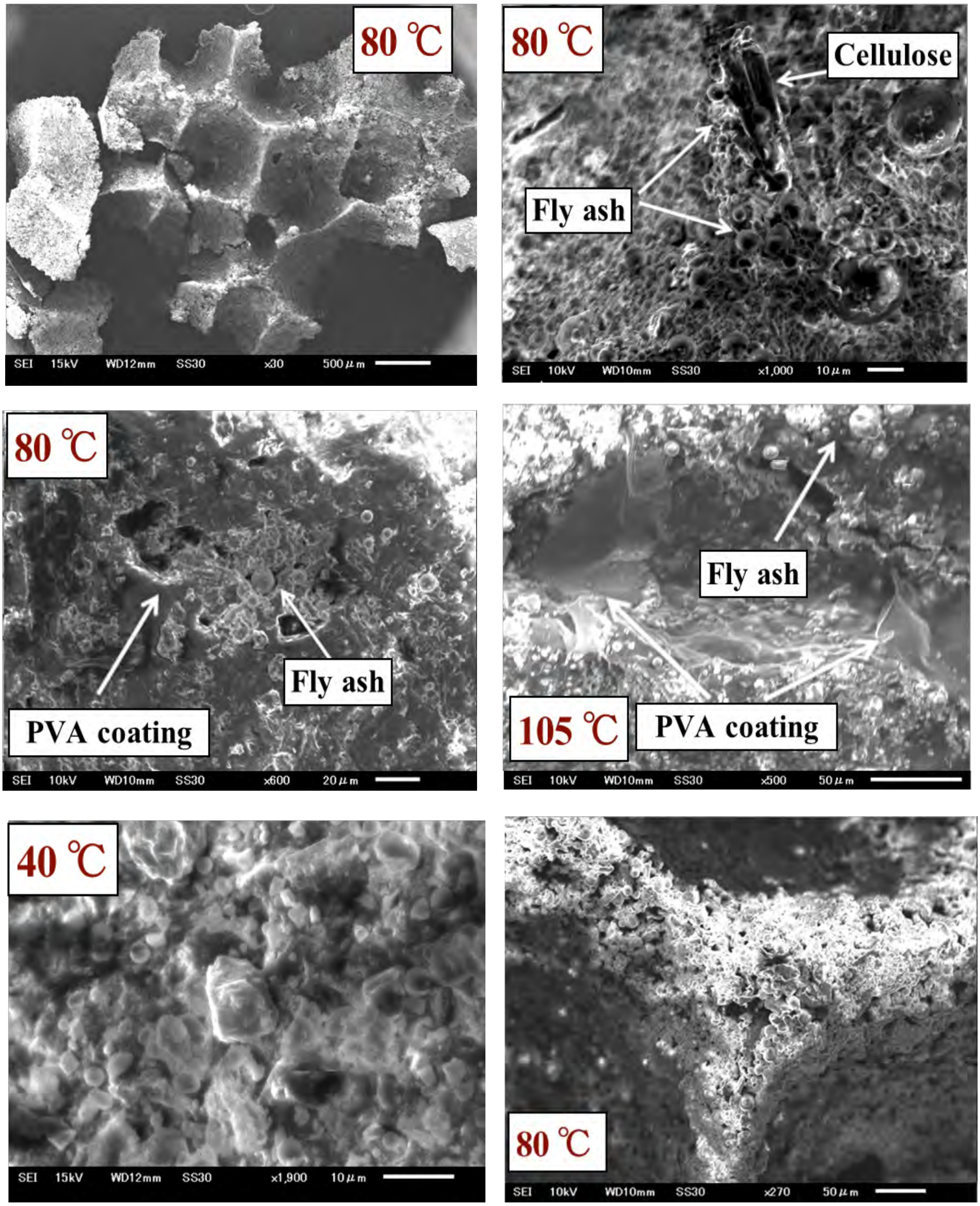


Figure 5. SEM image morphology of cellulose-PVA modified FA composites dried at 40°C , 80 °C and 105 °C

and the spectra were displayed in **Figure 6**. The selected peaks are assigned with reference **[10-14]**, and displayed in **Table 4.**

The stretching vibrations of Si-O-Al bonds mainly appeared in the ranges of 1200-600 cm-1. These dominant bands are centered at 1063, 843, and 800 cm-1 for the vibrations of Si-O and Al-O bonds in modified FA composites.

Hydrogen bonding between the Al-O/Si-O with long chain chemical functional groups may exist in the PVA-cellulose-modified FA, such as the plausible bonding of PVA and fly ash showed in **Figure 7 [10]**.

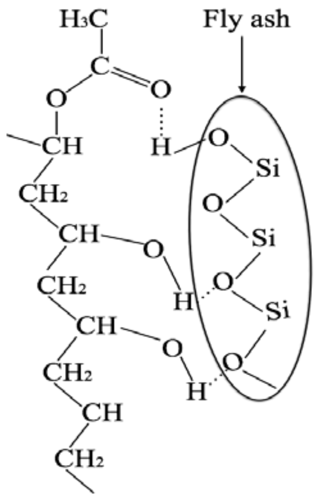


Figure 7. A plausible diagram of hydrogen bonding between PVA and FA

In fly ash particles and polymer modified FA composites, broad absorption bands are centered at 3400-3360 cm-1, which reflect the combination of –OH groups in PVA, cellulose or absorbed water. The well-known set of absorption bands at around 3340 cm-1 of –OH stretching, 2994/2908 cm-1 of C-H stretching, which are all appeared in the PVA, cellulose and polymer modified-FA composites, which indicate the existence of possible inter-molecular or intra-molecular hydrogen bonding between FA and polymer chains **[12]**. All the possible chemical reactions allowed forming new chemical bridges on the surface of FA particles, which may affect the mechanical properties of the polymer modified-fly ash composites.

The effect of cellulose-PVA modification of FA on mechanical properties

The effect of modification of FA in terms of the mechanical behavior was investigated. The results were compared to the PVA-FA composites with/without cellulose modification, dried at different temperature, which are summarized in **Table 4.** In general, The PVA-FA composites modified with cellulose showed higher unconfined compression strengths than those without cellulose modification **(Figure 9)**, which indicate cellulose may improve the inside structure of the PVA-FA composites to increase the compression strength. Drying temperature during fabrication process is significant impact factor to the mechanical properties

Table 4. Unconfined compression strength of polymer-modified FA dried at different temperature

The composition of FA composites				Compression strength (Mpa)	Drying temperature (℃)
Samples	FA (%)	PVA (%)	Cellulose (%)		
1	90	10	0	0.986	40
2	90	5	5	3.68	40
3	80	20	0	6.54	40
4	80	10	10	7.38	40
6	70	15	15	13.64	40
7	80	0	20	1.07	80
8	70	15	15	2.23	80

of FA composites. The compression strength of the FA composites dried at 40 °C is much higher than those FA composites dried at 80 °C. In the case of FA composites (70% FA, 15% PVA, 15% cellulose) dried at 40 °C, the compression strength is 13.64 MPa, while the compression strength of FA composites (70% FA, 15% PVA, 15% cellulose) dried at 80 °C, is 2.23MPa. In addition, the compression strength decreased as the percentage of FA in the composites increased (**Figure 8**).

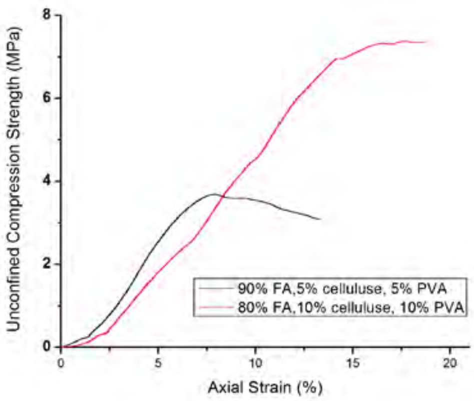


Figure 8. Unconfined compression strength of FA composites with different FA mixing ratios

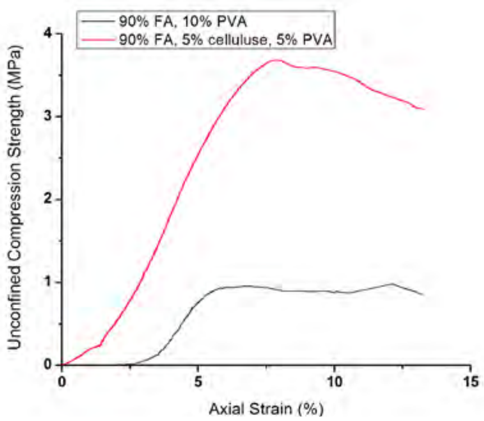


Figure 9. Unconfined compression strength of FA composites with/without cellulose modification

CONCLUSIONS

The temperature of fabrication process can affect the porosity of FA composites. The higher temperature results in active chemical reaction or effective water evaporation, which may increase the interstitial voids. The interstitial voids may also come from the chemical reaction of –CHO and –OH in the formation of acetal ring and other linkages. Restrict the mobility of the segmental chains of PVA can results in the lower elongation. Cellulose may strengthen structure inside the PVA-FA composites by increasing the inter-connectivity. By this mechanism the tensile strength of FA composites could also be increased. With proper cellulose and PVA proportion and suitable temperature in the fabrication process, a low-cost biodegradable porous FA composite could be synthesized.

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COPPER SLAG AS A CATALYST FOR MERCURY OXIDATION IN COAL COMBUSTION FLUE GAS

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ABSTRACT

Copper slag is a byproduct of the pyrometallurgical smelting of copper concentrate. It was used in this study to catalyze elemental mercury (Hg^0) oxidation in simulated coal combustion flue gas. The copper slag exhibited excellent catalytic performance in Hg^0 oxidation at temperatures between 200°C and 300°C. At the most optimal temperature of 250°C, a Hg^0 oxidation efficiency of 93.8% was achieved under simulated coal combustion flue gas with both a high Hg^0 concentration and a high gas hourly space velocity of 128,000 h^{-1}. Hydrogen chloride (HCl) was the flue gas component responsible for Hg^0 oxidation over the copper slag. The transition metal oxides, including iron oxides and copper oxide in the copper slag, exhibited significant catalytic activities in the surface-mediated oxidation of Hg^0 in the presence of HCl. It is proposed that the Hg^0 oxidation over the copper slag followed the Langmuir-Hinshelwood mechanism whereby reactive chlorine species that originated from HCl reacted with the physically adsorbed Hg^0 to form oxidized mercury. This study demonstrated the possibility of reusing copper slag as a catalyst for Hg^0 oxidation and revealed the mechanisms involved in the process and the key factors in the performance. This knowledge has fundamental importance in simultaneously reducing industrial waste and controlling mercury emissions from coal-fired power plants.

Keywords: *Copper slag, Catalyst, Mercury oxidation, Coal combustion, Flue gas*

INTRODUCTION

Copper slag is an oxide-rich byproduct of the pyrometallurgical smelting of copper concentrate (Huanosta-Gutiérrez et al., 2012). Approximately 2.2 to 3.0 tons of copper slag are generated during the production of a ton of copper metal (Ambily et al., 2015). Due to the increasing global demand for copper, more and more copper slag is being produced every year and many landfill sites are needed for its disposal. More importantly, copper slag contains heavy metals that are environmental hazards (Alter, 2005). To avoid these environmental challenges related to the disposal of copper slag, researchers are increasingly interested in alternative uses for copper slag, including its use as a raw material for other processes such as cement and concrete production (Ahmaruzzaman, 2010). Like copper slag, another waste product, coal combustion fly ash, has recently been diverted from landfills and reused as a raw material in concrete (Ding et al., 2012).Because even a negligible increase in carbon content would substantially lower the concrete's performance, fly ash with a low carbon content is more desirable, and the introduction of extra carbon into fly ash is unwelcome. For example, coal-fired power plants are generally unwilling to adopt the activated carbon injection (ACI) method to capture mercury (Hg), even though this method achieves the maximum achievable mercury control technology (Pavlish et al., 2003), because ACI increases the carbon content of fly ash and limits its usability and marketability. As stated above, both copper slag and coal combustion fly ash can be used as raw materials for concrete, so the introduction of copper slag into coal combustion fly ash does not inhibit its reuse as a raw material in concrete. In fact, Copper slag can produce fine aggregates and thus contribute to high-performance concrete with excellent strength and durability properties (Al-Jabri et al., 2009).

Of the three different mercury species in coal combustion flue gas-elemental mercury (Hg^0), oxidized mercury (Hg^{2+}), and particulate-bound mercury (Hg^p)- Hg^0 is the dominant mercury species emitted into the atmosphere (Galbreath et al., 2005). In contrast, Hg^{2+}, which is less volatile and more soluble, can be easily adsorbed on a particulate surface to form Hg^p and/or absorbed by wet flue gas desulfurization solutions (Li et al., 2012 and Liu et al., 2014). Copper oxide (CuO) always exists in copper slag, and a small amount of CuO can lead to an enormous increase in oxidation of Hg^0 to Hg^{2+} in the presence of hydrogen chloride (HCl) (Ghorishi et al., 2005; Schwaemmle et al., 2012 and Yamaguchi et al., 2008). The positive effect of CuO on Hg^0 oxidation probably occurs because CuO can accelerate the transformation of HCl to chlorine (Cl_2) via the Deacon mechanism (Over et al., 2013), which greatly enhances Hg^0 oxidation. Like CuO, ferric oxide (Fe_2O_3) and magnetite (Fe_3O_4) in copper slag are also able to facilitate Hg^0 oxidation (Presto et al., 2006 and Dunham et al., 2003), as shown by the oxidation rate of more than 90% Hg^0 achieved over model fly ash containing Fe_2O_3 and Fe_3O_4. In comparison, only 10% conversion of Hg^0 to Hg^{2+} was observed when Fe_2O_3 and Fe_3O_4 were removed from model fly ash (Ghorishi et al., 2005). Although most of the iron in copper slag exists in the form of fayalite (Fe_2SiO_4), the weight percentage of iron in copper slag is generally greater than 40% (Alter et al., 2005). Several other transition metal elements exist in copper slag in the form of oxides such as manganese dioxide (MnO_2), chromium trioxide (CrO_3), and molybdenum trioxide (MoO_3) (Gorai et al., 2003). Studies have demonstrated that all of these metal oxides are efficient catalysts for Hg^0 oxidation (Granite et al., 2000; Li et al., 2010; Kamata et al., 2009 and Ji et al., 2008). Accordingly, it is very reasonable to hypothesize that the transformation of Hg^0 to Hg^{2+} could be catalyzed by copper slag and that the injection of copper slag could not only achieve mercury control, it could also reduce the amount of copper slag waste in landfill.

In this study, copper slag was used to catalyze Hg^0 oxidation in coal combustion flue gas for the first time. The mechanisms involved in Hg^0 oxidation over copper slag were systematically investigated. The goal was to evaluate the technical feasibility of using copper slag as a catalyst for Hg^0 oxidation that can be injected upstream of the particulate matter control devices (PMCDs). The improved understanding of the role of different copper slag constituents on Hg^0 oxidation would maximize Hg^0

oxidation and help coal-fired power plants reduce their overall mercury emissions.

EXPERIMENTAL SECTION

Material and characterizations

Copper slag samples were provided by a metallurgical copper company located in Henan Province, China. Before the Hg^0 oxidation experiment, the copper slag samples were dried, ground, and sieved through 100 meshes. Brunauer-Emmett-Teller (BET) surface area analysis by N_2 adsorption was conducted using a micropore analyzer (Micromeritics ASAP 2020). The chemical compositions of the copper slag samples were examined using an inductively coupled plasma-optical emission spectrometer (ICP-OES). The crystalline phase composition of the copper slag samples was analyzed using an X-ray diffractometer (XRD; SIMENS D500Bruker); XRD analysis was performed at 40 kV and 40 mA using Cu Kα radiation (λ = 0.15406 nm) in the range of 10° to 80° (2θ) with a step size of 0.02°/s. The recorded XRD patterns were compared with the powder diffraction files (PDF) database for identification of crystal phases.

Catalytic activity measurement

To evaluate the catalytic performances of the copper slag on Hg^0 oxidation, a bench-scale experimental system was built with a design similar to that used in our previous study (Li et al., 2013). The simulated flue gas flow rate was kept at 1 $L \cdot min^{-1}$ for each test. A constant feed (75 $\mu g \cdot m^{-3}$) of Hg^0 was acquired from a Dynacal Hg^0 permeation device (VICI Metronics) using pure N_2 as a carrier gas. During each test, 0.30 g copper slag was loaded onto a support layer placed in the center of the reactor. The corresponding gas hourly space velocity (GHSV) was estimated to be 128,000 h^{-1}. The Hg^0 concentrations at both the inlet and outlet of the reactor were online-monitored with a mercury analyzer (Mercury Instruments Inc. VM3000).

Seven sets of experiments were conducted in this study. In Set I, catalytic Hg^0 oxidation activities over copper slag were evaluated under simulated coal combustion flue gas (SFG: 5% O_2, 8% H_2O, 300 ppm NO, 400 ppm SO_2, 20 ppm HCl, and 75 $\mu g \cdot m^{-3}$ Hg^0 balanced in N_2) at reaction temperatures from 100°C to 350°C. The Set II and III focused on the effects of HCl on Hg^0 oxidation over copper slag. To identify the effects of active components of copper slag on Hg^0 oxidation, pure oxides such as silica (SiO_2), ferric oxide (Fe_2O_3), and copper oxide (CuO), and four simulated copper slags (SCS: physical mixture of reagent grade oxides balanced in SiO_2) were used for the Hg^0 oxidation experiments conducted in Sets IV and V. The compositions of the four tested simulated copper slags are shown in Table 1. A copper slag sample pretreated by HCl plus O_2 and a Hg^0-loaded copper slag sample were studied in Sets VI and VII, respectively, to examine a possible mercury oxidation mechanism.

Table 1 Compositions of the four SCS

SCS	Composition (wt.%), balanced in SiO_2					
	MgO	ZnO	Al_2O_3	CaO	Fe_2O_3	CuO
SCS1	1.58	3.12	3.70	6.81	-	-
SCS2	1.58	3.12	3.70	6.81	46.72	-
SCS3	1.58	3.12	3.70	6.81	-	0.69
SCS4	1.58	3.12	3.70	6.81	46.72	0.69

At the beginning of each test, the gas stream bypassed the reactor and the inlet gas was monitored until the desired inlet Hg^0 concentration ($[Hg^0]_{inlet}$) was stabilized for at least 30 min. The outlet Hg^0 concentration ($[Hg^0]_{outlet}$) was recorded after the catalytic process had reached equilibrium, which was defined as the point at which the fluctuations in Hg^0 concentration were less than 5% for more than 30 min. The Hg^0 oxidation efficiency (E_{oxi}) in this study was calculated by equation (1):

$$E\text{oxi} = ([Hg^0]_{inlet} - [Hg^0]_{outlet})/[Hg^0]_{inlet} \times 100\% . \quad (1)$$

RESULTS AND DISCUSSION

Characterization of copper slag

The results of the ICP-OES analysis shown that the primary chemical components of the copper slag samples used in this study were similar to those of other copper slags and coal combustion fly ash (Shi et al., 2008), including SiO_2, Al_2O_3, CaO, and Fe_2O_3, implying that the addition of copper slag to coal combustion fly ashes would not noticeably affect the fly ashes' composition and usefulness. The most abundant element in the copper slag was iron, which made up 46.72% of the slag by weight in the form of oxides. SiO_2, at 32.86%, was the second most abundant element. The CuO content of the copper slag was 0.69%. The conglomerates of the crystalline phases were fayalite (Fe_2SiO_4), magnetite (Fe_3O_4), and quartz (SiO_2). The BET surface areas of the copper slag samples were lower than 1.0 $m^2 \cdot g^{-1}$.

Performance of copper slag in Hg^0 oxidation

The Hg^0 oxidation efficiencies of the copper slag sample as a function of temperature (100°C to 350°C) are shown in Figure 1. As depicted in the figure, E_{oxi} at 100°C reached 60.0%. The copper slag exhibited even better Hg^0 oxidation performance in the range of 200°C to 300°C, with more than 80% of the Hg^0 oxidized under the simulated flue gas atmosphere. The maximum E_{oxi} of 93.8% was achieved at 250°C. This temperature was close to the optimal temperature for Hg^0 oxidation over CuO-based catalysts (Zhou et al., 2014), indicating that the CuO in the copper slag probably played an important role in Hg^0 oxidation. It should be noted that the GHSV of 128,000 h^{-1} and the Hg^0 concentration of 75 $\mu g \cdot m^{-3}$ were much higher than the actual flue gas conditions, which would suggest an even higher Hg^0 oxidation efficiency for the copper slag in real-world applications. More importantly, the excellent Hg^0 catalytic oxidation performance of the copper slag at 150°C to 250°C means that it can be injected upstream of PMCDs, which allows the used copper slag particles to be efficiently captured at no additional cost.

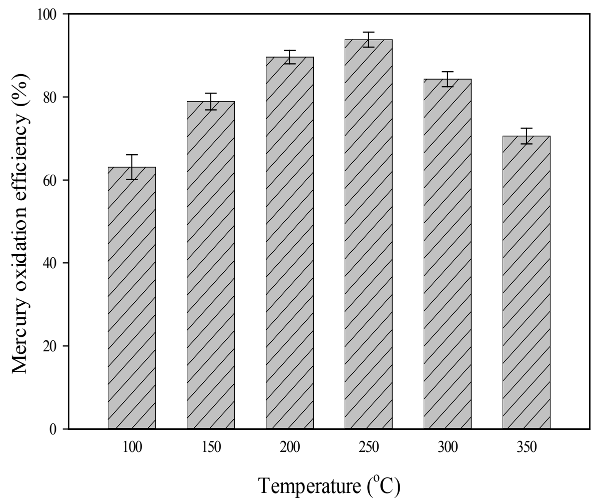

Figure 1 Hg^0 oxidation under simulated flue gas at different temperatures

Effect of HCl on Hg^0 oxidation

Because the primary oxidized mercury species found in coal combustion flue gas is mercury chloride ($HgCl_2$)（Cao et al., 2007）, HCl is generally regarded as the most important flue gas component related to Hg^0 oxidation. In previous studies of iron oxide-based catalysts (Chiu et al., 2015) and copper oxide-based catalysts (Xu et al., 2014), HCl significantly enhanced Hg^0 conversion to $HgCl_2$ due to the formation of active chlorine on the catalyst surfaces. In this study, a significant promotional effect of HCl on Hg^0 oxidation was observed over the copper slag samples. As shown in Figure 2, an apparent decrease in outlet Hg^0 concentration was observed downstream of the copper slag after adding 20 ppm HCl to the pure N_2 gas flow at point "b." This decrease was probably due to the formation of either Cl_2 or other active chlorine species due to the reactions between HCl and lattice oxygen and/or chemisorbed oxygen on the copper slag surface. Gas-phase O_2 could regenerate lattice oxygen and replenish chemisorbed oxygen and hence could provide abundant reactive surface oxygen for reaction with HCl to form more active chlorine species for Hg^0 oxidation. Therefore, the introduction of O_2 at point "c" further enhanced Hg^0 oxidation. As illustrated in Figure 2, the combination of 20 ppm HCl and 5% O_2 resulted in an outlet Hg^0 concentration close to 0.0, indicating that the copper slag is highly active for Hg^0 oxidation through HCl in an oxygen-enriched environment.

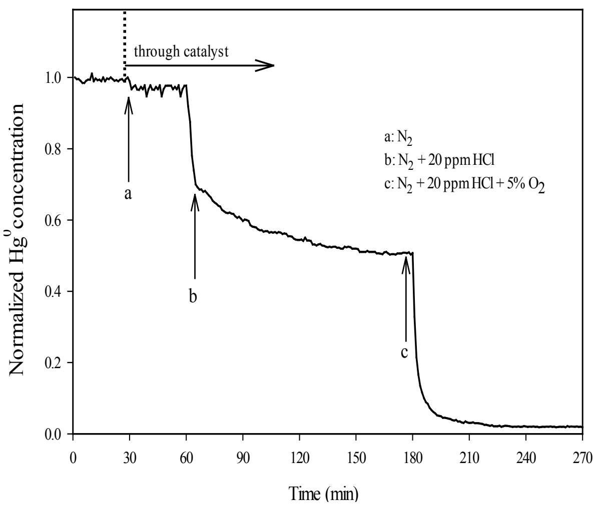

Figure 2 Hg^0 oxidation by HCl at 250 °C

Similar to Hg^0 conversion on fly ashes, HCl was probably adsorbed by the copper slag samples to form a chlorinated-surface (Zhuang et al., 2007). HCl-pretreated copper slags were used for Hg^0 oxidation under a pure N_2 atmosphere at 250°C to clarify the reaction mechanisms. As shown in Figure 3, the non-pretreated copper slag samples exhibited a negligible effect on Hg^0 oxidation under pure N_2 atmosphere. In contrast, the HCl-pretreated catalysts exhibited much better Hg^0 oxidation performance than the non-pretreated catalysts. The discrepancy indicated that the chlorine species that remained on the copper slag surface were responsible for oxidizing the Hg^0, because the HCl was already at a reduced state and could not directly oxidize Hg^0. The promotional effect of HCl on Hg^0 oxidation required the assistance of other oxidants such as oxygen (Niksa et al., 2001). With the aid of O_2, during the pretreatment, more adsorbed HCl was oxidized to form abundant active species, resulting in the better Hg^0 oxidation performance of the copper slag samples that were pretreated with HCl plus 5% O_2. The finding is also in line with the results shown in Figure 2, which indicate that copper slag significantly facilitated Hg^0 oxidation in the co-presence of HCl and O_2.

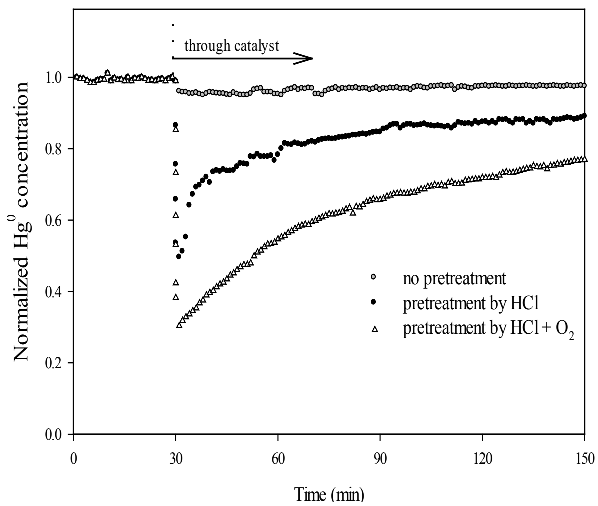

Figure 3 Hg^0 oxidation over HCl pretreated copper slags under pure N_2 atmosphere

<u>Identification of active constituents of copper slag for Hg^0 oxidation</u>

Previous studies of the effects of fly ash constituents on Hg^0 oxidation have mainly used reagent grade oxides such as SiO_2, alumina (Al_2O_3), calcium oxide (CaO), magnesium oxide (MgO), and Fe_2O_3 (Ghorishi et al., 2005). In this study, Hg^0 oxidation was investigated over pure inorganic components of copper slag including SiO_2, Al_2O_3, CaO, MgO, Fe_2O_3, zinc oxide (ZnO), and CuO, in the presence of HCl plus 5% O_2 at 250°C. As shown in Figure 4, SiO_2, Al_2O_3, CaO, MgO, and ZnO all exhibited minor effects on Hg^0 oxidation by HCl: Hg^0 oxidation efficiencies over these oxides were less than 5%. The negligible effects are in accordance with previous studies that showed that SiO_2, Al_2O_3, CaO, and MgO had little to no effect on promoting Hg^0 oxidation in simulated flue gases. In contrast, transition metal oxides such as Fe_2O_3 and CuO significantly boosted Hg^0 oxidation by HCl. The E_{oxi} over Fe_2O_3 was around 80%, and the E_{oxi} for CuO was close to 100%, indicating that CuO was even more active. This finding was also supported by a study that showed that adding copper oxide to a commercial SCR catalyst significantly enhanced the Hg^0 oxidation rate by a factor of two (Schwaemmle et al., 2012).

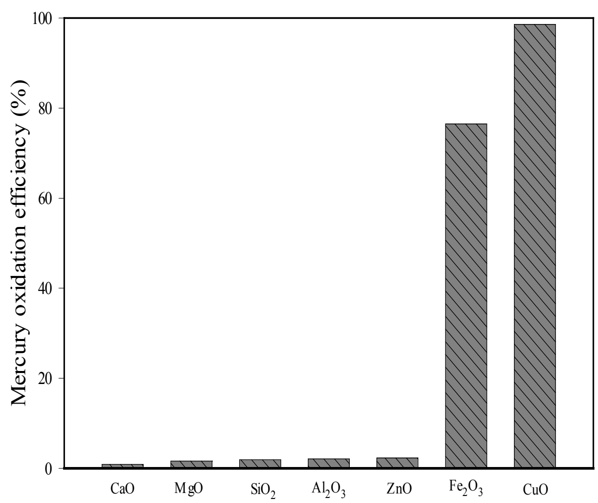

Figure 4 Hg^0 oxidation over pure inorganic components of copper slag

To further identify the active constituents in copper slag for Hg^0 oxidation, four simulated copper slags with different components were used to enhance Hg^0 oxidation in a simulated flue gas containing 20 ppm HCl and 5% O_2. As shown in Figure 5, only a small amount of inlet Hg^0 was oxidized after passing through the SCS1 with no Fe_2O_3 or CuO. This oxidation was ineffective because almost all of the components of SCS1 were inert for Hg^0 oxidation. After passing through the SCS2, the normalized Hg^0 concentration gradually dropped to about 0.4 in 1 hour, which was much lower than that observed over the SCS1. The SCS3 with CuO exhibited better performance than the SCS2 with Fe_2O_3, indicating that CuO is more active than Fe_2O_3 for Hg^0 oxidation in the presence of HCl. The E_{oxi} over SCS4 with both Fe_2O_3 and CuO was higher than that for SCS2 and SCS3 with either Fe_2O_3 or CuO, demonstrating that the co-presence of Fe_2O_3 and CuO resulted in a synergy for Hg^0 oxidation by HCl. After reaching equilibrium (the variation in outlet Hg^0 concentration was less than 5% for more than 30 min), the outlet Hg^0 concentrations downstream of SCS4 and real copper slag were close to each other, indicating that Fe_2O_3 and CuO were the two most important active constituents in copper slag for Hg^0 oxidation.

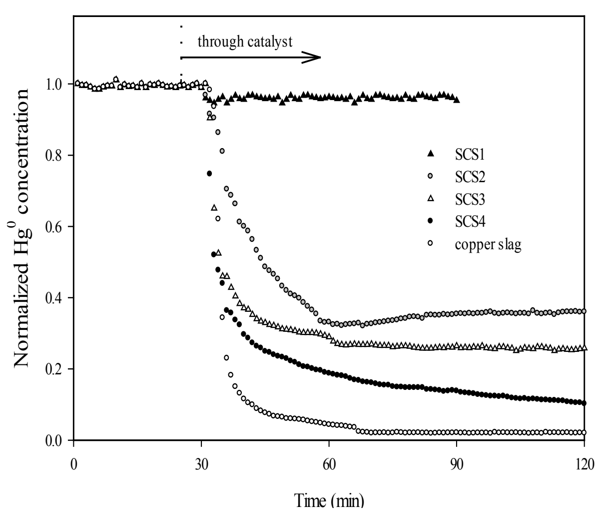

Figure 5 Hg^0 oxidation over model copper slags

Proposed mechanism in Hg^0 oxidation over copper slag

Three types of mechanisms - the Deacon process, the Langmuir-Hinshelwood mechanism, and the Eley-Rideal mechanism - have been proposed for heterogeneous Hg^0 oxidation in the presence of HCl (Presto et al., 2006). Copper slag has never been reported as a Hg^0 oxidation catalyst, much less studied as part of the Hg^0 oxidation mechanism. In this section, we discuss an experiment in which copper slag pretreated with HCl plus O_2 was used to identify the mechanism involved in Hg^0 oxidation, because HCl was shown in the above tests to be the most effective flue gas component for Hg^0 oxidation over copper slag. Fresh copper slag was first pretreated at 250°C by 20 ppm HCl plus 5% O_2 balanced in N_2 for 60 min and flushed with N_2 for another 30 min. The pretreated copper slag samples were then used for Hg^0 oxidation at different temperatures. As illustrated in Figure 6, more Hg^0 was discharged from the reactor outlet at higher temperatures. Hg^0 oxidation over the copper slag pretreated with HCl plus O_2 was facilitated at lower temperatures, which is more suitable for Hg^0 physical adsorption. This phenomenon implies that Hg^0 physical adsorption was indispensable for the Hg^0 oxidation by active chlorine species on the copper slag surface. If gas-phase Hg^0 could react with active chlorine species over the pretreated copper slag, then more Hg^0 oxidation should have been observed at higher temperatures because reaction rates generally increase with temperature.

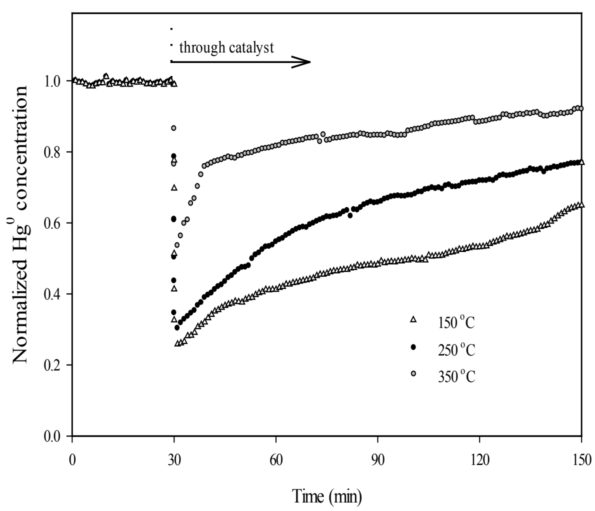

Figure 6 Hg^0 oxidation over HCl pretreated copper slag in pure N_2 atmosphere

Therefore, it is reasonable to believe that Hg^0 oxidation over copper slag occurs via the Langmuir-Hinshelwood mechanism, that is, active surface species react with adsorbed Hg^0 to form oxidized mercury. This finding agrees with the results previously shown in Figure 1. When the temperature was below 250°C, enough Hg^0 was adsorbed over the copper slag, as demonstrated by the Hg^0 desorption experiment shown in Figure 7. E_{oxi} increased along with the increase in temperature (shown in Figure 1) because the active components, mostly Fe_2O_3 and CuO in copper slag, more actively generate reactive species at higher temperatures (Borderieux et al., 2004). As shown in Figure 7, a significant amount of Hg^0 desorped when the temperature increased from 250°C to 350°C. Higher temperatures inhibited the physical adsorption of Hg^0 and hence led to the decrease in E_{oxi} from 250°C to 350°C shown in Figure 1. This further confirmed that the Langmuir-Hinshelwood mechanism was the dominant mechanism for Hg^0 catalytic oxidation on copper slag. Higher temperatures inhibited the physical adsorption of Hg^0 and hence led to the decrease in E_{oxi} from 250°C to 350°C shown in Figure 1. This further confirmed that the Langmuir-Hinshelwood mechanism was the dominant mechanism for Hg^0 catalytic oxidation on copper slag.

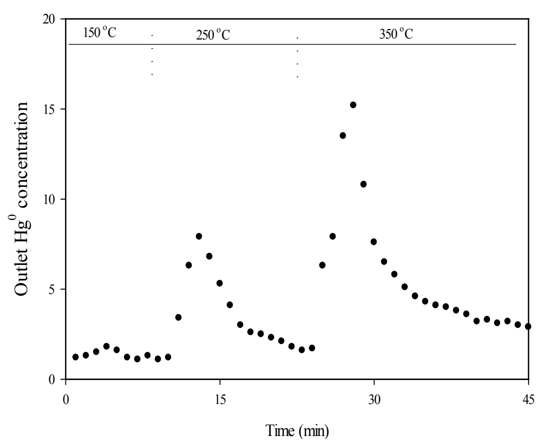

Figure 7 Desorption of Hg^0 from copper slag loaded with Hg^0

CONCLUSIONS

The copper slag was highly active for Hg^0 oxidation between 200°C and 300°C: more than 80% of the Hg^0 was oxidized under a simulated flue gas atmosphere. At the optimal temperature of 250°C, an E_{oxi} of 93.8% was achieved at a very high GHSV of 128,000 h^{-1}. Thus, the reuse of copper slag as a catalyst is a promising strategy for controlling Hg^0 emission from coal-fired power plants. As with many other catalysts, HCl was the flue gas component responsible for the most efficient Hg^0 oxidation over the copper slag. The use of 20 ppm HCl plus 5% O_2 resulted in almost 100% Hg^0 oxidation at 250°C. Transition metal oxides, mostly Fe_2O_3 and CuO, were identified as critical constituents of copper slag for the promotion of Hg^0 oxidation. The co-presence of Fe2O3 and CuO led to a synergistic effect for Hg0 oxidation by HCl. Hg0 oxidation on the copper slag probably follows the Langmuir-Hinshelwood mechanism, in which reactive chlorine species on the copper slag surface react with physically adsorbed Hg0 to form Hg2+. Further studies will be conducted in a sorbent injection experimental setup to further verify the feasibility of reusing copper slag as a catalyst for the removal of Hg0 from coal combustion flue gas.in the total amount of TOC eluted.

ACKNOWLEDGMENT

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RECOVERY OF Ca-P TYPE PHOSPHORUS BY USING CALCIUM COMPONENT IN THE RECYCLED AGGREGATE RESIDUE

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ABSTRACT

In this study, optimum extraction conditions for phosphorus recovery from sewage sludge ash(SSA) were investigated. For this purpose, an experiment was conducted to determine optimal recovery conditions for Ca-P type phosphorus by using calcium component in the recycled aggregate residue. The phosphorus content of sewage sludge ash was confirmed to be 5.0 %. When H_2SO_4 was used as an extract, concentration of 1 N H_2SO_4, L/S ratio of 10, and extraction time of 30 min were found to be the optimal extraction conditions. Phosphorus was extracted by using optimal extraction conditions, and then the heavy metals eluted with phosphorus were removed using 1～20 g of cation exchange resin. In 20 g of cation exchange resin, Fe 71.3%, Cu 82.4%, Zn 79.9%, and Cr 15% were removed. After that, the mixing ratio of the calcium extract obtained from the recycled aggregate residue (RAR) was changed to 1:1, 1:5, and 1:10. The pH of the SSA to RAR mixture was adjusted to 2, 4, 8 and 12 by the addition of 5 N NaOH to the mixture of 1:5, and the phosphorus was recovered as Ca-P type precipitate. The optimum pH was 8. When recycled aggregate residues were used, the weight of calcium phosphate increased, but the amount of wastewater generated also increased. Therefore, it was concluded that the use of recycled aggregate residue was not economically feasible.

Keywords: Sewage Sludge Ash, Phosphorus Recovery, Optimal Condition, Calcium Phosphate Type

INTRODUCTION

Due to the improvement of living standards and the increase of population, the amount of sewage generation and the resulting amount of sewage sludge are increasing in Korea. The amount of sewage sludge generation in Korea has increased 25 percent from 8,438 tons/day as of 2010 to 10,527 tons/day in 2015. As of 2015, the amount of sludge treated by incineration is 1,971 tons, which is about 19 % of total treated sewage sludge(Korea Ministry of Environment, 2016). Sewage sludge ash (SSA) contain about 10% of the phosphorus by weight.

A number of studies have been carried out to recover phosphorus from SSA. The method of extracting phosphorus by using strong acid such as sulfuric acid or hydrochloric acid is mainly used(Franz, 2008;

Donatello et al, 2010; Xu et al, 2013; Lee at al, 2014; Battsooj et al, 2016). The heavy metals that are extracted together are precipitated in the form of cation exchange resin or metal sulfide(Franz, 2008; Xu et al, 2013). Recovered form of phosphorus were liquid type phosphoric acid(Donatello et al, 2010), solid type struvite and calcium phosphate(Xu et al, 2013; Choi et al, 2009). Herzel et al. (2016) conducted a study on a thermochemical treatment with sodium and potassium additives under reducing conditions, whereby the phosphate-bearing mineral phases were transformed into plant available phosphates.

On the other hand, the amount of construction waste is about 198,259 tons/day as of 2015, of which the amount of waste concrete accounts for 62.8% of total construction waste(Ministry of Environment, 2016). The construction waste is composed of CaO, SiO_2, Al_2O_3, Fe_2O_3, and contains about 36.2% of CaO. It is expected that it will be source of calcium and pH adjustment agent when calcium phosphate precipitate is formed.

The purpose of this study is to find the optimal conditions for recovering phosphorus from acidic solution in SSA. In particular, calcium and alkali materials are extracted from recycled aggregate residue (RAR), and using this to examine the feasibility of precipitation and separation of Ca-P type phosphorus compounds through pH adjustment.

MATERIALS AND MTEHODS

SSA and RAR

The sewage sludge ash used in this experiment was collected from a fluidized bed incinerator at the C city. The ashes were dried at 105 ° C for 2 hours and then used.

Recycled aggregate residue(RAR) refer to materials that are not used as aggregates because they have small particle size during the production of recycled aggregate. RAR were mixed with distilled water at L/S ratio 5, 10, 20 L/kg.

The chemical composition of the ash was analyzed by X-ray fluorescence spectrometer (Olympus, DS-4050-C) and the particle size was analyzed using a particle size analyzer (HORIBA, LA-350). The amount of phosphorus that can be recovered was determined by measuring total phosphorus after completely digesting the ash by using pretreatment method of nitric acid-sulfuric acid in waste process test standard(Ministry of Environment, 2014). pH of RAR were measured and sieve analysis was performed to analyze the particle size.

Phosphorous extract concentration and L/S ratio

Phosphorus was extracted from SSA using sulfuric acid, and the effects of L/S ratio and sulfuric acid concentration on phosphorus extraction were investigated. The concentration of sulfuric acid was varied from 1 to 4 N and the L/S ratio was varied from 5 to 20. SSA and the acid extract were mixed and extracted with a jar-tester at 200 rpm for 30 minutes, and then filtered to measure phosphorus using an UV spectrophotometer (Mecasys, Optizen 2120UV QX).

Chemical properties of RAR extract

Calcium concentrations of RAR extract were measured using an Atomic Absorption Spectrometer (Shimadzu, AA-7000) and the pH was measured with a pH meter (Thermo Fisher, Orion Star A211).

Mixing ratio between SSA extract and Ca extract of RAR

To determine the optimum mixing ratio between SSA extract and Ca extract of RAR, the amount of SSA extract was set to 1 and the calcium extract of RAR of 10 L/S was mixed at 1, 5 and 10, and the mixture was stirred for 5 minutes with a magnetic stirrer and pH was measured. After removal of heavy metals by cation exchange resin, pH was adjusted to 2, 4, 8, and 12. The amount of phosphorus precipitated and remaining in the filtrate were measured and the optimum mixing ratio was found.

Heavy metals removal by cation exchange resin

After extracting phosphorus in SSA with optimum sulfuric acid concentration, cation exchange resin (Samyang, SCR-B) was used to remove heavy metals in extract.

The amount of cation exchange resin added was 1, 5, 10, and 20 g based on 100 mL of phosphorus extract, and the mixture was stirred at 200 rpm for 30 minutes using a Jar-tester. After filtration using a vacuum filtration apparatus, the filtrate was analyzed for heavy metals using atomic absorption spectrophotometer, and the removal efficiencies of heavy metals were calculated by comparing the initial heavy metal concentrations of phosphorus extracts. The pH of the cation exchange resin showed a weak acidity value of 3.06.

RESULTS AND DISSCUSSION

Characteristics of SSA

Table 1 shows the chemical composition of SSA before and after acid extraction by X-ray fluorescence spectrometer. The content of phosphorus was 4.98%. The phosphorus content in the ash was 50,940 mg/kg as measured by the nitric-sulfuric acid pretreatment method in the solid waste process test standard(Ministry of Environment, 2017). The phosphorus content of the ash after extracting the acid was 1.36% under the conditions of 1 N sulfuric acid and L/S ratio of 10 L/kg, indicating that 72.7% phosphorus was extracted by acid.

Table 2 shows the concentration of heavy metals in extracts of phosphorus extracted under the conditions of 1 N sulfuric acid and L/S ratio 10. Pb and Cd were not detected by AAS.

The particle size distribution of the SSA was measured using a particle size analyzer (Fig. 1). The median size of the SSA was 115 µm, the mode size was 186 ㎛, and the 80% weight passing particle size (d80) was 224 ㎛.

Table 2 Heavy metal concentrations of phosphorus extracts under 1 N H_2SO_4 and L/S ratio 10

Item	Fe	Zn	Cu	Cr	Pb	Cd
Conc. (mg/L)	992	519.9	282.8	1.623	ND	ND

Table 1 Chemical composition change of sewage sludge ash before and after acid extraction by XRF analysis

	Ca	K	P	Fe	Si	Ba	Zn	Cu	S	Other
Before acid extraction	7.71	5.68	4.98	4.44	2.50	0.56	0.27	0.12	0.11	72.3

After acid extraction	15.7	4.03	1.36	6.50	3.79	0.46	0.26	0.10	6.22	61.52

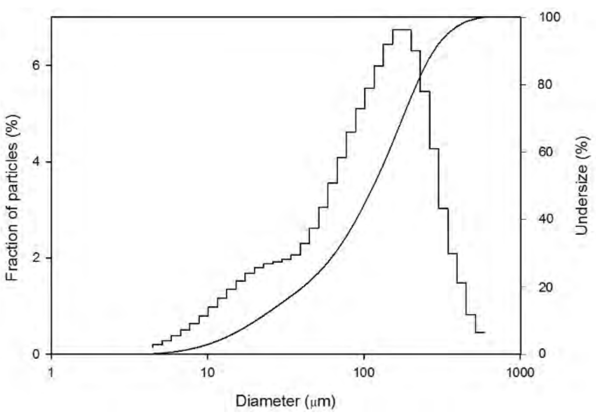

Figure 1 Particle size distribution of sewage sludge ash

Characteristics of RAR

The pH of the RAR by the measurement method of the waste process test standard was 10.77 and the pH by the measurement method of the soil pollution process test standard(Ministry of Environment, 2017), which extraction time is longer was 11.24.

As a result of the particle size distribution of the RAR, the weight percentage of 500～2000 ㎛ particle size accounted for about 75.3% of the total RAR weight. The median size of the RAR was about 500 ㎛. The RAR was used without separation when used as a sample.

Table 3 shows the results of measuring the pH and calcium concentration after mixing the RAR with L/S ratio of 5, 10 and 20 L/kg based on 1 L of distilled water for 24 hours.

Table 3 pH and Ca concentration of RAR leachate

L/S (L/kg)	5	10	20
pH	11.63	11.40	11.82
Leached Ca Conc. (mg/L)	76.5	113.2	309
Ca content in RAR (mg/kg)	382.5	1132	1545

Optimum phosphorus extract concentration

Table 4 shows the results of the phosphorus extraction with the L/S ratio of 5 L/kg using the extract concentration of 1~4 N H_2SO_4 in the SSA. As the concentration of H_2SO_4 increased, the concentration of phosphorus increased. In the case of 2N H_2SO_4, it was about 1.1 times higher than that of 1N H_2SO_4 and about 1.8 times that of 4N H_2SO_4.

In the case of 4 N H_2SO_4, it was considered uneconomical because the concentration of the extract was too high and additional costs were incurred in the subsequent treatment of the wastewater. In the case of 2 N H_2SO_4, it was thought to be inefficient and uneconomical because the amount of phosphorus to be extracted was almost same compared with 1 N H_2SO_4. Therefore, 1 N H_2SO_4 was used as the extract solution.

Table 4 Concentration of dissolved phosphorus with different acid extract concentration

acid extract conc.	1 N	2 N	4 N
phosphorus conc. (mg/L)	3085	3274	5450
phosphorus content in SSA (mg/kg)	15424	16370	27251
recovery rate (%)	30.3	32.1	53.5

Optimum L/S

Table 5 shows the phosphorus concentration according to the change of L/S ratio under 1 N H_2SO_4, and showed the highest phosphorus concentration at L/S 10 L/kg. When the L/S ratio was 5 L / kg, the recovery rate of phosphorus was the lowest, because the amount of the ash was too much, and it was thought that the extraction of phosphorus was not enough because it did not mix well with the extract when stirred with jar tester. In the case of L/S ratio of 20 L/kg, extraction efficiency of 1 N concentration of H_2SO_4 is higher than that of L/S ratio of 10 L/kg, but it is not optimal because the amount of generated wastewater increases.

Table 5 The concentration of dissolved phosphorus according to L/S ratio

L/S ratio (L/kg)	5	10	20
used SSA weight (g)	200	100	50
P conc. (mg/L)	3085	3242	1823
P content in SSA (mg/kg)	15424	32424	36461
recovery rate (%)	30.3	63.7	71.6

Effect of the calcium extract from RAR on the phosphorus recovery from SSA

The calcium extract from RRA was added at a ratio of 1, 5, and 10 based on 100 mL of the phosphorus extract. The mixture was stirred using a magnetic stirrer and the pH and appearance of the mixture were checked.

Table 6 shows the pH of the mixture of acid extract and calcium extract. In the case of 1: 1 mixture, the pH was almost unchanged, and the pH was increased by 0.59 and 0.93 at 1: 5 and 1:10, respectively. The mixing ratio of 1: 1 and 1: 5 did not change color of the solution. In the case of 1:10, a small amount of white precipitate was formed, and it was thought that $Ca_3(PO_4)_2$ was precipitated with increasing pH.

The mixing ratio of 1:10 was the most effective, but the increase of wastewater treatment cost would offset the economic effect of the reduction in the amount of the alkali agent. Therefore, it is concluded that the use of RAR extract as an auxiliary material for the alkali supply is not feasible.

Table 6 pH change according to mixing ratio of phosphorus extract to calcium extract

phosphorus extract vs. calcium extract	pH
1 : 0	0.95
1 : 1	1.26
1 : 5	1.68
1 : 10	2.02
0 : 1	11.40

Heavy metal removal using cation exchange resin

The removal efficiency of heavy metals and minerals was investigated by cation exchange resin in the range of 1~20 g based on 100 mL of phosphorus extract and stirring at 200 rpm for 30 minutes.

Fig. 2 shows the removal efficiency of heavy metals and minerals according to the amount of cation exchange resin.

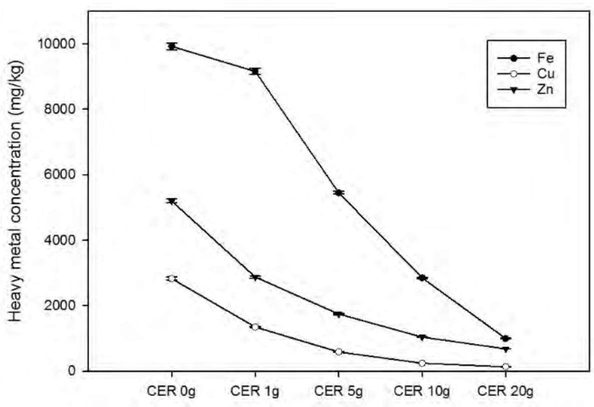

Figure 3 Removal of heavy metals with amount of cation exchange resin per 100 mL acid extract

Optimum pH for phosphorus recovery

The pH of the 1:5 mixture of acid extract and calcium extract was adjusted to 2, 4, 8, and 12 with 5 N NaOH. Table 7 shows the amount of precipitation and phosphorus recovery with pH change. It was concluded that the optimum recovery rate (%) of phosphorus was 84.1% at pH 8.

Table 7 Ca-P precipitate weight and phosphorus recovery with pH change

pH	2	4	8	12
Ca-P precipitate weight (g/kg)	1.24	6.70	8.79	9.05
P content in precipitate (mg/kg)	383.1	2068	2715	2793
P content in filtrate after pH adjustment (mg/kg)	2818	1124	513	224
P recovery rate (%)	12.0	64.8	84.1	92.6

Mass balance check

From the experimental results, the mass balance in the process of recovering phosphorus from SSA is summarized in Table 8.

The amount of P recovered during the addition of 1 kg of SSA was calculated as 0.008 ~ 0.02 kg-P, and 13 ~ 62.9 kg of wastewater was generated during the treatment.

The use of RAR as an alkaline and Ca source increases the amount of recovered P and decreases the amount of NaOH, but it is not economical considering the increase of wastewater generation and the earthworks cost of RAR leaching process.

Table 8 Mass balances of phosphorus recovery process for sewage sludge ash

Case	input (unit : kg)						output (unit : kg)				
	SSA	H_2SO_4	NaOH	Water	RAR	CER	Ca-P (P)	Wastewater	Ash	RAR	CER
1	1	0.49	0.398	11.99	-		0.0781 (0.008)	13.0	0.774	-	
2	1	0.49	0.384	61.99	5		0.0943 (0.020)	62.9	0.774	5	
3	1	0.49	0.334	61.67	5	2	0.0880 (0.015)	62.6	0.774	5	2

Case 1 : Acid extraction → 5 N NaOH

Case 2 : Acid extraction → RAR extract +5 N NaOH

Case 3 : Acid extraction → Heavy metal removal by CER → RAR extract +5 N NaOH

CONCLUSIONS

The optimum method of recovering phosphorus as Ca-P type from sewage sludge ash was investigated and the following conclusions were obtained.

1) The phosphorus content of the sewage sludge ash samples used in the experiment was found to be 5.0% (11.5% based on P_2O_5). The heavy metal and mineral contents of SSA were 9,920 mg/kg of Fe, 5,199 mg/kg of Zn, 2,828 mg/kg of Cu, and 16.23 mg/kg of Cr. The particle size of SSA ranged 4.8-592.4 ㎛ and a median diameter was 115 ㎛.
2) Recycled aggregate residues were used for pH adjustment and calcium source when recovering phosphorus in SSA to Ca-P form. The pH and calcium concentration of the supernatant were measured after mixing for 24 hours under the conditions of L/S ratio of 5, 10 and 20 L/kg. The pH and calcium concentration of the supernatant were 11.63 and 342.8 mg/kg at L/S is 5, 11.40 and 1771.5 mg/kg at L/S is 10, and 11.82 and 1532.2 mg/kg at L/S is 20, respectively. Under the condition of no agitation, the condition of L/S 10 L/kg was the condition to obtain the highest calcium concentration.
3) 1 N H_2SO_4 concentration, L/S ratio 10 L/kg, and 30 minutes was considered to be optimal condition when total use of chemicals and wastewater generation was considered. When phosphorus was extracted from SSA under this condition, about 32,424 mg/kg phosphorus could be recovered and the recovery rate of phosphorus was 63.7%.
4) Compared with the experiment without using the recycled aggregate residues, the weight of the precipitate increased, but the wastewater treatment cost increased due to the increase of wastewater generation. Therefore, it was concluded the method of recovering phosphorus using the recycled aggregate residues is economically not to be feasible.

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DEVELOPMENT OF A WASTE PLASTIC BASED CONSTRUCTION MATERIAL FOR OUTDOOR LIGHT CONSTRUCTIONS

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ABSTRACT

Various types of plastics are widely used and eventually ended up in waste stream as post-consumer plastic waste. Though Sri Lanka attempts to control plastic waste generation different strategies, more than 50% of post-consumer plastics waste is remained in dumpsites. Hence, this study was aimed at developing a technique to invent and synthesize waste plastic based construction material. The technique was to blend shredded polypropylene (PP) plastic films with sand and rock aggregates, and wood sawing waste into a hot mixture that can be moulded to form required shapes. A laboratory level extruder was designed and developed to prepare the blend and standard proctor hammer apparatus was used to reach standard compaction in moulds. Different ratios of plastics and aggregates were blended and tested for compression and split tensile strength. The strength testing showed that compressive strength and tensile strengths were varied between 5.84-17.55 MPa and 0.56-2.38 MPa for plastic: aggregate (1:1– 1:3). Moreover, density, water absorption, thickness swelling, and linear expansion were tested for polythene-wood samples. The feasibility of practical use was evaluated by energy use, mass balance, and cost of production. The developed material is light-weight (0.68-1.83 gcm^{-3}) and cost-effective ($128 per m^{-3}) compared to other commonly available construction materials. The results revealed the potential of developing post-consumer plastic waste as an alternative light construction material.

Keywords: Extruded plastic composite; Light construction material; Post-consumer plastic waste

INTRODUCTION

Solid waste disposal is a serious issue in developing countries with the economic growth and population expansion. In general, plastic wastes occupy a significant fraction of non-degradable waste that varies from 6% to 10% as post-consumer plastic wastes (Hegberg, et al., 1992; Li, et al., 2009). In Sri Lankan context, approximately 500,000 metric tons (MT) of virgin plastics are imported, yet only 30% is exported as manufactured goods (Jayasinghe, 2015). Among the many thermoplastic types that can be mechanically recycled, post-consumer plastic waste (PCPW) mainly consisted of Low Density Polyethylene- LDPE (65%), High Density Polyethylene- HDPE (20%), 5% of Polypropylene (PP) and 10% of other types of plastics (Hegberg, et al., 1992).

There are various options involved in managing plastic wastes as source reduction, landfilling, incineration, and recycling (Rebeiz and Craft, 1995). Source reduction has its own limitations because attempts to reduce one component may cause increase in another component. Although the plastics are considered non-biodegradable in landfills, due to additives in plastics and physicochemical degradations, persistent organic pollutants are formed and contaminates the environment. Moreover, excessive flame temperature, formation of incomplete combustion products, formation of slag and corrosive gases are the main issues of incineration of plastics. Furthermore, mixed and contaminated post-consumer plastic recycling is an expensive process due to extra burden on collection, separation and extensive manufacturing process. The issue is aggravated due to difficulty of sorting plastic resins in post-consumer plastic wastes, bulkiness post-consumer plastic wastes (Hegberg, et al., 1992) and still more than 50% of post-consumer plastics such as laminated food packages, are non-recyclable.

Emerging alternative way of recycling post-consumer plastic waste is to use non-recyclable plastic as raw materials for producing plastic based materials such as sand-plastic composite construction material (Dinesh, et al., 2016) and wood-plastic composite construction materials. Biomaterials such as sawdust is becoming popular as a reinforcing material in plastic composites due to its advantages such as low cost, availability, high strength, good mechanical properties and eco-friendliness (Fakhrul, et al., 2013).

Extrusion process plays a vital role in production of such waste plastic based composite materials. Plastics extrusion is a high-volume manufacturing process in which raw plastic is melted and formed into a continuous profile. Extrusion can be used to produce various products by using waste plastics and approximately 65% of currently used plastics can be extruded (Shiri, et al., 2015). Co-extrusion is the process of extruding two or more materials through a single die of an extruder. Different types of compatibilizers are added in co-extrusion process to increase bonding between two different materials, (Hegberg, et al., 1992) with the use of various types of plastic extruders (Adhikary, et al., 2007).

Therefore, this study aimed at developing a post-consumer plastic waste based construction material through co-extrusion with sand and saw dust.

MATERIALS AND METHODS

Material processing

Post-consumer Polypropylene (PP) clear films were sorted out from the general municipal solid waste collection received at a disposal facility in Ratnapura, Sri Lanka. The collected film plastics were thoroughly washed with clean water and then dried at 65°C for 12 hours. Then dried films were manually shredded in to small pieces about 4 mm. The processed particles were to be used as polymer matrix in waste plastic based composite construction materials.

River sand and chip stones were used as the dense aggregates. River sand (< 5 mm size) and chip stones (4-10 mm size) collected from a construction material supplier were cleaned and dried in an oven at

103°C ± 2°C for 24 hours in order to remove dirt and moisture. Alternatively, wood sawdust (*Alstonia macrophylla*) was collected from a saw mill and dried in an oven at 103°C ± 2°C for 24 hours to remove water. The saw dust had moisture content of 18% and the bulk density of 0.24 g cm^{-3} with particles ranging from 1mm to 10 mm (D10 =0.31; D50=1.00; D90=3.10).

As shown in Figure 2, a laboratory level small plastic extruder was designed and manufactured to produce test samples. Also, an electronic balance, cylindrical steel molds (60 mm diameter and 120 mm height), standard proctor drop hammer and bimetallic temperature sensors were used for sample preparation.

Preparation of Samples for Testing

First, extruder was heated up to 200°C (appropriate temperature to melt Polypropylene) using couple of 1000W infrared heat emitters. Once the extruder reached the desired temperature, the material chamber was filled with pre-mixed samples (plastic: sand or plastic: sand: chip stones or plastic: saw dust) at different ratios. The particular batch of mixture was heated in the extruder for 10 minutes while the mixture was stirred uniformly using a steel rod until a uniform and consistent mixture was achieved. Then the molted mixture extruded through the bottom nozzle using the screw handle. The extruded hot mixture (~200°C) was collected to steel mold and compacted using standard proctor compaction process (25 drop hammer blows). The compacted sample was allowed to cool at room temperature (~25°C) about an hour and removed from the mold. The plastic: sawdust samples were prepared at a lower temperature of 180°C to minimize burning of saw dust particles.

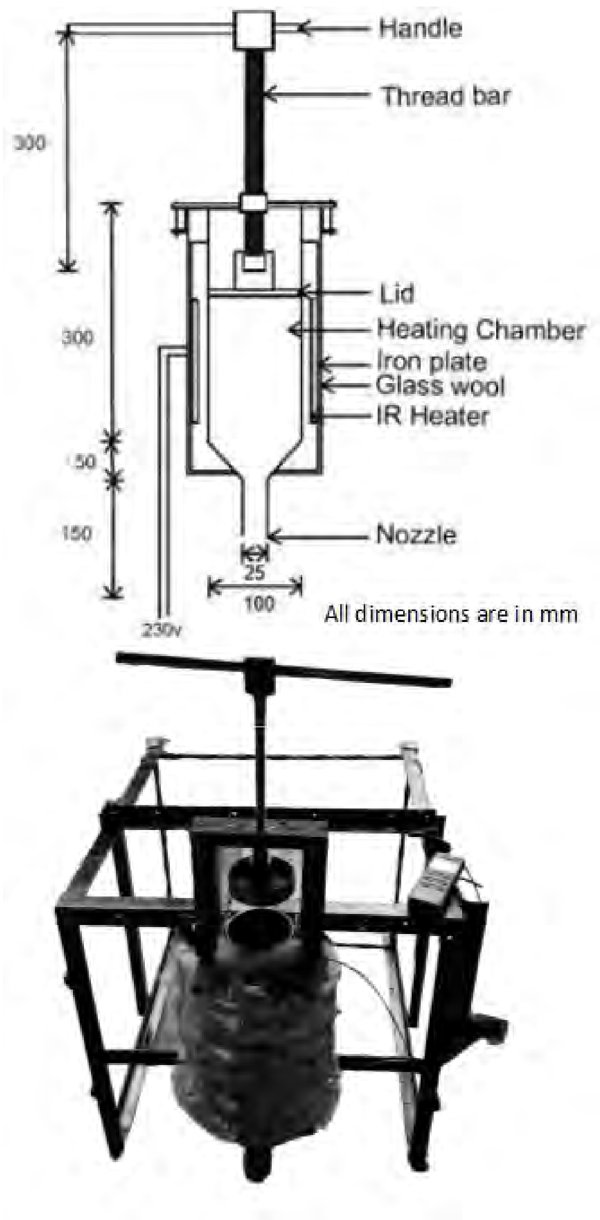

Figure 1. Schematic diagram and picture of the designed extruder

The molded samples were cured in room temperature for one week until used for laboratory analysis of strength parameters and pictures of molded samples are shown in Figure 2.

Figure 2. Manufactures plastic composite samples

Strength testing of plastic composites

Cylindrical test specimens with nominal sizes of 6 cm diameter and 20 cm height was used for the strength analysis. The compressive strengths of samples were determined using Auto-test Compression Testing Machine (Capacity 3,000 kN) that record the maximum load at failure. Splitting tensile strengths of samples were determined by using the Universal Testing Machine (Capacity 60,000lb) that records the load at failure. All tests were conducted in triplicates.

Testing of Water Absorption (WA), Thickness Swelling (TS) and Linear Expansion (LE)

Series of small sample specimens (diameter 60 mm, length 60 mm) were prepared and the initial weight and dimensions were measured. Then, the samples were immersed in distilled water and the weight gain, and dimension changes were recorded at every six-hour interval consecutively for five days.

Statistical analysis

The test result of compressive strength, splitting tensile strength and bulk density were analyzed using ANOVA at 5% probability level. Moreover, the results of compressive strength, splitting tensile strength and density were analyzed by Duncan's Multiple Range Test at 5% probability level for mean comparison suing statistical software SAS 9.2 and Microsoft Excel 2013.

RESULTS AND DISCUSSION

As shown in Figure 2, plastic: sand: chip stone samples showed the highest roughness and wearing while the Plastic: saw dust composite samples had a smooth finishing. Therefore, sample surfaces were smoothened with Sulphur capping to a smoother finishing during the strength testing.

The bulk density of plastic: fine sand composites increases from 1.47g cm^{-3} to 1.83 g cm^{-3} with the increase of fine sand content for composites having mass ratios of 1:2 and 1:4, respectively. The composite made out by different ratios of plastic: fine sand: chip stone showed higher densities that varied from 1.74 g cm^{-3} to 2.04 g cm^{-3} when the chip stone ratio increases. The plastic: saw dust composite had comparatively lower densities that range from 0.69 g cm^{-3} to 0.86 g cm^{-3} for ratios of 1:1 to 9:1, respectively. In general, density of plastic: saw dust composite increases with increasing plastic content; however, the densities were far below the plastic: sand or plastic: sand: chip stone densities.

Compressive strength test

Table 1 summarizes the strength characteristics of test samples prepared with different material mix ratios. As expected, the plastic content was responsible for the major change observed in both the compressive and the tensile strength. Generally, both the compressive and split tensile strength of composites increase with increasing plastic content. It was also found that rough samples that have high void ratios broke easy thus split tensile test results are not consistent.

Table 1 Strength characteristics of manufactured plastic composites

Material mixing Ratio (w/w)	Average compressive strength (MPa)	Average split tensile strength (MPa)
Plastic: fine sand		
1:2	16	1.91
1:3	11.4	2.38
1:4	13.05	1.30
Plastic: fine sand: Chips stone		
1:2:4	10.83	0.87
1:3:4	5.84	0.71
1:3:6	13.84	1.00
1:4:6	17.55	0.69
Plastic: Saw dust		
1:1	6.66	0.56
7:3	10.81	1.04
9:1	12.79	1.54

As shown in Table 1, plastic: fine sand: chip stone composite shows comparatively higher compressive strengths among which 1:4:6 ratio has the highest compressive strength. Plastic: fine sand composites showed comparatively higher split tensile test indicating that the voids in specimens have a greater effect on split tensile strength.

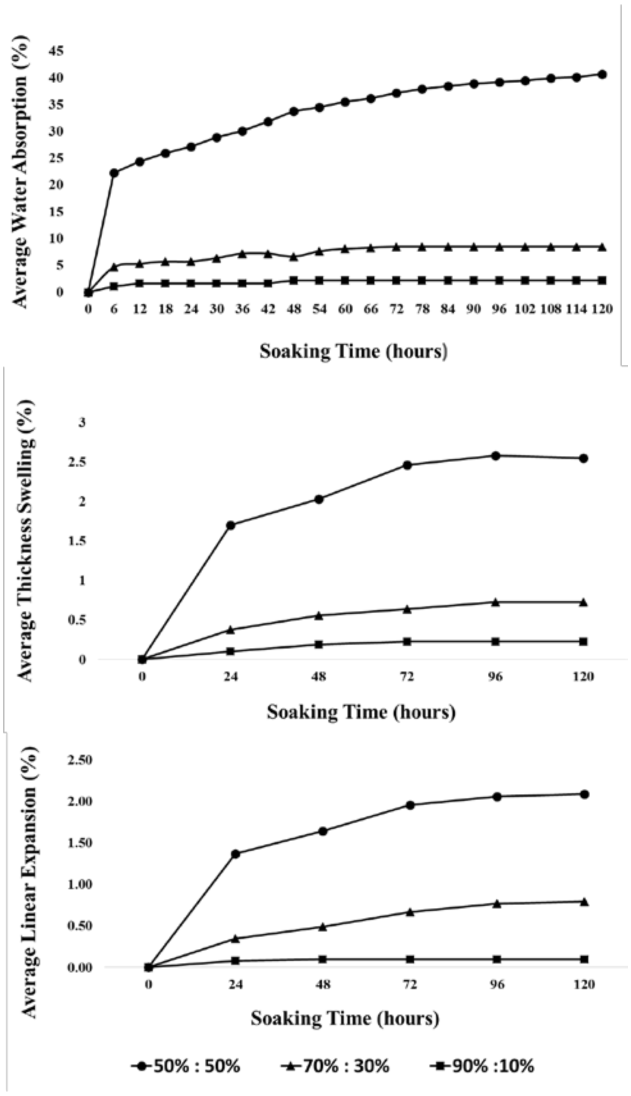

Figure 2 Water absorption, thickness swelling and linear expansion of plastic: sawdust composites under continuous soaking in distilled water

Experimental tests for the variation of mix proportion showed that plastic-finer aggregates mixtures developed to a smoother and low porous composites and showed desirable characteristics such as higher compressive and tensile strengths to be used as an alternative light construction material. Further it was revealed that the plastic not only leads to a high strength, but also a low dry density composite. This type of composite meets most of the requirements for non-load-bearing lightweight construction materials.

Water absorption, thickness swelling and linear expansion testes were not conducted with plastic: sand or plastic: sand: chip stone samples assuming that the responses are negligible. However, as shown in Figure 3, all plastic: saw dust composites showed a remarkable water adsorption, swelling and liner expansion under the prolong exposure to water. The composite with 50% saw dust adsorbed remarkably higher amount of water (40%) at 120 hours of testing. The swelling and liner expansion were also greater in 50% saw dust samples (2.5% and 2.0%, respectively). The plastic: saw dust composites with greater amount of plastics (9:1) showed the lowest water adsorption, swelling and liner expansion indicating that mass of saw dust in composite has greater interaction with water. Porosity is another factor that effect on water absorption of wood-plastic composite materials (Butylina et al., 2011). Also, as reported by Turku and Kärki (2013), gaps may form between plastic matrix and wood particles due to poor interfacial bonding. Thus a combination of different factors causes the material to swell in the presence of the moisture.

This developed plastic: sand, plastic: sand: chip stone and plastic: saw dust composite materials are having low density yet showed greater strength than some of commonly used light construction materials such as solid fired clay bricks, wood and masonry blocks (5-10 MPa).

The feasibility of practical usage was evaluated by energy use, material mass balance, and cost of production. The cost analysis showed that the total cost for manufacturing 1.0m^3 of composite material using the same procedure will cost about US$ 128.

CONCLUSIONS

The research demonstrated a successful attempt to manufacture post-consumer plastic waste based composites that can be further developed to use as light construction material. The hot mixtures of different plastic: sand, plastic: sand: chip stones and plastic: saw dust were extruded and molded to large specimens for strength characterizing. It was found that plastic, sand and stone chips can be hot mixed at different ratios to form composite materials. Among the tested ratios, plastic: sand mixture at 1:4 ratio and plastic: sand: chip stone at 1:3:6 ratios are having desirable characteristics to be used as alternative light construction material. Moreover, plastic: saw dust composites also showed average strength characteristics. Adding a larger amount of saw dust reduces the strength and increases the water adsorption, swelling and liner expansion.

The study showed the potential of post-consumer plastic waste recycling through hot extrusion with different aggregates to develop composites that can be used as an alternative light construction material. The developed process can be considered as a low-tech and environmentally friendly alternative way of recycling the low grade post-consumer plastic waste.

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Evaluation of applicability of CO_2 methanation efficiency using various Ni-based forming catalysts

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ABSTRACT

This study addressed conversion of CO_2 to CH_4 using catalyst to produce renewable energy and reduce greenhouse gas. Ni/CeO_2 catalyst in a form of powder was used. A product was produced in a form of honey-comb, granule for commercialization. The surface of catalyst was observed in a form of CeO_2 and NiO through H_2-TPR analysis. It was ascertained that there was temperature which catalyst's consumption of hydrogen was significant depending on reaction temperature. CO_2 methanation activity assessment found that granule type is less influenced by space velocity and reaction temperature than honeycomb type and it is easier to be produced which suggests that this product is likely to be used for commercial system.

Keywords: various shapes of catalyst, CO_2 methanation, Ni based catalysts, methanation, biogas

INTRODUCTION

As the amount of fossil fuel used has increased since industrialization, several environmental problems such as exhaustion of fossil fuel and greenhouse gas emission have occurred. It was found that greenhouse gas concentration in atmosphere has the greatest influence on increased global mean temperature. Accordingly, lots of studies have been conducted to reduce carbon dioxide emission causing global warming and climate change. According to advanced research, recoverable resources of fossil fuel on the Earth is limited (Hwang et al., 2012). As scarcity of resources has increased, it is expected that energy expense will rise and it will be difficult to secure energy. Therefore, it is necessary to reduce CO2 emission by developing renewable energy and develop future energy source for sustainable energy supply (Kato et al., 2012). Biogas produced through anaerobic digestion is used as environmentally friendly energy. Main ingredients in by-product gas produced from anaerobic digestion tank in sewage treatment tank are CH_4 and CO_2 which are renewable energy which are recognized as renewable energy (Kumar et al., 2013). It is reported that CH4 accounts for CH_4 60-70% and CO_2 30-40% in by-product gas. CH_4 is used as town gas or automotive fuel after passing through refinement process but a large quantity of remaining CO_2 is wasted. Converting CO_2 wasted to CH_4 will lead to production of a large quantity of renewable energy reducing greenhouse gas (Nakamura et al., 2009).

CO_2 methanation reaction which converts CO_2 in atmosphere to CH_4 is one of CCU (Carbon capture & Utilization) technologies. This technology can produce renewable energy efficiently and reduce CO_2 (Beuls et al., 2012). This reaction is $CO_2 + 4H_2 \leftrightarrow CH_4 + 2H_2O$, $\Delta H_{298K} = -165\ KJ \cdot mol^{-1}$. Reaction between 1M of CO_2 and 4M of H_2 produces 1M of CH_4 and 2M of H_2O (Arbag et al., 2016). This reaction requires low reaction temperature by thermodynamic equilibrium and metal catalyst for high CO_2 Conversion and reaction velocity. Various studies to enhance CO_2 conversion rate and CH_4 selectivity in CO_2 methanation reaction have been conducted. Advanced research found that metal catalysts used in CO_2 methanation reaction are Pt, Pd, Ru, Rh, Ni and among them, Ni is known as good competitive price and reactivity (Muroyama et al., 2016). Advanced research reported that there is a difference in activity of catalyst depending on types of support species in catalyst. Studies on how to produce various catalysts aiming to improve catalyst activity, metal condition, support species, catalyst characteristics and high diffusion coating have been carried out (Xu et al., 2016).

Studies on CO_2 methanation to improve methane performance in a form of powder catalyst have been made but secondary operation of catalyst is needed for commercialization in various industries (Fukuhara et al., 2017). It is important to rapidly remove thermal energy in methanation reaction to process a large quantity of CO_2. In order to solve above mentioned problem, it is necessary to form catalyst by fixing catalyst in a proper shape or through secondary operation. There are few studies that formed catalysts in a various form and coated them in support species.

This study made catalyst in a form of honey-comb, granule by using powder shaped Ni catalyst with good CO_2 methanation performance and compared CO_2 conversion according to space velocity. This study investigated physical property of catalyst produced through H_2-TPR, XRD, SEM analyses.

Methods and materials

Method for making catalyst

Powder catalyst used in this study was 10 wt% Ni/CeO_2 which was found to have good CO_2 methanation performance. Reagents used to make Ni/CeO_2 catalyst were Ni precursor Ni $(NO_3)_2 \cdot 6H_2O$ (Aldrich Chemical Co.), and pretreated CeO_2 (Aldrich Chemical Co.). Wet impregnation method was used to make catalyst. Final catalyst was made by burning material in furnace at 400 °C. Produced powder catalyst has even particles for smooth forming and coating. 50 mesh was used to make powder catalyst. Then, pressure of 10,000 lbf was applied to powder shaped catalyst to make granule shaped catalyst. 3 mm – 4 mm catalyst was made. Powder catalyst was coated in a method of dip-coating in porous support species by using D.W. (distilled water), coating solution to make honeycomb shaped catalyst. Catalyst coated on honeycomb support species was dried in dry oven at 105 °C for over 2hrs and then baked in furnace at 400 °C and heating rate of 10 °C/min.

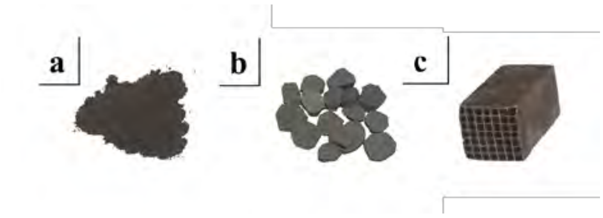

Figure 1 Photograph images of (a) Powder type (b) Granule type (c) Honey comb type catalyst

Experimental apparatus and method

<u>Apparatus for reaction of fixed bed</u>

Apparatus for experiment with CO_2 methanation is presented in Figure 2. Apparatus for experiment in this study largely consists of gas injection part, reactor part and reaction gas analysis part. H_2, CO_2, N_2 which are gases, reactant supplied to gas injection part were adjusted in a ratio of 4: 1: 1 by using MFC (Mass Flow Controller, MKS Co.). Reactor was quartz tube with inner diameter of 20 mm and height of 300 mm. Quartz wool was used to fix catalyst bed. Gas chromatography (YL6500GC) was used to measure concentration of reactant and product .

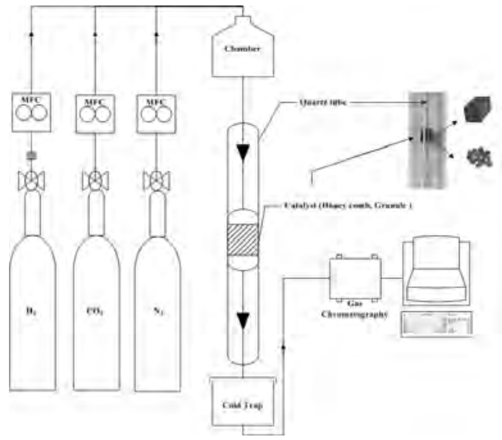

Figure 2 Image of Schematic of experimental equipment

<u>Experiment in reaction activity</u>

Catalysts produced in various forms such as powder, granule and honeycomb were prepared with them fixed in quartz tube in a reactor for experiment in reaction activity. Pretreatment was conducted for one hour in H_2 atmosphere to remove impurities and remaining moisture in catalyst after raising temperature to 300 °C in N_2 atmosphere. When temperature reached normal state, certain amount of gas was injected into a reactor to lower reaction temperature. Reaction activity of catalyst was expressed as conversion for CO_2, reaction gas as defined in Formula (1).

$$CO_2 \text{ conversion } (\%) = [(CO_{2\,IN}-CO_{2\,OUT})/ CO_{2\,IN}] \times 100 \quad (1)$$

Analysis of property of catalyst

Physical and chemical properties of materials used in this study were analyzed through XRD (X-ray Diffraction), H_2-TPR (Temperature Programmed Reduction) experiment and SEM (Scanning Electron Microscope). SEM analysis was used to ascertain whether powder catalyst was coated evenly on the surface of support species of honeycomb. As shown in Figure 3, for honeycomb catalyst, powder catalyst was coated on outer wall of support species thinly. XRD,

H_2-TPR analysis was used to analyze crystal and measure reduction of catalyst (Figure 4, Figure 5). Surface of catalyst was observed in a form of CeO_2 and NiO. It was ascertained that there was temperature in which catalyst's consumption of hydrogen was high according to reaction temperature. When examining activity with high consumption of hydrogen, it was found that there were two reduction peaks between 200℃ and 300-400 ℃. Reduction peak shown in specific temperature means that consumption of hydrogen in relevant reaction temperature is possible. When examining high reduction of 10 wt.% Ni/CeO_2 at 200 ˚C or fewer, it was ascertained that good methanation performance is possible in a range of low temperature. According to literature, high peak observed at 300 ˚C-380 ˚C is subject to conversion of Ni^{2+} to NiO species (Zhou et al., 2016).

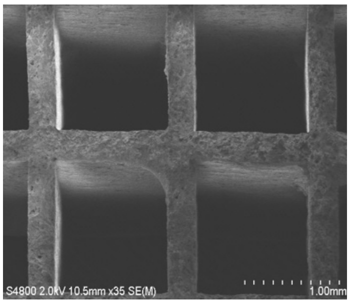

Figure 3 The SEM images of Honey comb coated Ni/CeO_2 catalyst

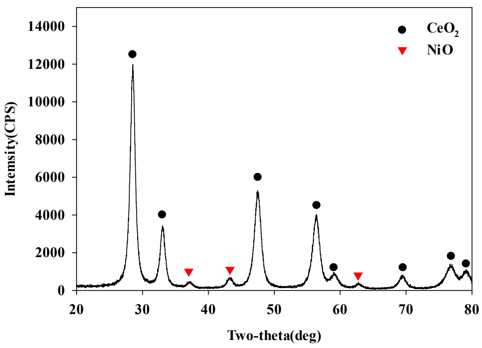

Figure 4 XRD patterns of Ni/CeO_2 catalyst

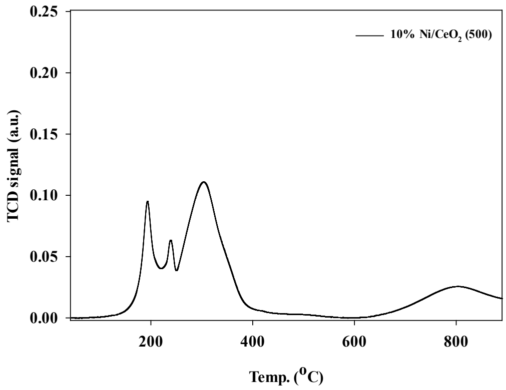

Figure 5 H_2-TPR profile of Ni/CeO_2 catalyst

CONCLUSIONS

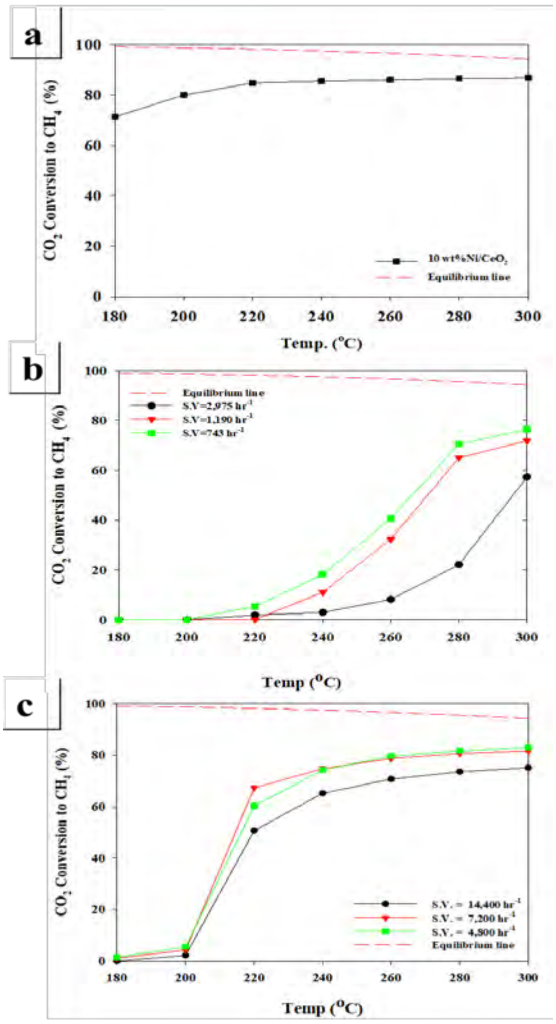

Figure 6 Catalytic performance of various shapes of

catalysts a) Power type b) Honey comb type c) Granule type for CO_2 methanation (CO_2: N_2: H_2 = 1: 1: 4)

Performance of CO_2 methanation reaction is presented in Figure 6. Experiment was conducted in a range of 180-300 °C. It was found that as temperature increased, conversion rate of all catalysts produced in various forms rose gradually. Conditions of temperature and space velocity were changed to determine an influence of space velocity on catalyst materials. This study found that as space velocity lowered, CO_2 conversion increased. Granule type catalyst is easy to be made but requires a large quantity of catalyst per unit volume. Granule type catalyst is likely to be worse than powder type catalyst in CO_2 conversion by pressure loss and channeling. This study assessed CO_2 conversion under space velocity of 4,800 hr^{-1}-14,400 hr^{-1} up to 180-300 °C by using Ni/CeO_2 granule type catalyst. Good conversion result of 80 % was shown at 300 ℃ and 4,800 hr^{-1}. Conversion was not changed significantly up to 220 ℃. Unlike granule type catalyst, honeycomb type catalyst was made with catalyst coated on support species. If honeycomb type catalyst is not coated on support species evenly, its CO_2 conversion is likely to be lowered. Ni/CeO_2 honeycomb type catalyst was used to assess CO_2 conversion up to 300-180 ℃ and space velocity of 743 hr^{-1}- 2,975 hr^{-1}. Good conversion result of 80 % was shown at 300 ℃ and 743 hr^{-1}. When compared with granule type catalyst, it was found that honeycomb type catalyst was affected by space velocity and temperature if temperature falls to 280 ℃ or fewer, which means that flux which catalyst can handle is finite. Granule type catalyst is less influenced by space velocity and temperature than honeycomb type catalyst and is easier to be made, which suggests that granule type catalyst is better than honeycomb type catalyst in application of commercial system.

1) This study succeeded in making granule type catalyst and honeycomb type catalyst to be used for CO_2 methanation.
2) Granule type catalyst is less influenced by space velocity and temperature than honeycomb type catalyst and is easier to be made, which suggests that granule type catalyst is better than honeycomb type catalyst in application of commercial system.
3) It was ascertained that CO_2 can be converted to renewable energy by applying granule type catalyst.

ACKNOWLEDGMENT

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STUDY OF ACID MINE WATER MANAGEMENT IN ONE MINING COMPANY THROUGH UTILIZATION OF COAL ASH (FLY ASH AND BOTTOM ASH)

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ABSTRACT

Prevention of acid mine drainage (AMD) can be done by attempting to cover material that has the potential to form AMD (Potentially Acid Forming / PAF) by using Non-Acid Forming (NAF) but the presence of NAF material is often not found in large quantities for can isolate all PAF material. Because other materials are needed as an alternative in preventing AMD formation. One material that has the potential as NAF material that can be used is fly ash (FA) and buttom ash (BA) which is the result of coal combustion at the PLTU. The results of the initial characterization of FA and BA from PLTU around coal mining showed that these samples met TCLP quality standards based on PP 101 in 2014. The XRD test results showed the main minerals from samples taken at coal mining sites is silica (SiO_2), while based on the results of XRF analysis it is known that the forming elements of coal mining samples are silica (Si), Alumina (Al), and alkali Potasium (K). The research was carried out with several variations of the mixture of fly ash and bottom ash as a mine acidic neutralizing material. The FDCL test was carried out on each trial. Validation through trial modeling of the FABA application as a PAF cover layer also showed that pH of leachate water from FA, BA samples and the FABA mixture is alkaline, can even increase the pH value of leachate formed in the layer of Mine Acid Rock which has been added to the FA, BA or FABA mixture.

Keyword : AMD, potentially acid forming, bottom ash, fly ash, non-acid forming

INTRODUCTION

Acid mine drainage (AMD) is the most significant environmental pollution problem associated with mining industry (Sangita, 2010). This is because the resulting environmental impact can be a long-term problem. The impact of AMD can cause problems for aquatic biota, either directly due to high acidity or because of an increase in metal content in the water. Although the issue of AMD is not new in mining, in fact until now the implementation of prevention and management is often difficult to implement.

The mining company under study is a local coal mining company that has been exploiting since 2016 located in West Sumatra. As a result, a large open pit area and ponds containing large Acid Mine Water (AMD) were formed.

The Mining Business Permit area in the exploitation phase of the company is on an area of 72.59 hectares where in that area there are several coal-fired steam power plants (PLTU) which produce solid waste in the form of coal burning coal. Coal ash consists of fly ash and bottom ash. Fly ash (FA) is an ash particle which is carried by exhaust gas and consists of fine particles. Bottom ash (BA) has a particle size larger and heavier than fly ash, so the bottom ash will fall at the base of the boiler. Based on previous research, it is known that FA and BA have the potential to be used as non-acid forming (NAF) material to neutralize AMD.

In the province of West Sumatera there are two power plants managed by PT. PLN (Persero), namely Ombilin PLTU and Teluk Sirih PLTU. With an installed capacity of 200 megawatts, Ombilin PLTU produces by-products in the form of FABA of 220,000 tons / year, while PLTU Teluk Sirih which has an installed capacity of 224 megawatts can produce FABA waste of ± 245,000 tons / year. FABA waste management is generally limited to temporary stockpiling at TPS or cooperating with third parties as raw material for cement or paving blocks and concrete blocks which only use about 15% of the total tons / year FABA generation. So there is a huge potential (± 85% of tonnes / year FABA generation) in utilizing FABA as NAF material for mining activities, especially in the coal mining companies under study.

SAMPLE AND METHOD

SAMPLE

In conducting mine acid water management in the coal mining companies studied, it is necessary to do soil and rock characteristics. The characteristics are done by taking samples of mine acid water and soil around the location of the excavated pit. Sampling of mine acid water was carried out at 2 locations. The characteristics of mine acid water samples are important to know the quality of acid mine drainage that has the potential to be formed at the company's location. In addition, land sampling is also located at the mining site.

METHOD

• The method of site investigation work consists of four phases, namely desk study, field work, studio work, and comprehensive analysis.

• Methods of analyzing rock samples and mine acid water

a. Mineralogical analysis of rocks: using X-ray assistance, two methods used X-Ray Diffraction (XRD) and Xray Flourescence (XRF).

b. Static Test: includes several tests namely total sulfur, paste pH, acid neutralizing capacity (ANC) Test, Net Acid Generation (NAG) Test

c. Modeling the FABA application as a PAF cover was carried out as a complement for the static tests that had been carried out. In this study the Free Draining Column Leach (FDCL) Test method was chosen.

In the study of the utilization of fly ash and bottom ash as acid mine neutralizing material, the FDCL test was carried out in 5 experiments with the following composition.

• Experiment I: water + mine acid rock (BAT), with a ratio of water: BAT 2: 1
• Experiment II: water + fly ash + BAT
• Experiment III: water + bottom ash + BAT
• Experiment IV: water + BAT + fly ash and bottom ash
• Experiment V: water + fly ash and bottom ash + BAT

RESULTS AND DISCUSSION

1. Results of Testing of Rock and Acid Mine Water Samples

1.1 Mineralogy Analysis with X-Ray Diffraction.

The XRD test is carried out to determine what mineral composition is contained in the sample. It is important to know the source of acid carrier minerals and acid neutralizing minerals contained in the sample. In addition, it can also be seen from the results of these minerals that contain heavy metals. The results of the XRD analysis for samples taken at the mining company location are shown in Figure 1.

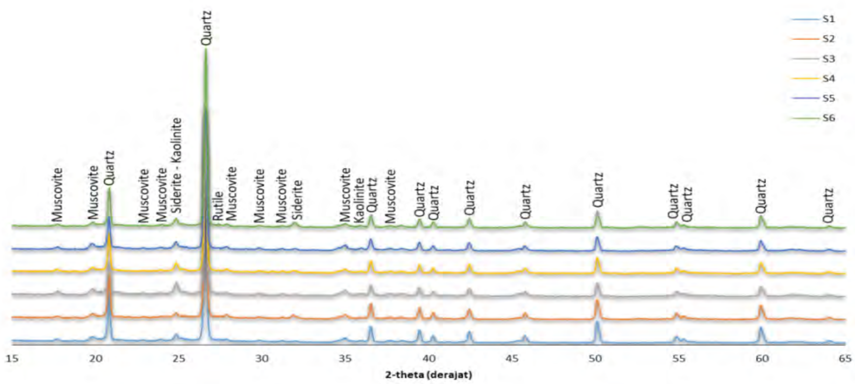

Figure 1. XRD analysis results from six samples taken at the coal mining company

1.2 Testing Elements in Samples with X-Ray Fluorescence (XRF)

The XRF test results in the quantity of elements and compounds contained in the sample. The XRF analysis results for 6 samples taken from the location of the coal mining company are shown in Table 1. The XRF test results can be used to find out the sources of minerals and elements and compounds related to the main source of acid carriers and metal contaminants. The XRD and XRF test results were used to strengthen the static test results and trial modeling of the FABA application as the PAF cover that had been done.

Table 1. XRF Analysis Results from Six Samples Taken at the coal mining company

	Element Concentration	Concentration in the Sample Code					
		S1 (%)	S2 (%)	S3 (%)	S4 (%)	S5 (%)	S6 (%)
Concentration (%)	**Na**	-	0,0688	-	-	-	0,0608
	Mg	0,2210	0,4180	0,3430	0,3410	0,3870	0,3170
	Al	15,1000	13,9000	19,3000	17,000	18,700	16,000
	Si	69,100	64,800	57,100	57,300	56,300	5,8000
	P	-	-	-	0,1170	0,0678	-
	S	**1,272**	**1,555**	**1,020**	**1,160**	**1,0500**	**1,4170**
	Cl	0,0196	-	-	0,0326	-	-
	K	6,580	6,340	7,410	6,240	7,600	5,660
	Ca	0,3750	0,6290	0,3460	14,600	0,8700	0,5750
	Ti	2,0900	1,9300	2,2400	1,8000	1,6900	1,6100
	Mn	-	0,1220	0,2160	0,3590	0,2170	0,4610
	Fe	5,550	11,000	12,200	13,600	12,700	16,300
	Zn	0,0660	0,0788	-	0,0775	0,0621	0,0581
	Rb	0,0839	0,0659	0,0983	0,0776	0,0903	0,0656
	Sr	0,0429	-	0,0621	0,0637	0,0483	-
	Zr	0,1870	0,1570	0,1280	0,1480	0,1380	0,1680
	W	0,2590	-	-	0,2830	-	0,2320

2. Static Test Results

The results of static tests for samples taken at mining sites, fly ash and bottom ash samples from PLTU around the crossings are shown in Table 2. It is shown that the largest pyrite content is found in the S-3 coal mining sample, and samples of fly ash, bottom ash and

FABA mixtures contain very small amounts of pyrite compared to samples of coal mining.

Table 2. Static Test Results Samples of coal mining and FABA

No	Sample Code	Elevation (mdpl)	Total Sulfur	MPA[1]	ANC[2]	ANC/MPA	NAPP[2]	pH Pasta	NAG pH	NAG	
										pH 4,5	pH 7
1	S-1	242,7	1,272	38,95	1,98	0,051	36,97	6,35	3,27	3,92	13,90
2	S-2	244,6	1,555	47,61	4,60	0,097	43,01	5,49	2,94	3,87	11,72
3	S-3	262,8	1,602	49,05	1,76	0,036	47,29	5,12	2,69	4,11	16,28
4	S-4	255,3	1,160	35,50	4,29	0,121	31,21	5,26	3,18	4,75	12,34
5	S-5	256,8	1,070	32,76	8,84	0,269	23,92	5,67	3,75	4,52	12,71
6	S-6	275,5	1,407	43,08	3,15	0,073	39,93	5,53	2,77	5,30	15,16
7	S-7 *Bottom Ash*	-	0,170	5,21	7,81	1,499	-2,6	10,71	8,11	0	0
8	S-8 *Fly Ash*	-	0,301	9,22	12,57	1,363	-3,35	10,12	6,98	0	0
9	S9 FABA mixture	-	0,219	6,71	9,94	1,481	-3,23	10,66	8,02	0	0

[1] unit in kg H2SO4 / ton
[2] units in kg H2SO4 / ton of rock

3. Characteristics of Fly Ash and Bottom Ash Test from the PLTU in the vicinity of the coal mining

3.1 Total Metal Content Test

Testing the total metal content in the FA, BA, and FABA mixtures from the PLTU around the coal mining is carried out to determine the total concentration of contaminated heavy metals contained in the sample. The results of the total test of metal content can be shown in Table 3.

Table 3. Total Test Results for Metal Content of FA, BA and FABA Mixtures

No	Parameters	Analysis results(mg/L)			Maximum Level Lampiran V PP 101/2014		
		FA	BA	FABA	Column A	Column B	Column C
1	Antimony, Sb	0,10	0,11	0,08	300	75	3
2	Arsenic, As	0,59	0,10	0,08	2000	500	20
3	Barium, Ba	<0,005	<0,005	<0,005	25000	6250	160
4	Beryllium, Be	<0,005	<0,005	0,67	4000	100	1,1
5	Boron, B	57,11	69,78	79,44	60000	15000	36
6	Cadmium, Cd	0,89	0,71	0,08	400	100	3
7	Chromium, Cr	2,33	0,78	1,33	2000	500	1
8	Copper, Cu	25,56	18,89	5,44	3000	750	30
9	Lead, Pb	848,89	80,00	20,00	6000	1500	300
10	Mercury, Hg	0,10	0,06	0,07	300	75	0,3
11	Molibdat, Mo	96,67	108,89	96,67	4000	1000	40
12	Nickel, Ni	0,84	0,90	1,38	12000	3000	60
13	Selenium, Se	0,26	0,14	0,15	200	50	10
14	Silver, Ag	<0,001	<0,001	<0,001	720	180	10
15	Zinc, Zn	57,78	138,89	71,11	15000	3750	120

3.2 Toxicity Characteristics Leaching Procedure Test (TCLP)

TCLP test results on samples of FA, BA and FABA mixtures from PLTU and TCLP quality standards which refers to Government Regulation No. 101 of 2014 is shown in Table 4 and it can be concluded that all test parameters have values that do not exceed TCLP quality standards.

Table. 4. TCLP Test Results for FA, BA, and FABA Mixtures

No	Parameters	Analysis results (mg/L)			PP No. 101 Tahun 2014	
		FA	BA	FABA	TCLP A	TCLP B
1	Antimony, Sb	0,021	0,032	0,054	6	1
2	Arsenic, As	0,060	0,09	0,064	3	0,5
3	Barium, Ba	0,749	0,392	0,811	210	35
4	Beryllium, Be	<0,001	<0,001	<0,001	4	0,5
5	Boron, B	<0,030	<0,026	<0,030	150	25
6	Cadmium, Cd	0,007	0,007	0,010	0,9	0,15
7	Chromium, Cr	<0,001	<0,001	<0,001	15	2,5
8	Copper, Cu	<0,001	<0,001	<0,001	60	10
9	Lead, Pb	<0,001	<0,001	<0,001	3	0,5
10	Mercury, Hg	<0,00001	<0,00001	<0,00001	0,3	0,05
11	Molibdat, Mo	0,015	0,029	0,013	21	3,5
12	Nickel, Ni	0,024	0,023	0,014	21	3,5
13	Selenium, Se	0,131	0,081	0,171	3	0,5
14	Silver, Ag	<0,001	<0,001	<0,001	40	5
15	Zinc, Zn	<0,001	<0,001	<0,001	300	50

4. Modeling results are testing the FABA application as a PAF cover

Modeling the FABA application as a PAF cover was carried out to validate the static test results, estimate the long-term weathering rate, see the oxidation behavior in rock samples in the long term and estimate the potential of samples to produce materials that can affect the environment. Modeling the FABA application as a PAF cover in this study was carried out using the Free Draining Column Leach (FDCL) method in approximately one month. There were 5 experiments conducted in the modeling trial of the FABA application as the PAF cover layer in this study. The results of each trial column are described as follows.

4.1 Experiment I (Water + Acid Mine Rock)

In experiment I, the column is filled with water and mine acid rock (BAT) originating from the coal mining location with a ratio of 2: 1. The measurement of pH, conductivity (EC) and DO. The results of measurements of the experimental leachate I water samples are shown in Table 5. Measurements in experimental leachate I samples showed a tendency to decrease pH and DO values and increase conductivity values (EC). This shows that BAT can produce leachate with an acidic one, as seen from the measurement of the 1st day which has given a pH value of 6.82 and continues to decrease until the 25th day shows a pH value of 4.21.

Table 5. Results of Measurement of Leachate Water Sample Experiment I

Days to-	Experiment I column Mine Acid Rock (BAT)		
	pH	conductivity	D.O.
1	6,82	3,45	7,21
3	6,52	3,9	7,19
5	5,57	4,07	7,59
7	5,53	4,07	7,45
9	5,51	4,33	6,57
11	5,54	4,28	6,38
13	5,64	4,5	5,39
15	5,63	4,44	4,4
17	5,61	4,45	4,15
19	5,11	4,49	4,19
21	4,64	4,34	4,21
23	4,28	5,45	2,83
25	4,21	5,5	2,99

4.2 Experiment II (Water + Fly Ash + Acid Mine Rock)

In experiment II, columns were added with Fly Ash (FA) originating from the PLTU, thus forming a top-down arrangement of water, fly ash and BAT. measurements of pH, conductivity (EC) and DO were measured with the results shown in Table 6. The conductivity value of the SFA sample (1) gradually decreases indicating that there is less metal content dissolved. And the DO value decreased from 7.15 mg / L to 4.18 mg / L. Whereas in the sample SFA (2) the pH results tend to be neutral which ranges at pH 7 and the conductivity values that tend to be stable range from 3.03 - 3.94 mS / sec. It can be concluded that the addition of FA can increase the pH value of BAT leachate.

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.Table 6. Result of Measurement of Leachate Water Sample Experiment II

Days to-	Experiment II column Fly Ash (FA) and BAT					
	SFA (1)			SFA (2) "Acidic rocks"		
	pH	conductivity	D.O.	pH	conductivity	D.O.
1	6,68	3,51	7,15	6,87	3,03	7,05
3	7,2	2,34	7,16	7,57	3,42	5,46
5	11,26	2,83	7,31	7,65	3,4	5,03
7	11,38	2,52	6,82	7,51	3,6	5,01
9	11,42	2,51	6,17	7,65	3,59	4,99
11	11,39	2,68	5,41	7,67	3,55	4,39
13	11,45	2,84	4,49	7,7	3,84	4,43
15	11,43	2,87	3,96	7,72	3,61	4,23
17	11,41	2,85	4,57	7,7	3,94	4,28
19	11,45	2,94	4,82	7,16	3,99	3,87
21	11,36	2,79	4,34	7,68	3,65	3,52
23	11,32	2,76	4,34	7,78	3,89	3,57
25	11,44	2,77	4,18	7,68	3,93	3,73

4.3 Experiment III (Water + Bottom Ash + Acid Mine Rock)

In general, experiment III is almost the same as experiment II, but with the addition of a Bottom Ash (BA) layer from the PLTU. The results of measurement of pH, conductivity (EC) and DO values for leachate samples can be seen in Table 7.

Table 7. Result of Measurement of Leachate Water Sample Experiment III

Days to-	Experiment II column Bottom Ash (BA) and BAT					
	SFA (1)			SFA (2) "Acidic rocks"		
	pH	conductivity	D.O.	pH	conductivity	D.O.
1	6,54	3,38	7,17	6,67	3,25	7,04
3	6,28	3,42	7,05	6,54	3,46	7,12
5	7,45	3,55	7,19	6,55	3,52	6,01
7	7,26	3,68	7,04	6,53	3,27	6,13
9	8,15	2,92	6,37	6,44	4,07	5,61

Days to-	Experiment II column Bottom Ash (BA) and BAT					
	SFA (1)			SFA (2) "Acidic rocks"		
	pH	conductivity	D.O.	pH	conductivity	D.O.
11	8,29	2,95	5,63	6,75	3,32	5,53
13	8,44	2,83	5,52	6,57	3,34	4,25
15	8,38	2,97	4,26	6,69	3,37	4,23
17	9,41	2,83	4,48	6,63	3,33	4,56
19	9,94	2,89	5,14	7,04	3,34	4,15
21	9,47	2,87	4,44	6,77	3,31	4,57
23	9,61	2,89	4,68	6,68	3,26	4,39
25	9,49	2,98	5,16	6,73	3,32	4,54

4.4. Experiment IV (Water + Acid Mine Rock + Fly Ash Bottom Ash Mixture)

The FABA mixture layer is carried out after the BAT layer. So that the arrangement of the layers from top to bottom is water, BAT, and the mixture of FABAH results in measurements of pH, conductivity (EC), and DO samples of SFABA (1) and SFABA (2) can be seen in Table 8.

Table 8. Result of Measurement of Leachate Water Sample Experiment IV

Days to-	Experiment II column mixture of fly ash and bottom ash (FABA) and BAT					
	SFABA (1) "Acidic rocks"			SFABA (2)		
	pH	conductivity	D.O.	pH	conductivity	D.O.
1	6,89	3,41	6,83	7,64	2,84	7,11
3	6,74	3,25	6,89	7,68	3,03	6,07
5	6,76	3,91	7,05	7,96	3,11	6,05
7	6,32	4,08	5,47	7,96	8,18	5,13
9	6,24	4,15	5,55	8,06	3,23	5,21
11	6,04	4,19	4,26	8,05	3,25	4,98
13	6,13	4,32	4,38	8,007	3,29	4,56
15	6,15	4,28	4,15	8,04	3,24	3,13
17	6,13	4,32	4,45	8,03	3,26	3,52
19	6,08	4,35	3,85	8,36	3,27	3,99
21	5,19	4,32	2,68	8,15	3,21	3,81
23	4,54	4,31	2,46	8,18	3,18	3,28
25	4,51	4,43	2,42	8,31	3,12	3,25

4.5 Experiment V (Water + Fly Ash Bottom Ash + Acid Mine Rock Mixture)

The arrangement in experiment V is the opposite of experiment IV, which is in the form of a layer of water, a mixture of FABA and BAT. The results of pH measurements, conductivity (EC), and DO samples of SFABA (3) and SFABA (4) are shown in Table 9.

Table 9. Result of Measurement of Leachate Water Sample Experiment V

Days to-	Experiment II column mixture of fly ash and bottom ash (FABA) and BAT					
	SFABA (3)			SFABA (4) "Acidic rocks"		
	pH	conductivity	D.O.	pH	conductivity	D.O.
1	6,37	3,34	7,02	6,31	3,33	7,01
3	6,38	3,43	7,02	6,34	3,46	6,87
5	7,3	3,51	7,11	6,46	3,54	6,32
7	7,36	3,49	7,05	6,43	3,35	6,13
9	7,89	2,97	6,29	6.46	3,47	5,42
11	8,11	2,95	5,72	6,62	3,32	5,53
13	8,21	2,85	5,55	6,57	3,24	4,11
15	8,18	2,77	4,31	6,59	3,29	4,29
17	8,41	2,83	4,32	6,61	3,31	4,49
19	8,4	2,88	4,44	6,59	3,31	4,11
21	8,37	2,88	4,41	6,72	3,31	4,52
23	8,44	2,89	4,57	6,65	3,24	4,35
25	8,42	2,92	5,03	6,63	3,22	4,54

From the five modeling experiments, testing the application of FABA as the PAF cover with the FDCL method above, it can be concluded that by adding the FA, BA or FABA layer above the BAT layer, the addition of the FABA mixture layer below the BAT layer can increase and maintain the pH value remain neutral. This can happen because basically the FA and BA, especially the FA, are alkaline with a pH around 11 so that they have the potential to neutralize leachate water from BAT.

5. **Trial Modeling results of FABA application and Static Test**
Based on the results of the static test and interpretation of the classification of samples based on the potential for acid mine formation, it was concluded that all samples taken from the coal mining is PAF material, while samples of FA, BA and FABA mixtures are NAF material. These results were validated by modeling the FABA application as a PAF cover layer and the same results were obtained, namely leachate produced from the BAT layer was acidic, according to the quality of mine acid water samples taken at the coal mining. As well as samples of FA, BA, and FABA mixtures from the PLTU that show alkaline pH measurements, they can even increase the pH value of leachate formed in the layers of BAT that have been coated with FA, BA, or FABA mixture.

6. **Calculation of FABA Needs for Neutralization of Acid Stones**

Based on the static test results, it is known that the MPA value of the samples taken at the mining site ranges from 32.76 - 49.05 kg H_2SO_4 / ton, with an average of 41.16 H_2SO_4 / ton. The S-6 coal mining sample is a sample that has an MPA value close to that average value, so this sample will be used as a reference in calculating the acidity potential at the mining site. Samples of S-6 coal mining were on sandy clay / soil lithology with a density of 1,470 kg / m^3. Thus the mass of overburden rocks that have the potential to cause acid mine drainage in the mining area is 4,116,000 tons. So the potential for acidity that can arise in the mining area is 100,000 tons of H_2SO_4.

7. **CONCLUSION AND RECOMMENDATION**

a. The XRD test results showed that the main minerals from the samples taken at the mining site were silica (SiO_2), followed by clay (kaolinite) and muscovite as other minerals. No sulfide minerals such as pyrite were found in these samples. While based on the results of XRF analysis it is known that the forming elements of coal mining samples are silica (Si), Alumina (Al), and alkali Potasium (K). The average content of sulfur in the coal mining sample is 1.34%.

b. The results of the initial characterization of fly ash (FA) and bottom ash (BA) from the PLTU around coal mining showed that these samples met TCLP quality standards based on PP 101 of 2014.

c. Mining pit in coal mining planned to be stockpiled has the potential to cause acidity of 100,000 tons of H_2SO_4. To neutralize the acidity potential, it takes 56,000 tons of CaO or 3,758,389 tons (1.75 m^3) of FABA from PLTU around coal mining

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LIFE CYCLE ASSESSMENT OF ON-SITE DOMESTIC WASTEWATER TREATMENT SYSTEM IN INDONESIA

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ABSTRACT

Central sewer system coverage in Indonesia is only 3%, and a conventional on-site treatment system which is called Septic tank is commonly used to treat domestic wastewater in both of household and industrial sectors. However, there are concerns that its environmental burden is high in the operational stage as well as disposal stage. In the operational stage, it emits high concentrate of methane (CH_4) and nitrous oxide (N_2O), also produces sludge as waste. In the disposal stage, large amount of rubbles are disposed in landfills. Japanese technology of Johkasou has been adopted as an alternative system of Septic tank, starting from industrial sectors such as major factories. The objective of this study is to conduct a Life Cycle Assessment (LCA) and compare the two different types of wastewater treatment system which is installed in a factory; a septic tank and a Johkasou of which is installed in Indonesia but is originally developed in Japan, for the purpose of mitigating the environmental burden of wastewater treatment system in Indonesia.

Keywords: Life cycle assessment, wastewater treatment, Johkasou, septic tank, inventory data

INTRODUCTION

Providing sanitation facilities for all and encouraging hygiene at every level by 2030 became one of the targets of Sustainable Development Goals (SDGs) which is adopted at United Nations Summit in 2015. In response to that, Indonesian government made an original goal to increase sanitation access to 100% of population; 15% of central sewer system and 85% of on-site system by 2019[1)]. In 2013, only 3% of population has access to central sewer system, 58% are using on-site system, and remains have not access to sanitation facilities. Under circumstances, conventional Septic tank is most commonly used as on-site wastewater treatment system. However, it is concerned that environmental burden of Septic tank is high because it emits high CH_4 through anaerobic treatment proses. Also, its treatment performance is often not enough to meet national effluent standard, and the untreated effluent of Septic tank might directly contaminate the soil and water body. Instead of the conventional Septic tank, Japanese technology of *Johkasou* is expected to be installed as alternative on-site treatment system in Indonesia. Given that on-site system would cover the most of the population in the near future, besides the central sewer system, environmental impact assessment of on-site system is also necessary to mitigate environmental impact of wastewater treatment system in Indonesia.

By the way, Indonesia is the world's fourth largest emitter of greenhouse gases, mainly due to the conversion of its forests and carbon-rich peatlands. In November 2016, Indonesia submitted its target of reducing GHG emissions by 2030: 29% by their own efforts or 41% beyond business-as-usual (BAU) [2), 3)]. One of the targets is mitigating GHG emissions from wastewater management section. With the development of wastewater treatment system in Indonesia, along with cost and treatment performance, GHG emissions also should be taken into an account to decide the facilities. However, there is not enough inventory data available to calculate the accurate volume of GHGs in Indonesia. Although there are some previous studies on life cycle assessment (LCA) of *Jokasoou* including some cases in Japan [4)-9)], there is no report on LCA of Septic tank and *Johkasou* with actual measurements of GHGs emissions which is directly emitted from the facilities. On the wastewater treatment proses, CH_4 and N_2O are emitted as GHGs. N_2O has a Global Warming Potential (GWP) 265 times, and CH_4 has a GDP 28 times higher than CO_2[10)]. Also, those gas emissions are fluctuate depends on climate, wastewater composition, and other regional conditions. It means clarifying the accurate volume of CH_4 and N_2O emissions on the operation stages is important to assess the wastewater treatment system, other than aggregating date of input resource and energy, and CO_2 emission[11)].

The objective of this study is collecting and analyzing the inventory data of life cycle of conventional Septic tank and *Johkasou* which is developed in Japan, but installed in Indonesia, and compare life cycle GHGs emission between the two different types of systems.

INVENTORY DATA COLLECTION

Analysis Object

This study examines environmental burden of life cycle of one Septic tank and one *Johkasou*. The functional unit is wastewater treatment for one person per year. The details of the system are shown in Table 1. Both systems are located at the same factory in Jakarta, Indonesia, and inlet water quality and patterns are almost the same. Inlet wastewater contains black water from toilet and grey water discharged from hands wash basin. Working hours are 8 hours per day. Because the object of this study is domestic wastewater treatment system which is installed in a factory, and its usage conditions are different from those installed in household, it is not possible to simply compare them to sewer system or *Johkasou* which is installed in household.

Table 1 Outline of the analysis subjects

System	Capacity (㎥/day)	Volume of tank (㎥)	Number of user (person)
Septic Tank	–	7.22	164
Johkasou	30	21.04	357

Common type of Septic tank doesn't have bottom, and the raw water may potentially seep into the underground. However, in this study, the environmental burden of underground seepage is not considered because underground structure of Septic tank of the object is unknown because the drawing is not available. The structure of Septic tank shown in Figure 1 is made from hearing results. Treatment process of *Johkasou* is shown in Figure 2.

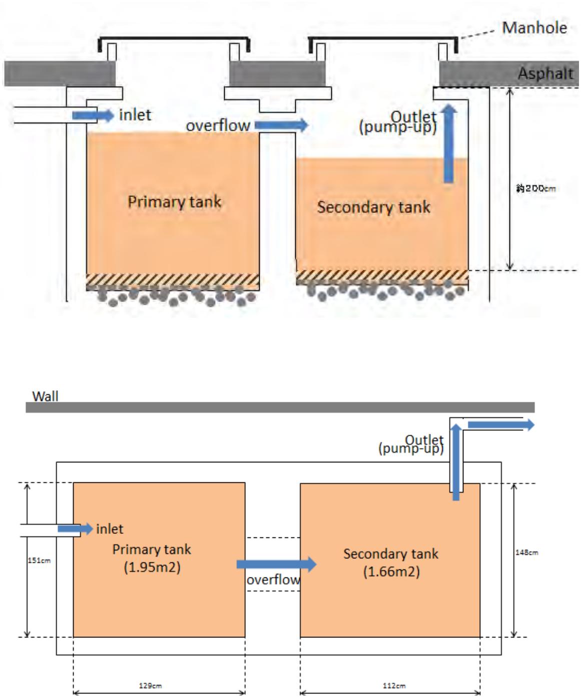


Figure 1 Structure of Septic tank

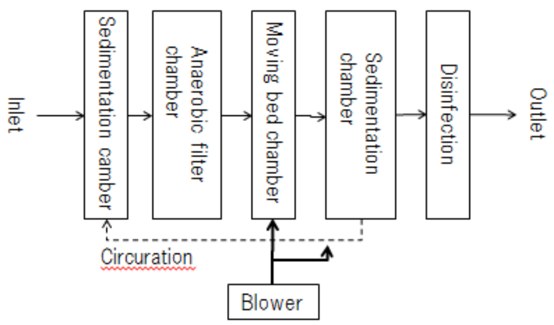


Figure 2 Treatment process of *Johkasou*

Evaluation indicators

The amount of GHG emissions and waste generation of each life cycle stage of Septic tank and Johkasou are calculated. The life cycle stages include material procurement, manufacturing, transporting products, installment, operation and disposal. Evaluation indicators are shown in Figure 3. Input of Johkasou includes electricity to manufacturing the product, and to operate with blower. On the other hand, input of Septic tank doesn't include electric power. On the actual site of this study, effluent discharged from Septic tank is delivered to secondary treatment system with water pomp because the effluent doesn't meet the national standard. However, in this study, the effluent is assumed to be discharged directly to the soil of water body without pomp in order to assess common case in Indonesia. Also, chlorine is added into disinfection chamber of *Johkasou*, but it is not used in Septic tank.

On the operation stage, CO_2, CH_4, N_2O are directly emitted from the wastewater treatment facilities, but CO_2 is not counted as GHG because organic substances in the wastewater are biological origin, and it said to be carbon neutral[12)].

Another environmental burden on the operational stage is waste water quality. Indonesian government defined the effluent standard; pH 6-9, BOD 30mg/L, COD 100mg/L, TSS 30mg/L, oil and grease 5mg/L, ammonia (NH4-N) 10mg/L, coliform 3000Co/100mL[13)]. In this study, BOD, COD, SS, NH_4-N are measured as environmental burden, and pH as a reference.

Also, the volume of sludge which is generated on the operational stage, and the volume of used products are calculated as waste. CH4 emissions from the disposal of sludge are calculated in reference to IPCC Guideline[12)].

Both of Septic tank and Johkasou is assumed that the products life is 30 years. After aggregate the input and output data, some of them are divided by 30 as necessary.

Water sampling and analysis

Sampling inlet and outlet water are conducted for 19 days in October 2018, and 25 days in January 2019. Inlet water of Septic tank is taken from the primary tank, and outlet water is taken from storage tank which

Table 2 Water analysis result

System	No. Parameter	Standard	Oct-18		Jan-19		Average		Removal rate
			Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
Septic tank	1 pH	6-9	7.13	7.17	7.07	7.10	7.10	7.14	-
	2 BOD	30 mg/L	130	92	146	119	138	106	23
	3 COD	100 mg/L	257	220	275	250	266	235	12
	4 SS	30 mg/L	173	156	245	221	209	188	10
	6 NH4-N	10 mg/L	-	-	111	67	111	67	40
Johkasou	1 pH	6-9	7.12	6.46	7.18	6.92	7.15	6.69	-
	2 BOD	30 mg/L	150	16	209	17	179	16	91
	3 COD	100 mg/L	301	54	316	56	308	55	82
	4 SS	30 mg/L	308.6	20	326	19	317	19	94
	6 NH4-N	10 mg/L	-	-	107	21	107	21	80

is located after discharged from Septic tank. Inlet water of *Johkasou* is taken from sump pit into which raw water directly flow from the toilet, and outlet water is taken from the control pit of effluent. All samples are analyzed in accordance with Indonesian National Standard (pH: 06-6989.11-2004, BOD: SNI 06-6989.72-2009, COD: SNI 6989.2-2009, SS: SNI 06-6989.3-2004, NH4-N: SNI 06-6989.30-200). The results are shown in Table 2. Septic tank doesn't meet the national standard, and the removable rate was low. Effluent of Septic tank may cause negative effects to the environment, including soil contamination and eutrophication. On the other hand, all of parameters of *Johkasou* meet the national standard except for NH_4-N. It is considered that treatment performance declined because desludging has never done for more than one year since the *Johkasou* was installed.

Gas sampling and analysis

Gas sampling is conducted for 2 days on May 2018, based on the sampling method on previous report[11), 14), 15)]. Gas samples are taken several times a day because the inlet water volume may fluctuate depending on the sampling time. Dynamic chamber method is applied to sampling from Septic tank. 1~2 hours after setting gas chamber (0.051 ㎡) on the water surface of Septic tank, the gases are pumped up from the chamber into aluminum bags. Mini pump (SHIBATA MP- Σ 100HN) was set on 1L/m.

On *Johkasou* sampling, inlet pipe and the manholes are sealed up so that all air from the blower flew out only from the exhausting pipe.

Besides 4 bags of gas samples, 1 bags of air is taken as a background on each time. CH_4 and N_2O was analyzed with GC-8A (SHIMAZU) with Flame Ionization Detector (FID) and GC-8A (SHIMAZU) with Electron Capture Detector (ECD) respectively, in references to previous report[14)]. Gas volume was calculated with the formula below.

$$w = \frac{pVM}{RT}$$

(W: weight, R: Ideal gas concentration, p: pressure, T: Absolute temperature, V: volume, M: Number of moles of gas)

As a result, N_2O and CH_4 emission of Septic tank is 0.00038 and 1.60, and *Johkasou* is 0.0098 and 0.12 respectively. GHG emissions of each system are shown in Figure 3.

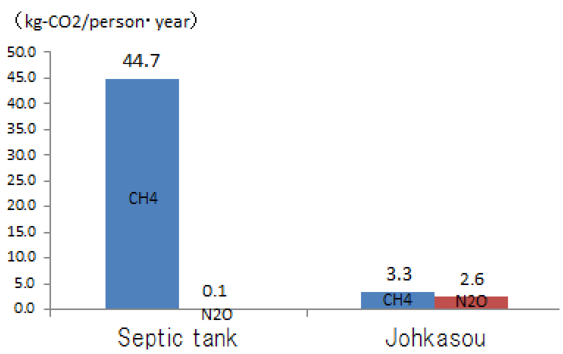


Figure 3 GHG emission

The volume of GHG emission derived from CH_4 of Septic tank is 73% higher than *Johkasou*, and 76% higher in total. GHG emission derived from N_2O of Septic tank was much lower than *Johkasou*, but it implies untreated wastewater with high ammonia content may be discharged directly into soil and water body[18]. This study indicates that there is significant difference between Septic tank and *Johkasou* on GHG emissions, although this result was based on limited data which is collected from only one site, and further survey is needed.

RESULTS OF INVENTRY DATA COLLECTION

Inventory data of each system are shown in Table 3, 4, 5 and 6. The volume of material of *Johkasou,* electric power consumption on manufacturing plant and the blower were calculated from the data provided by the *Johkasou* manufacturer. Fuel consumption was estimated from the volume and transport distance. Consumption of chlorine was estimated as the concentrate is 5mg/L[16]. The volume of sludge generated from Septic tank was calculated in references to previous study in Indonesia [17], supposing the wet volume is 0.5kg/person a day. The volume of sludge from *Johkasou* is calculated from the actual dislodged volume. Dry volume of sludge was calculated as the moisture content is 99.2%.

Table 3 Input inventory of Septic tank

Phase	Item	Volume/tank･year
Material	Sement	31.9 kg
	Bricks	27.6 pieces
	Reinforced steel	3.73 kg
Transportation	Diesel oil	0.01 (t x km)
Installment	Diesel oil	0.757 L
Operation & Maintenance	Diesel oil	1 (t x km)
Waste	Diesel oil	5 (t x km)

Table 4 Output inventory of Septic tank

	Item	Volume/tank･year
Gas emission	CO2	543 kg-CO2
	CH4	262 kg-CH4
	N2O	0.06 kg-N2O
Wastewater effuluent	BOD	317 kg
Waste	Sludge	80 kg-DS
	Rubbles	105 kg

Table 5 Input inventory of *Johkasou*

Phase	Item	Volume/tank･year
Material	Unsaturated polyester resin	61 kg
	Glass roving	14 kg
	Glass mat	5 kg
	PVC	1 kg
	Sement	131 kg
	Reinforced steel	3 kg
Material transportation	Diesel oil	11 (t x km)
Manufacturing	Electricity	45 kW
Products transportation	Diesel oil	1.09 L
Installation	Diesel oil	0.4 KL
Operation & Maintenance	Electricity	6,307 kW
	Chroline	0.06 kg
	Diesel oil	0.18 (t x km)
Disposal	Diesel oil	3 (t x km)

Table 6 Oput inventory of *Johkasou*

	Item	Volume
Gas emission	CO2	7,233 kg-CO2
	CH4	42 kg-CH4
	N2O	3.5 kg-N2O
Wastewater effluent	BOD	104 kg
Waste	Sludge	13.6 kg
	Rubbles	134 kg
	Plastics	3 kg

Because not enough data on CO_2 emission intensity is available in Indonesia, the volume of GHG emissions is calculated in reference to IDEA ver.2. As for the main materials, intensity is multiplied based on the comparison of Indonesia and Japan in reference to previous reports[19), 20)]. Intensities of cement, reinforced steel and unsaturated polyester resin based on IDEA ver.2 are multiplied 1.03, 1.86 and 1.43 respectively. Intensity used in this study is shown in Table 7.

Table 7 Intensity

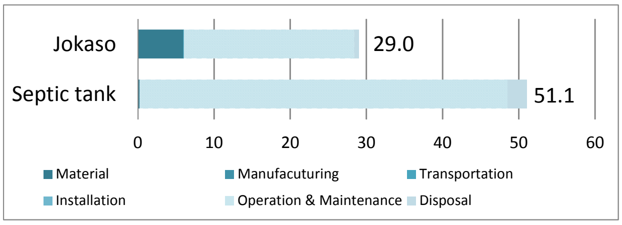
Item	Intensity	
Electricity	0.903 kg-CO2/kWh	18)
Cement	0.362 kgCO2/kg	
Bricks	0.822 kgCO2/piece	
Reinformed steel	1.162 kgCO2/kg	
Unsaturated polyester resin	5 kgCO2/kg	
Galass roving	2.06 kgCO2/kg	5)
Glass matt	2.81 kgCO2/kg	5)
PVC	1.36 kgCO2/kg	5)
Chroline	1.275 kgCO2/kg	
Diesel oil	2.62 kgCO2/L	
Diesel oil	0.08 tCO2/t・km	
BOD	1.517 kg-CO2/kg-BOD	

The volume of BOD is calculated based on the water analysis result shown in table 2, as the volume of row water is 50L/person per day. CO_2 emission intensity of BOD treatment is calculated in reference to the previous report on the electric power consumption of BOD treatment in Japan [23], and CO2 emission intensity of electricity in Indonesia.

COMPARISON OF WASTEWATER TREATMENT SYSTEMS BY LCA

Total GHG emissions of Septic tank and Johkasou are shown in Figure 4.

Figure 4 Total GHG emissions



As a result, the total GHG emissions from life cycle of Septic tank per person a year is 1.76 times higher than *Johkasou*. Althoug GHG emissions from *Johkasou* are higher than Septic tank on the material procurement, transportation and disposal stages, there is no significant difference in the whole life cycle. GHG emissions on operation stage occupy most of the life cycle on both systems. 85% of GHG emissions of Septic tank are derived from CH_4 and N_2O emission. On the other hand, 60% of GHG emissions of *Johkasou* are derived from electricity use of blower. Compared with Johkasou, Septic tank emits GHG 7.6 times higher on the operation stage. Although further study is necessary to increase generality, this study shows that replacing conventional Septic tank with *Johkasou* reduces GHG emissions on operational stage, and by 48% on total life cycle. On the other hand, *Johkasou* needs to reduce the electricity consumption for further reduction of GHG emissions.

CONCLUSIONS

<u>Summary of the results</u>

1) GHG emission of Septic tank is 1.76 times higher than *Johkasou*.
2) As a result of actual measurements of N_2O and CH_4 emissions, direct GHG gas emissions of Septic tank on the operational phase is 7.6 times higher than *Johkasou* (44.8 and 5.9 kg-CO_2eq/person・year respectively). Given GWP of N_2O and CH_4 are relative high, collecting further accurate data is required.
3) To mitigate the GHG emissions of *Johkasou*, further development of energy saving blower is required.
4) Because of the difference of water treatment performance, there is significant difference in quality of discharged water. Discharging untreated wastewater from septic tank may cause negative effects.

Challenges for the further study

1) More data collection of cases in Indonesia is necessary to increase generality, including actual data of gas emissions, volume and pattern of inlet wastewater in order to compare the BOD conversion ratio.
2) More data collection on energy intensity in Indonesia is necessary to figure out more accurate volume of energy emissions.
3) Although it is confirmed that *Johkasou* has high wastewater treatment performance in this study, it fluctuate depends on the maintenance condition. In order to evaluate its performance more accurately, it is necessary to grasp the maintenance condition.
4) In order to evaluate the comprehensive wastewater treatment system in Indonesia, LCA on sewer system is also necessary, besides on-site system.

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APPLICATION OF RESISTIVITY MEASUREMENT FOR ASSESSING THE PLASTIC MATERIAL IN LANDFILL

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ABSTRACT

Landfilling and open dumping are the most common disposal methods of municipal solid waste (MSW) in Thailand. According to the National Waste Roadmap, the old landfilled waste must be managed. Moreover, Ministry of Energy also enforced the waste to energy policy by utilizing MSW as an alternative energy. Landfill mining is the upcoming aspect for these issues. The way to make the effective landfill mining is a systematic planning which needs the qantitative and qualitative information. One of the promising technique that might be used for characterizing the waste composition in the landfill is the resistivity measurement. Normally, this measurement is used in landfill for investigating the moisture distribution and groundwater contamination. In order to test the potential of this technique for evaluating the waste characteristics, the resistivity measurement had been conducted at Phatthalung landfill. One portion of landfill had been measured. After finish the resistivity data processing, fifteen representative of waste samples had been excavated and analyzed for waste composition, moisture content, and heating value. The results showed that the amount of plastic material which will be processed to RDF had strong correlation with the resistivity values (R = 0.748) and moisture content had moderate correlation with the resistivity values (R = 0.503).

Keywords: Resistivity Measurement, Plastic Material, Landfill, Landfill Mining, Refuse Derived Fuel (RDF)

INTRODUCTION

Presently, landfill mining is a new approach that applied to expand MSW landfill capacity and reduce the cost for additional land (Rosendal, 2009). In 2018, the total generated MSW in Thailand was 27.37 million tones (Thailand status pollution report, 2017). Of this amount, only 23% of generated MSW were recovered. About 65% of generated were treated improperly by using open dumpsites. There was only 11% of generated waste which treated properly at landfills, composting plants and incinerators. The waste flow of Thailand is shown in Fig.1. Landfill mining is the promising process in the material recovery from old final disposal sites by excavating the usable materials. The combustible materials can be processed and used as Refuse Derived Fuel (RDF) in power or cement plants. The mining process was proved that emission of waste from the process can be negligible compared to benefits provided from mining (Jain et al., 2014). In order to invest the landfill mining project, the preliminary study of waste characteristics, such as composition, heating values, moisture content and homogeneity, should be conducted. Direct measurement by excavation is traditional method. However, this is a time consuming method. Therefore, resistivity measurement becomes popular to detect and monitor any changes of landfill properties as well as avoid time consuming (Kamura, 2005). In addition, the huge amount of data can be collected with short period.

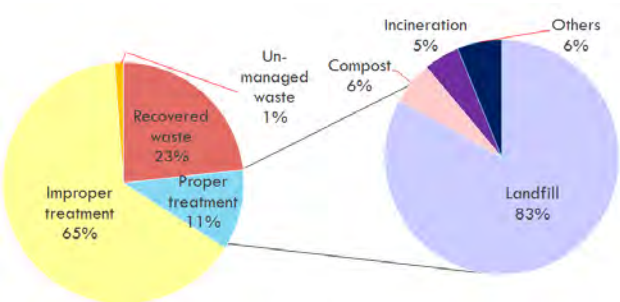

Fig. 1 Waste flow in Thailand

Source: Thailand State of Pollution Report 2017

Electrical measurement is the one of geophysical method that measures the electrical properties of materials. Each material has individual resistivity range. For example, water saturated clay has very low resistivity value while ignore rocks have quite high resistivity (Burger, 2006). Nowadays, geophysical method and resistivity measurement (indirect measurement) is usually used for waste characterization at the dumpsites such as moisture content distribution, geological observation, rock waste dumps containing metallic sulphides, as well as leachate contamination in groundwater and environment (Oladapo, 2013; Dahlin et al., 2010; Campos et al., 2003). In order to study the possibility of resistivity measurement as an indirect tool for assessing the waste properties, the resistivity measurement was conducted. The main objective in this study is to evaluate the relationship between the resistivity values and waste characteristics.

MATERIAL AND METHODS

Site Description

The Phatthalung landfill locates in Phatthalung, Thailand as show in Fig.2 this site locates in the sedimentary rocks and operated since 1996. Currently, the facility accepts MSW approximately 30 tons per day. The total area is about 21 hectares.

In order to protect the groundwater contamination, the liner system was constructed. This system comprises of 0.6 compacted clay, 1.5 mm HDPE sheet, geotextile and 0.3 m compacted sand for drainage layer.

Resistivity Survey

The resistivity measurements were conducted by using 72 electrodes, with a programmable two-way intelligent cable with roll-along mode setup. The GD-10 SUPREME 2D Multi-electrode Res Imaging System instrument which manufactured by Geomative CO., LTD. was used in this study. The resistivity survey line is located north-west to south-east direction as shown in Fig. 2. The spacing of electrodes were set at 2.5 m, resulting in a survey line length was 180 m. (with roll-along mode). The Global Navigation Stateliest System (GNSS) with Real Time Kinematic mode was used to identify the location of each electrode. Apart from that, the Schlumberger configuration was used during the resistivity measurement, as it provides better resolution in terms of vertical direction (probing depth) and less time-consuming field deployment (Boulding, 1993).

The collected fieldwork data was processed using RES2DINVX64 software version 4.03 which used the forward modeling to calculate apparent resistivity values from the fieldwork data. The inversion model with a non-linear least-squares optimization technique was used in the inversion process for creating the 2D resistivity image.

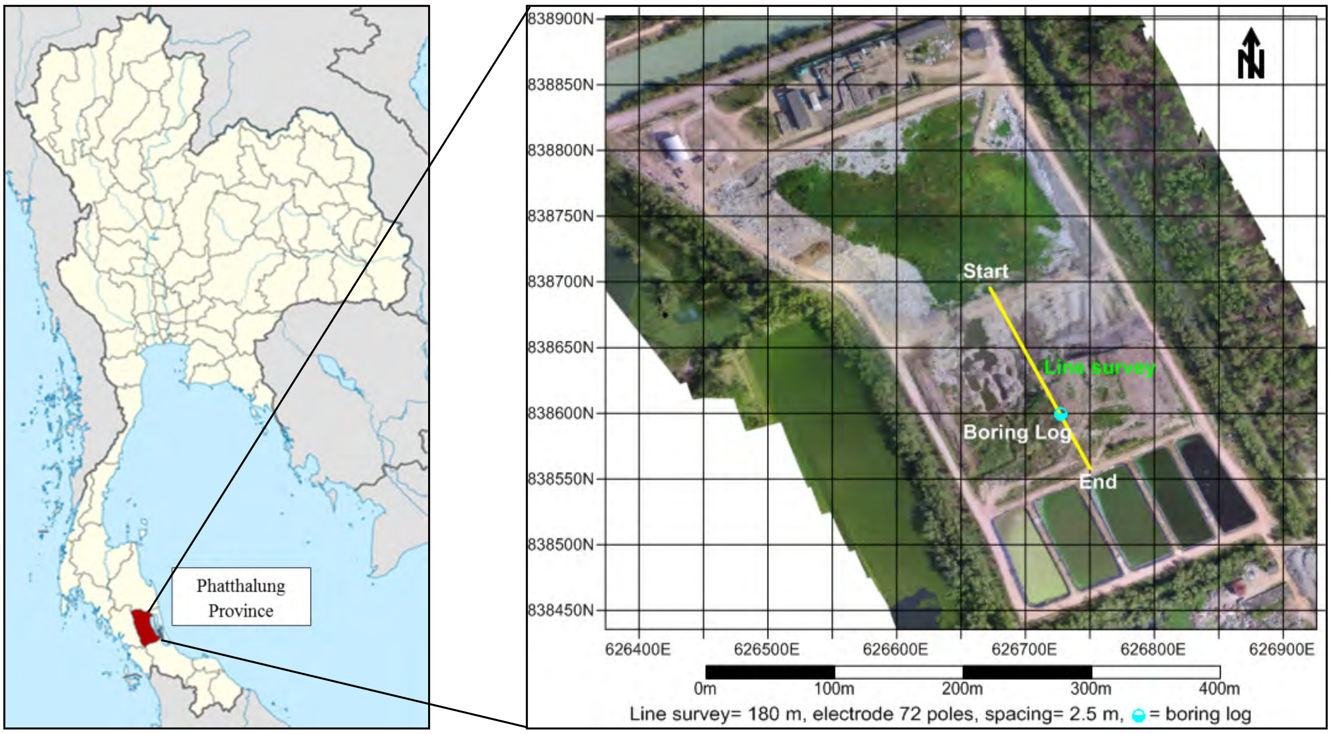

Fig.2 Mapping and survey line in Phatthalung landfill

Waste Characterization

After accomplished the data process, sixteen locations were determined from resistivity values which selected gradually from low to high values from the 2D resistivity image. The locations of excavated representative waste were marked by GNSS with RTK mode. About 200 kg of each sample was excavated by the excavator and minimized to 30 kg by quartering method for further analysis. One kg from this waste was sent to the laboratory for analyzing the moisture content (MC), soil percentage, heating value. The remaining waste was analyzed for the waste composition. After finish, this waste was mixed and reduced to 10 kg by quartering method. This 10 kg of waste was tested for MC. The summary of work flow in this study is show in Fig.3.

When finish the waste analysis, the study of their relationships had been done by using SPSS software version 17.0 for evaluating the correlation between resistivity and waste properties (MC, HV and waste composition) in term of correlation coefficient (R), coefficient of determination (r^2), and standard error of estimate.

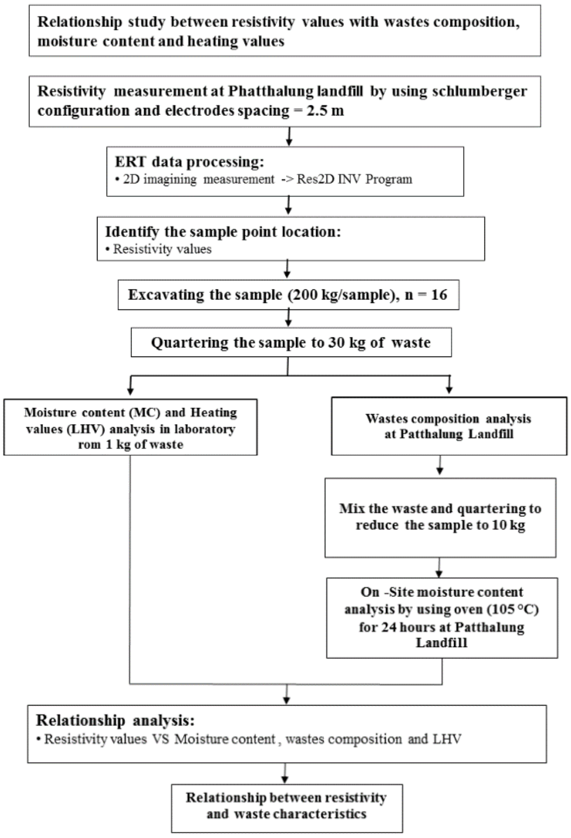

Fig.3 Flow diagram of experiment

Table1 Parameters and Methods for Waste

Parameters	Method
1. Waste composition	Quartering method
2. Moisture content (MC)	Oven drying method at 105 °C (ASTM D 3173-3187)
3. Heating values	Standard Test Method for Gross Calorific and Ash Value of Waste Materials (ASTM D5468-02(2007))

RESULTS AND DISCUSSION

Resistivity measurement with structural landfill

The 2D resistivity image as shown in Fig. 4 illustrates the variation of the resistivity values especially inside in the landfill body. From this image and the compared data from the boring log which shown in Fig. 4, the materials can be classified by using the resistivity values in 3 groups including 1) high resistivity values (> 60 Ohm.m) are hard sandy clay in bottom of section and plastic materials (on the top of section) 2) moderate resistivity values (5-59 Ohm.m) are clay and other waste materials in landfill 3) low resistivity value (< 5 Ohm.m) are saturated clay and leachate of waste.

Both of 2D resistivity imaging data and boring log data are very important input for structural geology analysis. They can be used to identify the boundary of landfill body, which is important information for the waste excavation planning. In this study, the boundary of waste within landfill from the sedimentary rock is clearly identified. It was found that the landfill liner located at the level of -3.0 m. as shown in Fig. 5. Moreover, the resistivity values around that level also implied that the leachate could not penetrate to the sedimentary rock.

The relationships between resistivity and waste characteristics

Sixteen sampling points were selected based on accessibility and workability. The characterization of waste was compared with excavating samples, including LHV, soil percentage, plastic material percentage and moisture content. The resistivity values were varies from 13.1 to 62.0 ohm.m while LHV were varies between 1,260 to 7,000 kcal/kg. Soil percentage and moisture content were in between 13.50% to 82.50%, and 15.91% to 29.14%, respectively. An about 8.03% to 71.38% were for plastic materials as presented in Table 2.

Fig.6 shows the correlation between resistivity value and waste characteristics. It is remarkable that the high percentage of plastic materials lead to the high value of resistivity. Due to high resistivity affected by the high porosity in plastic materials which caused from the voids or air bubbles contained in itself as well as high resistance by itself (Fig.6a). There is an inverse relationship between resistivity and soil percentage that is presented in Fig.6b. The high percentage of soil leads to the low value of resistivity due to the main composition that was found in soil is saturated clay with high water holding capacity. The low value of moisture content should be found in accordance with the high portion of plastic material and low portion of soil, both relate to resistivity value. However, there is no significant correlation between moisture and resistivity because sample materials are not only consisting of plastic and soil but also consist of other materials, which could be contaminated with water or leachate as shown in Fig.6c. As a result of correlation between low heating value (LHV) and resistivity (Fig.6d), there is no significant relationship, since it could have been an influence of dry daily cover on landfill and the results of waste composition show the higher percentage of soil than plastic material in landfill.

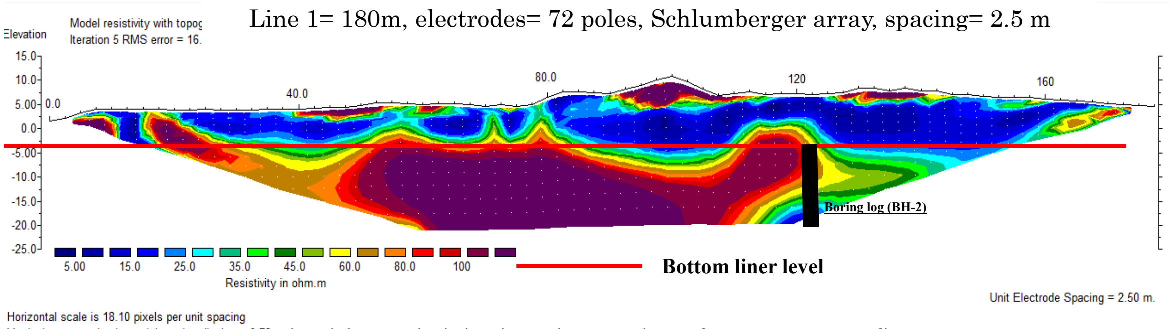

Fig. 4 2D resistivity imaging section of the study landfill

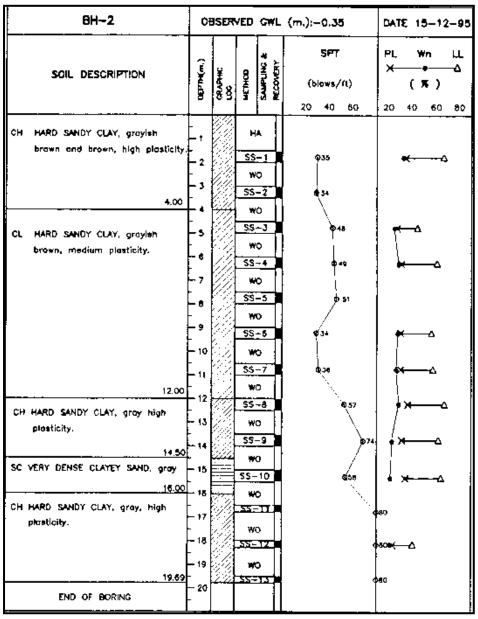

Fig. 5 Boring log data

Table 2 Resistivity values with waste characteristics

Sample Number	Resistivity Values (Ohm.m)	LHV (kcal/kg)	Moisture Content (%)	Plastic Material (%)	Soil (%)
1	38	4,020	22.20	22.25	66.20
2	43	3,020	17.48	26.85	56.00
3	30	4,040	17.99	22.93	47.50
4	24	7,000	15.72	18.06	61.10
5	39	3,110	18.70	33.93	55.70
6	39	4,340	21.03	31.18	66.20
7	16	3,340	25.74	19.27	68.90
8	13	3,780	15.92	16.75	75.50
9	26	3,220	15.91	8.03	82.50
10	45	2,750	23.96	24.89	63.00
11	48	4,350	16.41	31.56	62.20
12	62	4,370	24.41	36.59	56.20
13	35	2,870	23.20	15.77	41.20
14	50	1,260	27.37	30.41	57.80
15	61	2,860	29.14	71.38	13.50
16	60	3,800	22.05	37.66	46.50

R squared (R^2) is used to measure the data are closely fitted to regression line; it also refers to the predictive power of regression model. Normally, the higher R^2 is gained, the better model fits the data. The results as shown on the figure 7, R^2 of model 1 and 2 are higher than R^2 of model 3, but it doesn't mean that model 1 and 2 are more suitable than the other. Additionally, the more added variables bring about the higher R^2 in the regression model. For the reason, adjusted R squared is used to objectively assess the regression model

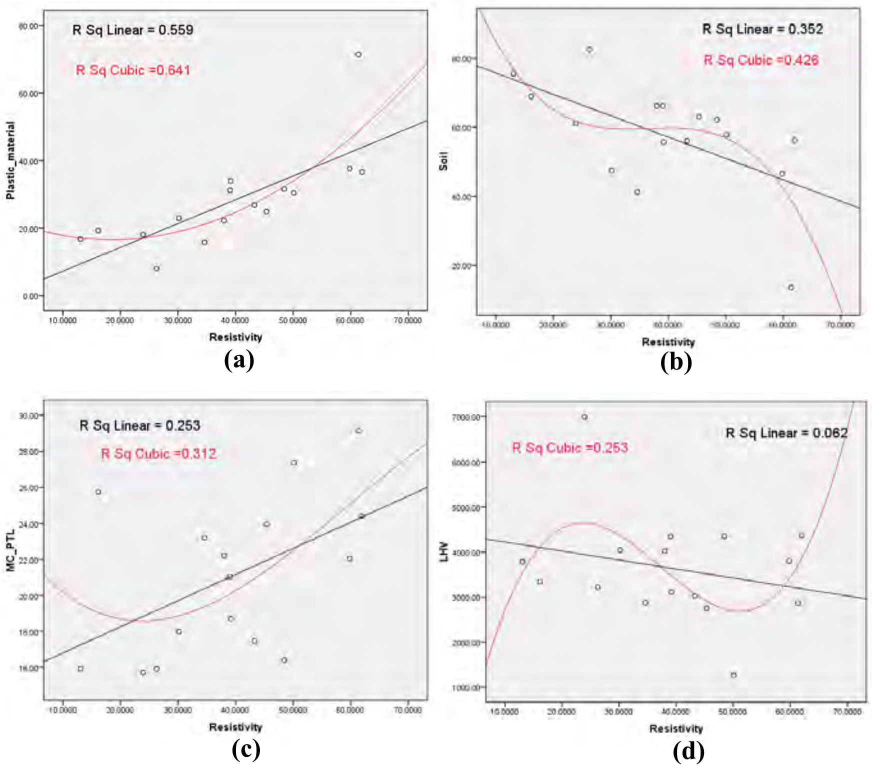

Fig. 6 Linear regressions of resistivity with waste characteristics

	Mathematical Model (Resistivity=constant+aX_1+bX_2+cX_3)	R^2	Adjusted R^2
1	Resistivity= 9.291 + 0.419(MC) + 0.733(%Plastic) + 0.014(%soil)	0.569	0.461
2	Resistivity= 10.533 + 0.431(MC) + 0.722(%Plastic)	0.569	0.502
3	Resistivity= 17.237 + 0.739(%Plastic)	0.559	**0.527**

Fig. 7 Mathematical models

containing different predictive variables. If an added variable suits to the regression model, adjusted R^2 increases, and vice versa. The result shows that model 3, relationship between resistivity and %plastic material, is the most appropriate model as the highest adjusted R^2 (0.527). Moreover, the correlation level of both is strong as shown on Fic.6a, while the others are weakly relate to resistivity leading to the decrease of adjusted R^2 in the regression models. It is clear that resistivity could estimate plastic material proportion in this study.

CONCLUSIONS

From the results of this study, the implementation guideline of landfill mining using indirect measurement (ERT) is obtained. The mathematical model is used to analyst the relation between resistivity value and waste characteristics. The resistivity value is mainly affected by plastic materials percentage and follow by soil percentage.

The main conclusions are as follows:

1) The information from 2D resistivity image and soil boring log can be interpleaded and separated the section into 3 categories including (1) high-resistivity value (higher than 60 Ohm.m) derived from "hard sandy clay" in bottom liner level and "plastic material" from the top of landfill, (2) normal-resistivity value (5 to 59 Ohm.m) represented of "clay" and other component in landfill and (3) low-resistivity value (less than 5

Ohm.m) originate from “saturated clay”, “soil-like material” and “leachate”.

2) The apparently correlation of resistivity value is occurred with percentage of plastic material. The moderately and weak correlation are appeared with soil percentage and moisture content, respectively.

It is possible to establish a method for assessing the potential of RDF production from landfill mining by using indirect measurement (ERT). This method could assess the potential for excavated and evaluation of the efficiency for RDF production. However, more excavation sample points should be analyzed in order to obtain high accuracy and precision. Furthermore, the study of the correlation between resistivity value and component of plastic materials by using ERT should be established in open dump; the mainly disposal method in developing countries, for the aspect of waste utilization as RDF production.

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ENVIRONMENTAL AND ECONOMIC EVALUATION OF HYDROGEN RECOVERY FROM MUNICIPAL SOLID WASTE INCINERATION RESIDUE

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ABSTRACT

This paper attempted to apply material flow analysis (MFA) and life cycle assessment (LCA) on a system of hydrogen recovery from incineration residue in order to evaluate its environmental and economic efficiency. Specifically, this study focused on was Clean Park Seibu of Fukuoka city as a target facility, Al flow in municipal waste treatment, life cycle cost and life cycle CO_2 emission of hydrogen recovery system were estimated. A result of material flow analysis on Al in 2015 showed that the amount of Al contained in incineration residue was 686t. In this amount of Al, 90% came from combustible waste and 10% came from incombustible waste. The amount of hydrogen gas recovery of hydrogen recovery system was 15,435Nm^3 and life cycle cost of hydrogen recovery system was 4.25million yen/year. In life cycle cost, 83 % was initial cost and 17% was running cost. According to the estimation of the amount of hydrogen gas recovery and life cycle cost of hydrogen recovery system, hydrogen production cost was 275 yen/Nm^3. In order to meet a standard of hydrogen sales price 103-113yen/Nm$_2$, it is necessary to increase flow rate of hydrogen gas in 8Nm^3/h. And also, it was revealed that the amount of CO_2 emission of hydrogen recovery system and unit CO_2 emission were21.0t-CO_2/year and 1.36kg-CO_2/Nm^3 respectively.

Keywords: Hydrogen gas, incineration residue, municipal solid waste, MFA, LCA

INTRODUCTION

According to the statistics in FY2016, 32.9 million ton of municipal solid waste (MSW) were incinerated in Japan, and 3.1 million ton of incineration residue generated (Ministry of the Environment, Japan, 2018). Aluminum (Al) is contained in incineration residue, and it is known that Al contributes to generation of hydrogen gas (e.g. R.D. Armstrong et al., 1996, Yasuda et al.,1997, Mizutani et al, 2000), but little is known about quantitative information about detailed Al source in MSW and material flow of Al in MSW has not been clarified. In addition, economic and environmental assessment about a hydrogen recovery system from incineration residue has not been accomplished.

This paper attempted to apply material flow analysis (MFA) and life cycle assessment (LCA) on a system of hydrogen recovery from incineration residue in order to evaluate its environmental and economic efficiency. Specifically, this study focused on was MSW treatment plant Clean Park Seibu in Fukuoka, Japan, which has a incineration plant and a crushing-and-sorting plant. Al flow in MSW treatment, life cycle cost (LCC) and life cycle CO_2 (LC-CO_2) emission of hydrogen recovery system were estimated.

Estimation of waste and metal Al flow in MSW treatment

MSW treatment flow of Clean Park Seibu in Fukuoka City was shown in Fig.1. This facility consists of an incineration plant with capacity of 750t/day （250t/day × 3 units） and a crushing-and-sorting facility with capacity of 100t/day (100t/5hours×1unit). Composition surveys were conducted for 256kg of combustible waste sample which was taken from the waste pit of the incineration plant, 10kg of combustible residue and 30kg of incombustible residue which were taken from the crushing and sorting plant. As shown in Fig.2, samples were sorted into aluminum products such as aluminum cans, aluminum foils, plastics and papers deposited with aluminum film on the surface such as food and drink packaging material, and waste without Al, then the weight was measured for each composition. For the wastes which have Al deposition, metal Al content was measured with ICP after conducting wet acid hydrolysis. Bottom ash and fly ash were taken from the incineration plant, then Al content was measured by Atomic Absorption Spectrometry (D. S. Gough, 1976).

Fig.3 shows composition of metal Al in combustible waste and Fig.4 shows metal Al content in the MSW treatment plant. Fig.5 shows estimated flow of MSW treatment regarding metal Al content in each waste fraction. The result shows that the amount of Al contained in incineration residue was 659t. In this amount of Al, 595t (90.4%) came from combustible waste and 63t (9.6%) came from combustible residue generated from crushing and sorting plant.

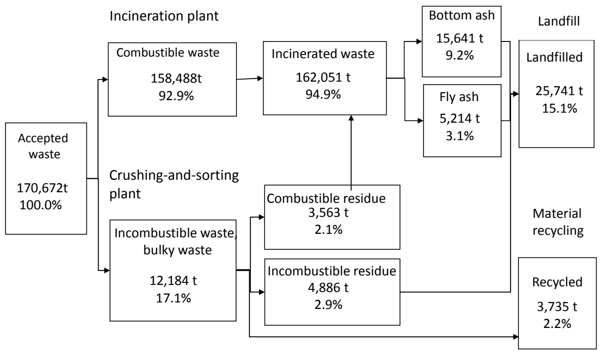

Fig.1 MSW treatment flow in Clean Park Seibu

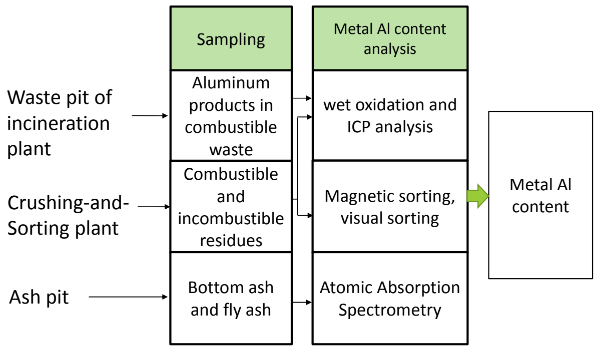

Fig.2 Measurement of metal Al content in MSW and MSWI residues

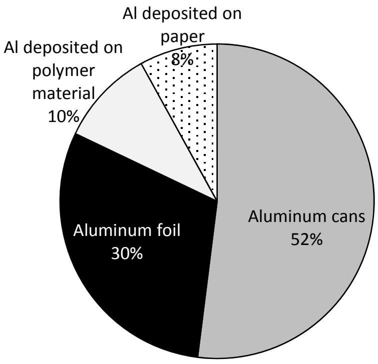

Fig.3 Composition of metal Al in combustible waste in Clean Park Seibu

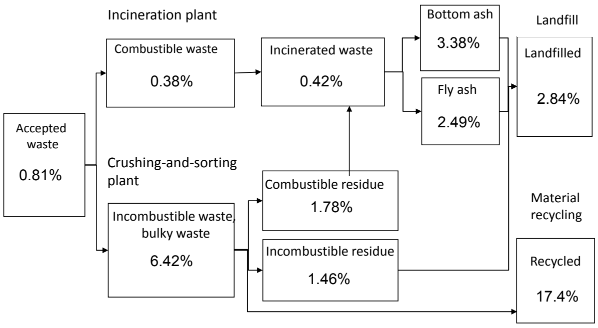

Fig.4 Metal Al content in MSW treatment in Clean Park Seibu

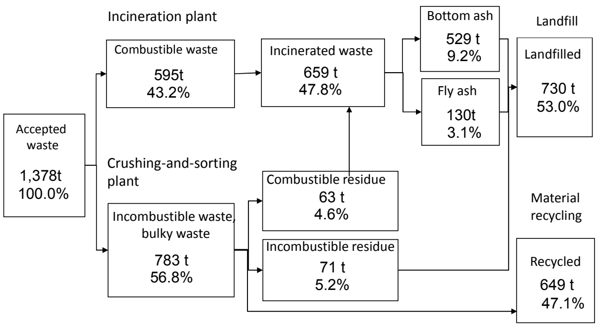

Fig.5 Metal Al flow in MSW treatment in Clean Park Seibu

LCC and LC-CO_2 estimation in hydrogen recovery from MSW incineration residue

LCC and LC-CO_2 were estimated for the system shown in Fig.6. In this analysis, the hydrogen gas generation amount from bottom ash was set as 1500ℓ/t-dry bottom ash according to the previous study by Amirhomayoun Saffarzadeh et.al (2016). At this condition, the estimated flow rate of hydrogen gas was 2N m^3/h, and estimated amount of hydrogen gas recovery of this system was 15,435N m^3/year.

As shown in Table 1, LCC of hydrogen recovery system was estimated 2.91million yen/year. In that cost, 40% was used for hydrogen generation, 30% was used for hydrogen purification, the reset of 30% was used for hydrogen compression. And 83.1 % was initial cost and 16.9% was running cost. According to the results of the amount of hydrogen gas recovery and LCC of hydrogen recovery system, unit hydrogen production cost was estimated 189 yen/Nm^3, which was 17-1.8 times bigger than standard hydrogen gas sales price (Tokyo gas, ENEOS, Iwatani). In order to meet the standard price, it is necessary to increase flow rate of hydrogen gas in 8N m^3/h.

Fig. 7 shows estimated LC-CO_2 emission of the hydrogen recovery system. It was calculated that the annual CO_2 emission was 21.0t-CO_2/year and the unit CO_2 emission was1.36kg- CO_2/Nm^3.

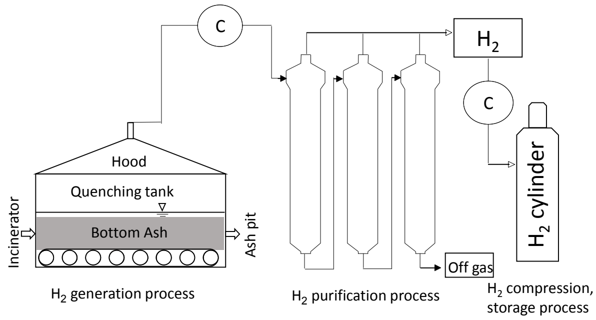

Fig.6 Hydrogen recovery system in this study

Table 1 Estimated LCC of the H_2 recovery system

(Unit: 1000 yen/year)

Process	Initial cost	Running cost	Total (LCC)
H_2 generation	1,100	50	1,150
H_2 purification	650	220	870
H_2 compression and storage	670	220	890
Total	2,420	490	2,910

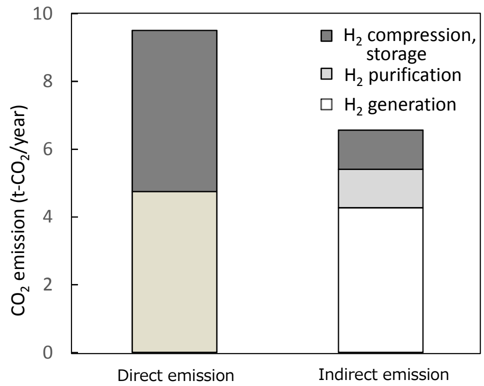

Fig. 7 Estimated LC-CO_2 of the hydrogen recovery system

CONCLUSION

This paper attempted to evaluate environmental and economic potential of the hydrogen recovery from municipal waste incineration residue. The main results of the study were as follows;

From material flow analysis of MSW treatment focusing on metal Al content in the waste, it was revealed that metal Al contained in incineration residue was 659t, and 595t (90.4%) came from combustible waste and 63t (9.6%) came from combustible residue generated from crushing and sorting plant.

The estimated flow rate of hydrogen gas in the hydrogen recovery system was 2N m^3/h, and estimated amount of hydrogen gas recovery was 15,435N m^3/year.

LCC of hydrogen recovery system was estimated 2.91million yen/year, and unit hydrogen production cost was estimated 275 yen/Nm^3 which was 1.7-1.8 times bigger than standard hydrogen sales price.

Annual CO_2 emission of the system was estimated 21.0t-CO_2/year and the unit CO_2 emission was1.36kg-CO_2/Nm^3.

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EFFECTS OF AERATION AND WASTE COMPOSITION ON BIO-DRYING OF MUNICIPAL SOLID WASTES

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ABSTRACT

Municipal solid wastes (MSW) conversion to refuse-derived fuel (RDF) is an alternative energy recovery option. Bio-drying is one of the techniques that can remove moisture from wastes at low cost and increase the energy content of RDF. It relies on microbial activities which generates heat from aerobic decomposition of organic wastes to evaporate water from the waste matrix. This research investigated the effects of aeration and waste composition in bio-drying of MSW. The experiment was conducted at different aeration rates under continuous and intermittent aeration modes using simulated MSW having different organic waste composition. The results showed that moisture content of wastes could be reduced effectively by supplying continuous aeration rate at 0.2 L/min while higher air supplied rate led to physical drying of MSW. Intermittent aeration with same amount of optimum air supply produced treated wastes with non-uniform moisture content. The composition of organic wastes (food, paper, plastic and yard wastes) also affected the oxygen availability for microbial activities. The food waste component determined the extent of heat development whereas bulking materials (plastic & yard wastes) helped facilitating air distribution resulting in homogeneous drying.

Keywords: Aeration, Bio-drying, Moisture, Refuse-derived fuel, Waste composition

INTRODUCTION

The quantity of municipal solid wastes (MSW) is increasing rapidly in the urban area where population and economic condition is growing. Majority of MSW composition are food wastes, plastics, papers and other packaging materials and they are commonly disposed in landfills or open dumpsites. Modern waste management strategy is focusing on the avoidance of solid waste disposal through recycling or transforming them into other useful products. One possible option is to convert MSW into refuse-derived fuel (RDF) for recovering energy from wastes. In Thailand, RDF produced from MSW has high potential to be used in cement kilns and industrial boilers (Nithikul et al., 2011). Nevertheless, pre-treatment may be required for solid wastes with high moisture content before converting them to RDF (Intharathirat and Salam, 2016). Bio-drying is one of the techniques that can remove moisture from wastes at low operating cost. The moisture reduction by bio-drying process relies on microbial activities which generates heat from aerobic decomposition of organic wastes. The produced heat is then utilizes in evaporation of water and the water vapor is transported from the waste matrix by the air flow (He et al., 2013). Nevertheless, determination of appropriate condition for bio-drying process is still a challenging task. In order to have effective bio-drying process, the amount of supplied air should be optimized in order to preserve organic matter in the wastes while allowing bio-drying to proceed utilizing heat released from aerobic microbial activities under limited air supply without allowing significant loss of heat through convective air flow. In this study, the effect of aeration and waste composition on bio-drying of MSW was investigate to optimize bio-drying of MSW with high moisture in laboratory scale lysimeter experiment.

EXPERIMENTAL METHODOLOGY

Laboratory-scale lysimeters having 0.30 m diameter and 1.50 m height were used (Figure 1). The lysimeters were equipped with moisture (volume basis) and temperature sensors and they were placed on a weighing machine. In the first experiment, the lysimeters were supplied with different aeration modes, i.e. continuous aeration at 0.2, 0.5, 1 and 2.25 L/min and intermittent aeration of 0.4 L/min (1 h on: 1 h off and 3 h on: 3 h off). The lysimeters were loaded with 22.0 kg MSW collected a municipality in Thailand corresponding to initial waste density of 325 kg/m^3. In the second experiment, the lysimeters were supplied with continuous aeration of 0.2 and 0.5 L/min using MSW (26.0 kg) with different composition, i.e. L1 (50% food waste, 10% paper, 20% plastic, 20% yard wastes) and L2 (40% food waste, 10% paper, 10% plastic, 40% yard wastes). Moreover, the effect of C/N ratio in food wastes during bio-drying was also studied. In each experiment, the lysimeters were operated for 14 days during which moisture content, temperatures and wet weight of wastes were monitored. Gas samples were collected and analyzed for CH_4, CO_2, O_2, N_2O composition. At the end of experiment, moisture (weight basis), volatile solids (VS) and heating value (LHV) in treated wastes were determined using Standard Methods (ASTM, 2003).

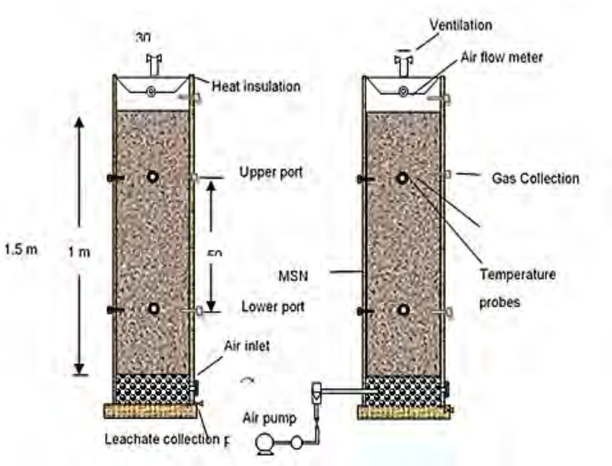

Figure 1 Experimental lysimeters

RESULTS AND DISCUSSION

Bio-drying under continuous aeration

Figure 2 shows the variation of temperature and moisture content in the lysimeter operated under continuous aeration rate of 0.2 L/min. It was found that the temperature varied mostly between 34-39^{o}C and fluctuated in daily pattern whereas moisture content in wastes started decreasing significantly on the 5th day and remained relatively constant after 7 days. Development of bio-drying in the lysimeter were promoted from the heat released from aerobic decomposition of organic wastes which could be developed within 5 days. The moisture and temperature pattern observed during the lysimeter operation at aeration rate of 0.5 L/min had similar patterns .as those observed at the aeration rate of 0.2 L/min.

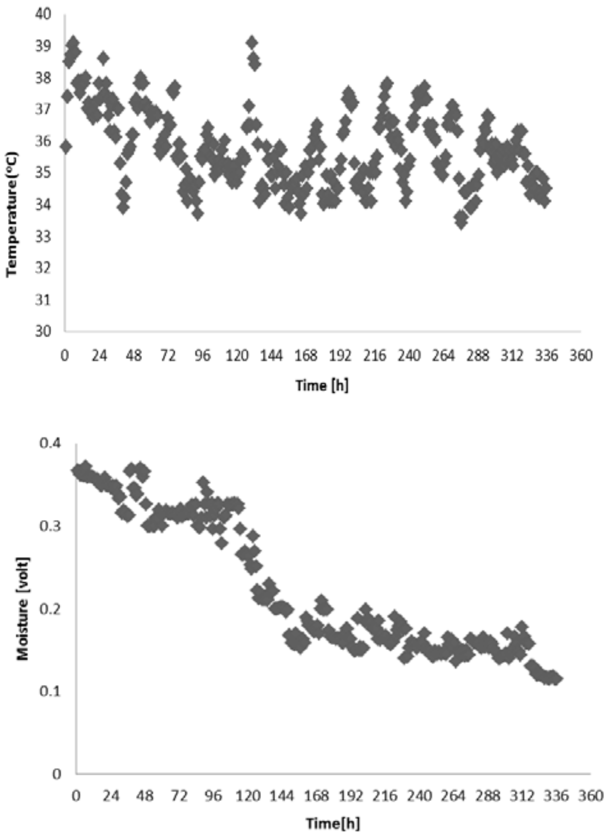

Figure 2. Temperature and moisture content of MSW during continuous aeration of 0.2 L/min

When the lysimeters were operated at higher aeration rate of 1 and 2.25 L/min, physical evaporation of wastes was promoted, evidenced by sudden drop of moisture content in the wastes to 20-40% during the first day and it was gradually declined afterwards. The experimental results suggested that the aeration rates of 0.2 and 0.5 L/min could promote bio-drying condition in the lysimeters and the optimum aeration rate was 0.2 L/min in this study.

Table 1 shows the comparison of moisture content and heating value of wastes before and after biodrying process at different aeration rates. The moisture content in MSW (weight basis) could be reduced from 65.2% to 11.9-14.1% in the lysimeters. The aeration rate of 0.2 L/min yielded moisture content in treated waste (11.9%) with heating value of 4,630 kcal/kg. Meanwhile, higest aeration rate of 2.25 L/min gave highest remaining heating value as the moisture loss was mainly due to physical evaporation.

The analysis of gas samples collected from the lysimeter operated under continuous aeration of 0.2 L/min revealed lowest O_2 (15%) and highest CO_2 concentrations, being 2-4% initially and increased to 10%, as compared to the other lysimeters. CH_4 was found generally at low concentration (< 10 ppm). Meanwhile, N_2O was detected at lower concentration in most lysimeters among which slightly higher concentrations (up to 2.5 ppm) were detected in the lysimeters operated at higher aeration rates.

Table 1 Moisture content and heating value of treated wastes under different aeration patterns

Condition		Heating Value (kcal/kg wet wt.)	Moisture content (%)
Initial		3361	65.2
0.2 L/min		4630	11.9
0.5 L/min		4748	13.9
1 L/min		5226	12.5
2.25 L/min		6105	14.1
Initial MSW		2,194	63.6
0.2 L/min continuous	Upper	4,573	18.5
	Lower	4,845	18.2
0.4 L/min (1h on/1 h off)	Upper	6,171	37.7
	Lower	5,415	14.8
0.4 L/min (3h on/3h off)	Upper	4,483	25.8
	Lower	3,610	16.7

Bio-drying under intermittent aeration

Figure 3 shows the variation of moisture content of MSW in the lysimeter operated under intermittent aeration mode of 0.4 L/min (1 h on/ 1 h off). In comparison with continuous aeration (Figure 2), it was found that moisture reduction were affected by aeration mode. While the lysimeter operated under continuous aeration had moisture content in wastes decreased drastically after 5 days, the moisture reduction started earlier after 3 days under intermittent mode with the same amount of air supply. Nevertheless, condensation of moist air was taken place during aeration off period resulted in higher moisture content detected at the upper part of the waste layer.

Table 1 also presents the moisture content and heating value of MSW before and after bio-drying process with continuous and intermittent aeration modes. It was found that the moisture content in MSW could be reduced from 63.6% to 14.8-37.7% in the lysimeters. The reduction of moisture was mainly taken place upon heat development in the lysimeters indicated by increased temperature of MSW after 3-4 days. Among different aeration mode applied, continuous aeration of 0.2 L/min yielded lowest average moisture content (18.2-18.5%) and being consistent along the depth of lysimeter. As a result, the heat value of 4573-4845 kcal/kg was obtained. Meanwhile, intermittent aeration at the same amount air flow yielded lower moisture content (14.8-16.7%) at the lower part where aeration was supplied but the moisture content was found higher in the upper part due to condenstation of moist vapor so non-uniform drying was achieved when intermittent aeration was supplied.

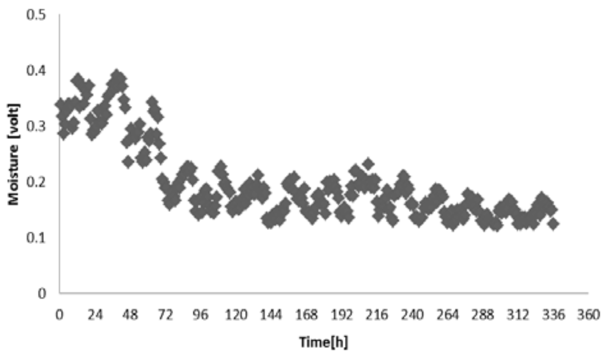

Figure 3. Variation of moisture content under intermittent mode at 0.4 L/min (1 h on/ 1 h off)

Figure 4 shows the weight reduction of MSW in the lysimeters operated under different aeration modes. It was found that a significant drop in the waste weight was observed at the 5th-6th days when bio-drying took place. Another period of high weight loss was observed at the 8^{th}-11^{th} day. During this time, the moisture of content of wastes in the lysimeters were mostly maintained relatively constant so the weight loss was possibly resulted from the degradation of MSW. Comparing between weight losses of wastes under different aeration pattern, it was found that intermittent aeration yielded higher weight loss than continuous aeration. However, the moisture content of treated wasters was not homogeneously achieved along the lysimeter depth.

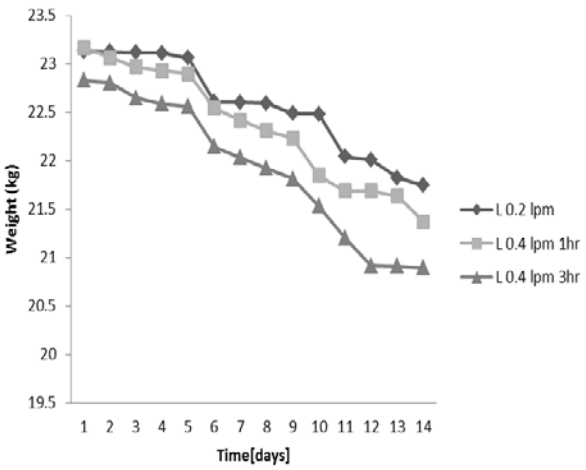

Figure 4. MSW weight change under different aeration pattern

The amount of condensed water and waste subsidence during the lysimeter operation were also monitored to determine the progression of waste bio-drying process. Intermittent aeration of 0.4 L/min (3 h on/3 h off) yielded highest weight loss, amount of condensed water and waste subsidence comparing to other operations. These results suggested that the drying of wastes was well developed at a higher aeration rate (0.4 L/min) over longer period (3 h). However, the condensation also took place in the top part of waste layer during aeration off period resulting in higher moisture content remaining in the wastes. Highest weight loss also relates to the decomposition of MSW during bio-drying. Comparing between the lysimeters, it was found that the dry mass losses of solid wastes under intermittent aeration were higher than that under continuous aeration. This results confirmed that the supply of aeration in continuous mode at lower aeration rate was better than the intermittent air supply if organic matter in MSW is to be conserved.

Effect of waste composition in bio-drying

Table 2 presents moisture content and heating value of MSW in the lysimeters (L1, L2) having different waste composition at aeration rates of 0.2 and 0.5 L/min. Initial moisture content was higher in L1 (60-62%) than L2 (56-60%) as it contained higher percentages of food wastes. When the MSW was supplied with 0.2 L/min aeration, the moisture content of MSW in L1 was reduced to 30.5-31.2% after 14 days. In L2, the moisture content was reduced to 24.1-31.3. The moisture content could be reduced by 49-54% in L1 and 44-57% in L2. These inadequate moisture removals could be due to ineffective air flow through waste matrix for microbial activities to produce heat from microbial degradation (Velis et al., 2009). The supply of higher aeration rate at 0.5 L/min yielded better bio-drying of MSW in L2 but not in L1. The moisture could be effectively reduced by 69-72% and the drying was quite uniform throughout the lysimeter. It was anticipated that lower food waste percentage coupled with higher content of bulking material, i.e. yard wastes in L2 could facilitate better air supply into the lysimeter. The experimental results suggest that continuous aeration of 0.5 L/min could promote

Table 2 Moisture content and heating value of treated wastes with different initial composition

Air flow rate (L/min)	Lysimeter	Moisture (%)		LHV (kcal/kg wet wt.)	
		before	after	before	After
0.2	L1	60	30.5 (Lower) 31.2 (Upper)	1933.1	2856.8 (Lower) 3361.4 (Upper)
	L2	56	24.1 (Lower) 31.3 (Upper)	1318.6	3254.1 (Lower) 3182.5 (Upper)
0.5	L1	62	33.3 (Lower) 30.0 (Upper)	1816.6	2297.6 (Lower) 2572.7 (Upper)
	L2	60	16.3 (Lower) 18.7 (Upper)	1594.6	4350.6 (Lower) 4289.2 (Upper)

Table 3 CO_2, CH_4 and N_2O concentrations in emitting gas at different C/N ratio in food wastes

C/N	**Moisture (%)**		**LHV (kcal/kg wet wt.)**		**CO_2 (ppm)**	**CH_4 (ppm)**	**N_2O (ppm)**
	before	**after**	**before**	**after**			
10	60	26.1 (Lower) 28.3 (Upper)	1407.7	2062.8 (Lower) 1746.5 (Upper)	8389-14640	159.6-297.9	0.74-2.27
30	60	25.2 (Lower) 29.8 (Upper)	1697.8	2726.3 (Lower) 2395.9 (Upper)	9781-14332	146.9-215.6	0.91-1.36
50	60	25.8 (Lower) 20.4 (Upper)	1690.9	2396.9 (Lower) 3156.6 (Upper)	1472-4582	147.2-229.3	0.89-1.24

effective bio-drying in the L2 and it was the optimum aeration condition in this experiment.

Figure 5 shows the variation of temperature and moisture content of MSW in L2 during continuous aeration of 0.5 L/min. During the operation, moisture content of MSW was decreasing corresponding to the rising temperature. Significant changes in moisture and temperature were observed during the first few days after which the stable bio-drying condition was developed in the lysimeter.

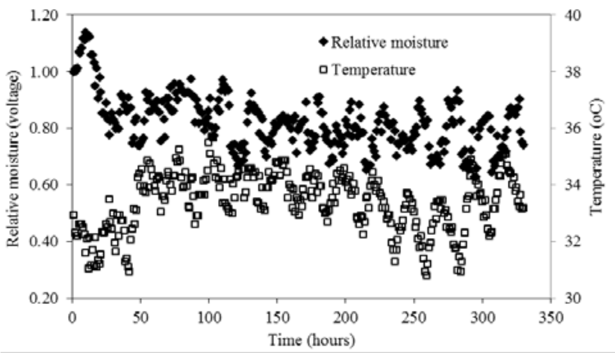

Figure 5. Temperature and moisture content of MSW in L2 under aeration rate of 0.5 L/min

At stable condition, maximum temperature of 35.7°C was achieved after 4 days operation. The rise of temperature could not reach thermophilic temperature as has been reported in Zhang et al. (2008) possibly due to higher heat dissipation from the lysimeter. During the bio-drying process, gradual decrease in moisture content of MSW was observed up to 9 days after which there was insignificant reduction in moisture content even though their fluctuation was observed due to continuous evaporation and condensation of water within the waste layer. On average, temperature variation was very much similar in both 0.2 L/min and 0.5 L/min aeration. It was found that both sets of experiment recorded their initial average temperature around 32°C and average peak temperature around 34°C after reaching to 4th day of the operation.

The effect of C/N ratio in food wastes on bio-drying is presented in Table 3. In this experiment, the bio-drying was performed at aeration rate of 0.5 L/min.

The C/N ratio of food wastes was varied at 10:1 (L1), 30:1 (L2) and 50:1 (L3) in the lysimeters containing 40% food wastes. It was found that the variation of C/N ratio also affect moisture, temperature and heating value of treated wastes as well as GHG emission during bio-drying process.

The effect of C/N ratio on moisture reduction was slightly observed. The lysimeters with C/N ratio of 10 and 30 had slightly higher moisture as compared to the C/N of 50 especially at the upper part. High heating value was obtained at the upper part of lysimeter with C/N of 50. The temperature was found similar among the lysimeters, being highest at 38^{o}C on day 7. Afterwards, there was insignificant reduction in moisture even though some fluctuations was observed due to evaporation and condensation of water in the waste layer.

There were some differences in gas emission between the lysimeters especially CO_2. Lower CO_2 emission observed in L3 may suggest that the drying at the upper part of L3 was not caused by heat produced from biological activities but rather from physical evaporation. The biodegradation of food wastes possibly took place better in L1 and L2. L1 with highest N content in wastes also had slightly higher N_2O emission towards the end of experiment.

CONCLUSIONS

Bio-drying of MSW was successfully developed in the lysimeters operated at continuous aeration of 0.2 L/min yielding treated MSW with moisture content of 18.2-18.5% and heating value of 4,573-4,845 kcal/kg. Meanwhile, intermittent air supply produced non-homogenous moisture content in treated wastes due to the condensation of moist vapor during aeration off period. The provision of continuous aeration at optimum air supply rate also helped conserving organic content in wastes while providing sufficient heat from the biodegradation of organic wastes for moisture evaporation. In the lysimeter containing 40% food wastes and 40% yard wastes, aeration rate of 0.5 L/min yielded effective biodrying condition. High percentages of food wastes together with poor waste structure led to ineffective air flow. Good bulking condition of MSW should be therefore considered prior to the bio-drying process. The C/N ratio of 10 and 30 in food wastes helped activating microbial activities during bio-drying.

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STATISTICAL ANALYSIS BY MAIN FACTOR MONITORING AND CORRELATION ANALYSIS ON ANAEROBIC DIGESTION OF FWL

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ABSTRACT

As the ban on a direct dumping of organic waste has been implemented since 2005 and ocean dumping of organic waste was prohibited under London Dumping Convention that took effect in 2006, measures to dispose of and recycle organic sludges on land are urgently needed. Most European advanced countries and South Korea has focused on wastewater with lower organic content compared with domestic food waste leachate (FWL) such as sewage sludge and livestock excretion and thus optimum model and stable operation technology for producing biogas which is suitable for characteristics of food waste leachate have not been developed. This study operated mesophilic temperature (35±1 ℃) lab-scale anaerobic digester for food waste leachate and evaluated VS removal and biogas yield according to organic loading rates (OLRs). VS, TAN, FA, pH and VFAs were selected as main monitoring factors for stable digestion operation. Correlation analysis of biogas yield and VS removal were conducted according to changes in main factors on the basis of monitoring data. Optimum operation condition according to changes in factors of food waste leachate anaerobic digestion was figured out by using multi-variate analysis. The results of this study are expected to be used as basic data for stable operation technology and optimum conditions for food waste leachate anaerobic digestion.

Keywords : Anaerobic Digestion, Monitoring, Food Waste Leachate, Correlation Analysis, Statistical Analysis

INTRODUCTION

As the "London Dumping Convention 96 Protocol" came into force in 2006, Korea is also banned from ocean dumping for organic wastes including food waste effluent from 2013, they need to be treated in land and recycled(Behera et al, 2010, Lee et al, 2011).

The food waste leachate in Korea is mostly generated in a food resource facility and occurs in the process of solid-liquid separation of the dehydration and washing process of food waste (Song et al., 2016). The amount of food waste leachate in Korea was 8,274 tons/day as of 2014, of which 6,304 tons/say was the largest, while food waste leachate had a high salt content and a high concentration of organic matter (More than 150 g / L based on TCOD) and low pH (MoE., 2013, Kim et al., 2008).

As a result, the installation of anaerobic digester and biogas plant suitable for treatment of high concentrated organic wastewater such as food waste leachate has been increased (Song et al., 2016). Food waste leachate has higher total solids content than other organic waste (livestock manure, sewage sludge, etc.) and is known to be suitable for use as an energy resource through anaerobic digestion (Kim, 2009). However, in most developed countries including Korea, facilities for anaerobic digestion were installed with feedstock in low organic matter content compared to food waste leachate such as livestock manure and sewage sludge. Therefore, it is necessary to establish influential factors to improve the stable operation and efficiency of food waste leachate anaerobic digestion (Song et al., 2016).

The anaerobic digestion process is a process in which organic wastes are decomposed by anaerobic microorganisms to produce the final product, methane. Anaerobic digestion is mainly divided into three stages: hydrolysis, acid production and methane production (Sawatdeenarunat et al., 2015). In order to increase the efficiency and stabllize operation of the anaerobic digestion process, control of factors to maximize the activity of the microorganisms acting at each stage should be preceded (Yun et al., 2013). The major factors causing inhibition of anaerobic digestion are organic contents, total ammonia nitrogen (TAN), free ammonia (FA), pH, volatile fatty acids (VFAs) and temperature. If these influencing factors are not controlled, the activity of the anaerobic microorganism would be adversely affected. As a result, biogas production may be reduced and erroneous operation may lead to failure of the digestion process (Yenigun et al, 2013, Martin-Gonzalez et al., 2013, Zhao et al., 2013).

Especially, ammonia, which is known to be a major inhibitor of anaerobic digestive microorganisms, is produced by microbial degradation of nitrogenous forms such as proteins and urea in organic wastes. Ammonia exists in the form of ammonia ion (NH_4^+) and free ammonia. Ammonium ions are known to have no significant effect on the reduction of microbial activity, but FA has been reported to cause lethal microbial activity reduction due to easy penetration of microorganisms into the cell membrane compared to ammonia ions (Yenigun et al, 2013, Zhao et al., 2013). In general, pH of the acid-producing step and methane-producing step is known to be 5.5 to 6.5 and 6.5 to 8.2, respectively (Kim et al, 2003, Lee et al., 2009). Jiang (2013) et al have reported that the accumulation of VFA in the digester reduces the pH and the activity of methanogenic bacteria, resulting instability of the digester (Jiang et al., 2013). In order to improve the efficiency and stabilize operation of the anaerobic digestion process, it is necessary to understand the interaction between the influential factors.

Therefore, in this study, food wastewater leachate was used as substrate and TS, VS, TAN, FA, pH, VFA of digested sludge were measured. Lab-scaled mesophilic single-phase anaerobic digester was operated for 200 days. Biogas yield, VS removal and digestion efficiency factors were evaluated as the organic loading rates increase. In addition, correlation analysis of influence factors with changes in organic loading rates, biogas yield and correlation analysis of VS removal were performed according to the influence factors. Based on the correlation analysis, multi-variate regression analysis was performed to predict the biogas yield and digestion efficiency. Based on the predicted results, the predicted value was compared with the experimental value to determine the suitability. In the future, this study would be used as basic data for improving efficiency and stabilizing operation of food waste leachate single anaerobic digestion process.

MATERIAL&METHOD

Substrate and Seed Sludge

The food waste leachate used in this study was collected from a biogasification plant, located in I city, South Korea. The seed sludge for microorganism inoculum was collected from a WWTP with operational volume of 85,000 m3/d, located in S city, South Korea. These samples were stored at 4˜ after removing inert matter with mesh sieve (0.85 mm). Characteristics of food waste leachate is shown in Table 1.

A.D Operation Condition

Anaerobic digestion performance of food waste leachate was assessed by using semi-continuous stirred tank reactor. Fig. 1 shows configurations of semi-continuous anaerobic digester used for experiment. The equipment consists of a reactor with a stainless steel vessel that is agitated and heated with a total volume of 15 L, and a working volume of 12 L. Digestion tank was equipped with water jacket system and recirculating pump to control temperature.

Table 1. Characteristics of food waste leachate

Parameter	Unit	Concentration
TS	mg/L	67,632
VS	mg/L	58,217
TCOD	mg/L	106,105
T-N	mg/L	2,300
NH4+	mg/L	338
pH	-	4.10

Using programmable logic controller (PLC) made it possible to monitor and control temperature within digestion tank, recirculating pump, agitator and pH automatically.

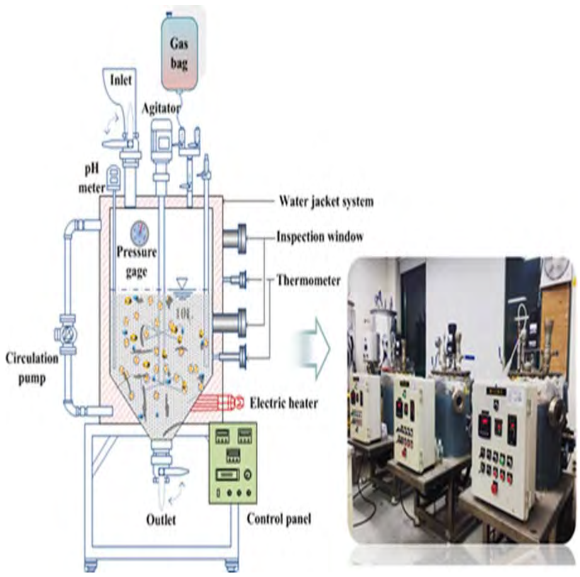

Fig. 1 Configurations of Lab-scale A.D reactor.

Analytical methods

TS, VS, TAN analyses were performed using standard methods (APHA, 2005). Soluble fractions of TAN and VFAs were analyzed using filtrate obtained from filtering supernatant with a GF/C fileter (Whtman, UK) after centrifugation at 6,000 rpm for 15 minutes. pH was measured using a pH meter (Hanna HI223, USA). Volitile fatty acids (VFAs) were analyzed by gas chromatography with a flame ion detector (GC-FID) (Agilent 6890 A, Agilent Technologies, Inc., USA). Also, the concentration of FA was calculated according to Eq. (1). The volume of biogas produced in the reactor was measured using a wet gas meter (W-NK-0.5, Shinagawa Corporation, Japan).

$$\mathrm{FA} = \frac{1.214 \times \mathrm{NH4}^{+} \times 10^{\mathrm{pH}}}{e^{6344/\mathrm{T(K)}} + 10^{\mathrm{pH}}} \qquad (1)$$

Statistical Analysis

Correlation analysis of parameters affecting on biogas yield was conducted by using Minitab 14 (Korean Version 14, Eretec Inc). Prediction values of biogas yield and VS removal were calculated by R program (R project, University of Auckland, New Zealand) using multi-variate regression analysis function.

RESULT&DISCUSSION

Result of Main Factor Monitoring

Lab-scale anaerobic digester was operated for 200 days to figure out the changes in the key parameters depending on OLR increase. The characteristics of food waste leachate as feedstock in different OLRs is shown in Table 2. OLR was controlled by increasing 0.5 kg VS/m3 step by step until 2.5 kg VS/m3(phase 1 to phase 6). At the beginning, VS concentration was increased consistently from 6,950 mg/L to 17,970 mg/L. VS removal was calculated by VS concentration of feedstock and digested sludge(Eq. (2)). VS concentration of Digested sludge was increased more rapidly compared to VS concentration of feedstock which resulted in decrease of VS removal. VS removal at the beginning was 88.1% which is caused by dilution effects in the anaerobic digestion reactor. However, concentration of VS in the reactor was increased due to continuous input of highly VS concentrated feedstock which led to decrease in VS removal. VS removal at the end was 69.0% in which 19.1% was decreased from the beginning. VS concentration and VS removal in different OLRs are shown in Fig. 2.

$$\mathrm{VS\ Rem.}(\%) = \frac{\mathrm{VSin} - \mathrm{VSout}}{\mathrm{VSin}} \times 100 \qquad (2)$$

The results of TAN, FA and pH depending on OLR changes are shown in Fig. 3. TAN was increased gradually from 820 mg/L to 2,500 mg/L as OLR increase. FA was calculated with the factors(TAN, pH and Temperature) as shown in Equation (1). When operated with 1.5 kg VS/m3 of OLR, pH was increased to 8.83 and concentration of FA to 640 mg/L. Existing literatures had reported that concentration of FA above 500 mg/L is a impediment to anaerobic digestion process, but in this study, it did not show any negative effects in temporary increase of FA.

Table 2. Characteristics of food waste leachate in different OLRs

Phase No	TS (mg/L)	VS (mg/L)	VS/TS (%)	T-N (mg/L)	NH4+ (mg/L)	pH
Phase 1	70,913±740	58,354±315.5	83.2±0.4	-	-	-
Phase 2	69,989±1,909	59,098±1,488	84.5±1.3	2,405±94	503±116	4.19±0.07
Phase 3	72,948±5,063	58,616±2,692	80.5±3.6	3,864±745	376±67	3.84±0.32
Phase 4	74,946±3,335	60,244±1,825	80.4±1.9	4,061±266	526±138	4.03±0.08
Phase 5	72,034	58,376	81.0	-	-	-
Phase 6	69,946	57,963	82.9	-	-	-

When operated with 2.0 kg VS/m3 of OLR, pH was decreased which lead to decrease in FA concentration. It showed that pH has higher impact on FA concentration rather than TAN. In the precedent research, It was reported that VS removal does not decline at TAN concentration below 3,000 mg/L and FA concentration below 500 mg/L. Accordingly, it did not show any obstruction phenomenon by Ammonia during 200 days operation in this study.

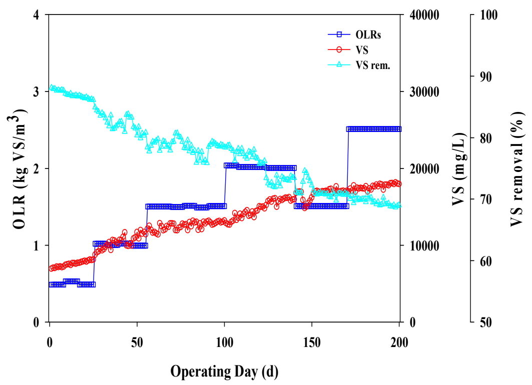

Fig. 2 Result of VS and VS removal efficiency as OLRs increase

Biogas yield and VFA concentration depending on OLR changes are shown in Fig. 4 and average value of biogas yield in each phases are shown in Table 3.

Biogas yield was shown as amount of biogas production(m3) per VS of feedstock(kg VSadd). As OLR increase, biogas yield was decreased at the beginning but it slowly increased after stabilization which was caused by adaptation of

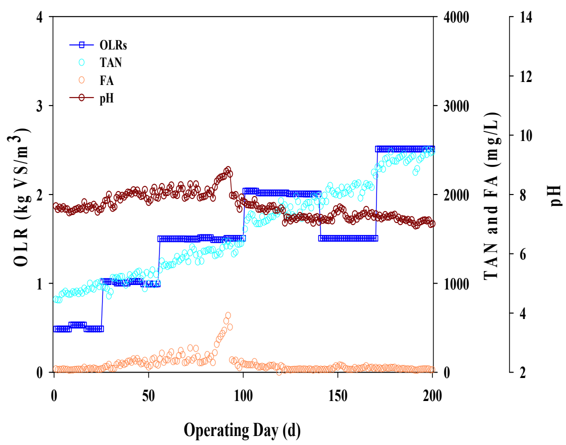

Fig. 3 Result of TAN, FA and pH as OLRs increase

microorganisms to feedstock loading. In addition, biogas yield was unstable as OLR increase from 1.5 to 2.0 kg VS/m3, therefore OLR was decreased to 1.5 kg VS/m3 at Phase 5. When biogas yield was unstable, concentration of VFA was increased to maximum 2,010 mg/L which lead to unstable condition in anaerobic digestion process. At Phase 6, OLR was increased to 2.5 kg VS/m3 and the biogas yield was decreased to 0.871±0.037 m3/kg VSadd but maintained stably.

Table 3. Average value of biogas yield in each phases

Phase	OLR (kg VS/m3)	Biogas Yield (m3/kg VSadd)
1	0.5	0.769±0.02
2	1.0	1.144±0.034
3	1.5	1.109±0.010
4	2.0	0.971±0.025
5	1.5	1.034±0.042
6	2.5	0.871±0.037

VFA concentration was 1,880 mg/L which was higher than other phases(except phase 4). It was caused by accumulation of VFA due to increase of organic matter loadings. As seen that biogas yield was maintained stably, it shows that microorganisms have adapted to the feedstock loading.

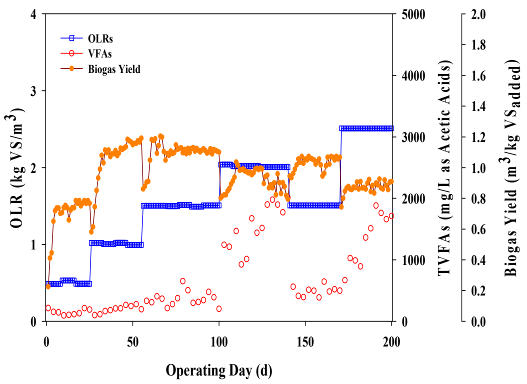

Fig. 4. Result of VFAs and Biogas Yield as OLRs increase

Result of Correlation Analysis

Mutual influence of the parameters was figured out by correlation analysis using Minitab. The result of correlation analysis of parameters depending on OLR changes is shown in Table 4.

As shown in the result, most of parameters showed correlation with each other(p-value = 0.000). '-'of r-value shows negative correlation and vice versa. r-value of VS and TAN concentration in different OLRs were 0.864 and 0.870 respectively, which means that VS and TAN concentration are in proportional to OLR. In addition, p-value of FA in different OLRs was 0.203 (> 0.05) which shows low reliability and p-value between VS and FA was 0.027 (< 0.05) which show high reliability but low correlation. Also, r-value between FA and TAN was –0.264 with low correlation. In contrast, r-value between FA and pH was 0.834 with high correlation. In conclusion, concentration of FA is a function between TAN, pH and temperature, but it was revealed that pH has the most impact on FA concentration.

Table 4. Result of correlation analysis

Correlation Analysis		OLR	VS	TAN	FA	pH
VS	r	0.864				
	p	0.000				
TAN	r	0.870	0.954			
	p	0.000	0.000			
FA	r	-0.090	-0.157	-0.264		
	p	0.203	0.027	0.000		
pH	r	-0.420	-0.528	-0.654	0.834	
	p	0.000	0.000	0.000	0.000	
VFA	r	0.793	0.660	0.692	-0.323	-0.630
	p	0.000	0.000	0.000	0.008	0.000

R : correlation coefficient

P : P-value

Result of Multi-variate regression analysis

As a result of multi-variate regression analysis, the prediction values of biogas yield and VS removal are shown in Fig. 5-6. The prediction values were calculated to figure out the biogas yield and VS removal of Phase 6 using the experimental results in different OLRs. Error factors were computed by comparing experimental and prediction values, and the results are 4.04±2.31% for biogas yield and 2.40±0.78%

for VS removal. As shown in the result, it is appropriate to predict biogas yield and VS removal which would be used as baseline data for food waste leachate anaerobic digestion process application.

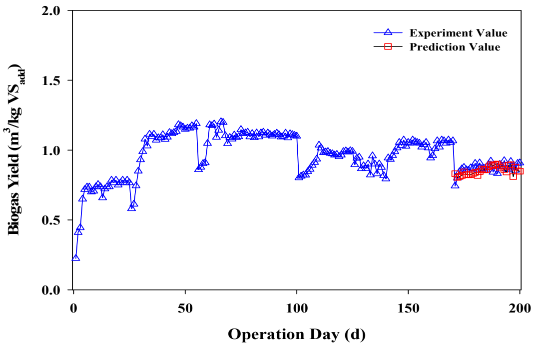

Fig. 5. Prediction result of biogas yield by multi-variate regression analysis

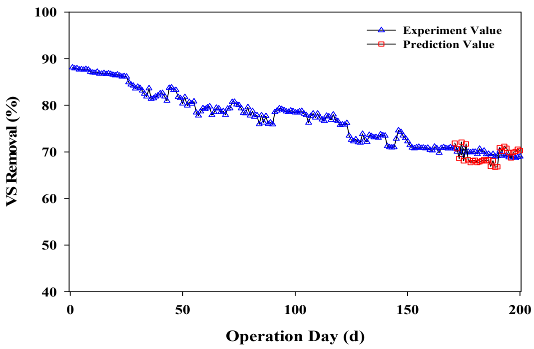

Fig. 6. Prediction result of VS removal efficiency by multi-variate regression analysis

CONCLUSIONS

In this study, anaerobic digestion of food waste leachate was conducted to figure out the correlation between the parameters, and predict biogas yield and VS removal by applying multi-variate regression analysis considering correlation. The results are:

1) The changes in parameters depending on OLR were monitored when food waste leachate is unilaterally digested.

2) Correlation analysis was conducted on the basis of monitoring results, and most of parameters showed correlation with the p-value of 0.000. In case of FA, OLR and VS showed low correlation compared to other parameters, and pH showed highest correlation with FA.

3) Multi-variate regression analysis was conducted on the basis of correlation analysis result. Error factors of biogas yield and VS removal were 4.04±2.31% and 2.40±0.78% respectively, which means that the predicting value is quite appropriate.

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THERMODYNAMIC EQUILIBRIUM CALCULATIONS TO DETERMINE THE CAPABILITY FOR REMOVING GASEOUS MERCURY USING IMPREGNATED ACTIVATED CARBON

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ABSTRACT

Different chemical substances adhered to activated carbon to remove mercury has attracted attention in municipal solid waste incinerators. However, there have been few studies that evaluated the effect of the adsorbents in the presence of an acidic gas such as HCl in the incinerators. Furthermore, in recent years some techniques have been proposed to increase the temperature of the bag filter inlet in the incinerators to about 190℃, with the aim of reducing the thermal energy loss. This temperature change affects the form of the mercury and could thus affect its removal rate.

The aim of the present study is to determine the influence of different kinds of adsorbents and temperature changes on the chemical forms and removal rate of mercury, based on with equipment analysis and calculations of thermodynamic equilibrium.

The result of the study shows that the form of mercury present, as determined using calculations of thermodynamic equilibrium, is mainly $HgCl_4^{2-}$ in solution at temperatures lower than 168℃ and mainly $HgCl_2$ gas when temperatures were higher than 168℃, with no difference confirmed between them depending on the type of the adsorbent. In addition, the acidic environment in the incinerator ensures that Hg^0 is easily oxidized to $HgCl_2$. Results also suggest that $FeCl_3$ and ZnS are effective for mercury removal.

Keywords: Mercury, impregnated activated carbon, thermodynamic equilibrium calculation, adsorption, power generation efficiency

INTRODUCTION

The Enforcement Regulation of the Air Pollution Control Law was revised based on the establishment of the Minamata Convention on Mercury. Municipal solid waste incinerator (MSWI) operators have responded by increasing the amount of powdered activated carbon (AC) or chelate in scrubbers when the continuous mercury measurement data show an increasing trend. However, AC is also sprayed in many furnaces for reasons from mainly removing dioxins. We report that the removal rates of both insoluble gaseous metallic mercury (Hg^0) and soluble gaseous divalent mercury (Hg^{2+}) such as $HgCl_2$ can almost certainly indicate when impregnated AC was used to remove mercury, whereas these removal rates are low when AC is used for general odor in air condition of 160℃, which is the general temperature of a bag filter. However, there have been few studies to clarify how mercury is removed from acidic gases such as HCl. Furthermore, it has been proposed that power generation would be more efficient if, instead of reheating exhaust gas for catalytic denitration, the inlet temperature of the bag filter is raised to about 190℃. This suggests that changes in the chemical form of mercury that occur with changes in temperature may affect its removal rate. Therefore, the present study used thermodynamic equilibrium calculation to clarify the influence of the type of impregnated AC used, and the temperature change, on the chemical form of mercury.

METHODS

Removing mercury using impregnated AC involves chemical and physical adsorption in the pores. Therefore, theoretical calculations of the type and amount of compounds that might be present after an infinite time were estimated using the laws of thermodynamics. The equilibrium was calculated by inputting the gas weight at initial conditions and the quantity of chemical substances at the entrance of the bag filter (**Table 1**) into the "equilib" mode of the software FactSage 7.2, and the type and amount of the product of the reaction were estimated. The initial conditions were calculated using the following data: amount of waste incinerated, properties of the waste, flue exhaust gases, amount of air blow, the ratio of water-soluble mercury, and the quantity and ratio of bottom ash in the fly ash. A mercury concentration of the factory standard value (50 μg/m^{3}N) applicable under the current Air Pollution Control Law is considered contaminated. Data in **Table 1** was used to analyze AC sample A, which was examined for general odor, whereas analyses of samples B, C, D, and E also used the information in **Table 2**, which were based on assumptions from Material Safety and Data Sheets and scanning electron microscopy-energy dispersive x-ray analysis. Both sets of data (in **Tables 1 and 2**) were wet-based per 1 kg garbage weight. A pure substance database (FactPS) was used for the equilibrium calculation and the products for pure gaseous (g), aqueous (aq), pure liquid (l), and pure solid (s) substances were adopted. The temperature range was set to 100 to 250℃, which is wider than the usual temperature at the entrance to bag filters (about 160 to 200℃). The equilibrium state of mercury based on the impregnating agents used were estimated using the chemical reaction equation and calculations of ΔG, satisfying the law of the conservation of mass in the presence of gases such as HCl, SO_2, O_2, and H_2O in the Reaction mode in FactSage. Mercury removal using ZnS, which Takaoka and Takeda (1999) considered effective, was also calculated as a reference.

Table 1 Input data on gas and chemicals

Gas/ chemicals	Weight	Unit
CO_2	1.09	kg
H_2O	0.78	
N_2	4.46	
O_2	0.45	
SO_2	194	mg
HCl	1104	
$HgCl_2$	0.177	
Hg^0	0.095	
C(AC)	263	
$Ca(OH)_2$	3061	

Table 2 Input data on adsorbents

Activated carbon	Adsorbent	Weight	Unit
B	$CaCl_2$	262.8	mg
C	$FeSO_4$	18.4	
	KI	5.3	
	S	5.3	
D	KI	12.6	
	I_2	3.2	
E	$FeCl_3$	26.3	

RESULTS AND DISCUSSION

Estimating the chemical form of mercury

Figure 1 shows chemical forms of mercury at 100 to 250℃, as estimated from the calculation of thermodynamic equilibrium when AC sample A was used. The parentheses indicate the state of the substance and 167.76 ℃ is the phase transition temperature. Almost all the mercury is $HgCl_4^{2-}$ in the aqueous state at 100℃; however, when the phase transition temperature is exceeded, almost the entire amount is converted into gaseous $HgCl_2$. Since this occurs at about 160 ℃ at the entrance of the bag filter in actual operation, $HgCl_4^{2-}$ might dissolve in residual water vapor particles. Both $HgCl_4^{2-}$ and $HgCl_2$ are water-soluble; however, since it is considered that the AC impregnated agent absorbs the former more easily in its ionic form, a low temperature can be considered suitable when treating mercury with AC. A similar tendency was also confirmed for AC samples B through E which were coated with the impregnating agent.

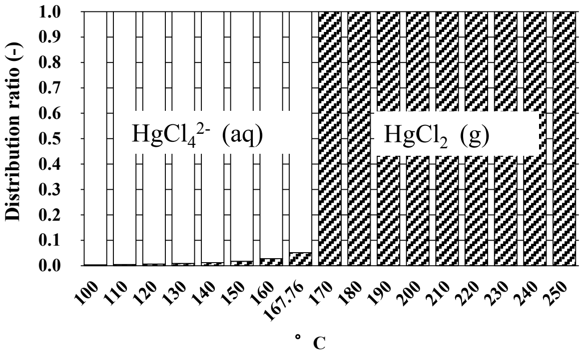

Figure 1 Changes in the chemical form of mercury

Estimating the reactions of mercury and impregnation agents in the presence of various gases

When Hg^0 was reacted only with various gases, in the absence of the impregnation agent formula, the basic reaction equation for the maximum ΔG at 160℃ is as follows:

$$Hg\ (l) + 2HCl\ (g) + 1/2O_2\ (g) = HgCl_2\ (s) + H_2O\ (g)$$
$$\Delta G = -192.8\ kJ/mol \qquad (1)$$

In the reaction between $HgCl_2$ and various gases, ΔG is positive; thus, the reaction does not proceed spontaneously and it can be said that $HgCl_2$ is more stable than Hg^0. **Table 3** and **Table 4** show the reaction equations of the used to impregnate Hg^0 and the materials added to $HgCl_2$, respectively, when ΔG is negative values. Since R1 and R2 have smaller ΔG compared to equation (1), Hg seems to react preferentially with HCl instead of $CaCl_2$ and $FeSO_4$. S seems to react preferentially with O_2 instead of Hg^0 (equation 1, R4). Even when HCl is not present, $FeCl_3$ reacts spontaneously with Hg^0 and $HgCl_2$ is generated (R6, R7), whereas Hg^0 and ZnS react with HCl and O_2 before the former finally becomes the stable HgS (R11, R12). In any reaction of Hg^0 with $FeCl_3$ (R6, R7) and ZnS (R11, R12), ΔG is equivalent to the result of equation (1). Therefore, Hg^0 reacts directly with HCl and/or O_2, and with $FeCl_3$ and/or ZnS and is converted into $HgCl_2$ or HgS; as a result, the Hg is considered removed. As shown in **Table 4**, further reactions progressing from $HgCl_2$ are limited. HgI_2 is generated from $HgCl_2$ when KI is present (R15), and ZnS reacts with $HgCl_2$, O_2, and HCl and is thus converted into $ZnCl_2$ and/or ZnO (R18 through R20).

Reduction of slaked lime spray in dry treatment of Hg and expectations for $FeCl_3$

Slaked lime is generally sprayed at the entrance of a bag filter when HCl gas derived from garbage is being desalted by dry treatment in a MSWI. However, while using HCl improves mercury removal, if the concentration of the former at the entrance of the bag

Table 3 Reaction of adsorbent / additive substance with Hg^0 or various gases at 160℃

Reaction No.	Activated carbon	Adsorbent/ additive substance	Chemical reaction formula	ΔG (kJ/mol)
R1	B	$CaCl_2$	$Hg(l) + 1/2O_2(g) + CaCl_2(s) = HgCl_2(s) + CaO$	-25.8
R2	C	$FeSO_4$	$Hg(l) + 1/2O_2(g) + FeSO_4(s) = HgSO_4(s) + FeO$	-1.5
R3		S	$Hg(l) + S(l) = HgS(s)$	-41.9
R4			$S(l) + O_2(g) = SO_2(g)$	-301.0
R5	D	I_2	$Hg(l) + I_2(g) = HgI_2(s)$	-98.9
R6	E	$FeCl_3$	$Hg(l) + 2/3FeCl_3(s) + 1/2O_2(g) = HgCl_2(s) + 1/3Fe_2O_3(s)$	-196.0
R7			$Hg(l) + 6/7FeCl_3(s) + 3/7O_2 = HgCl_2(s) + 2/7FeCl_2(s) + 2/7Fe_2O_3(s)$	-185.7
R8			$Hg(l) + 2FeCl_3(s) = HgCl_2(s) + 2FeCl_2(s)$	-123.7
R9			$FeCl_3(s) + 3/2H_2O(g) = 1/2Fe_2O_3(s) + 3HCl(g)$	-5.0
R10			$FeCl_3(s) + 3/4O_2(g) = 1/2Fe_2O_3(s) + 3/2Cl_2(g)$	-48.8
R11	-	ZnS	$Hg(l) + ZnS(s) + 2HCl + 1/2O_2(g) = HgS(s) + ZnCl_2(s) + H_2O(g)$	-220.7
R12			$Hg(l) + ZnS(s) + 1/2O_2(g) = HgS(s) + ZnO(s)$	-151.0
R13			$ZnS(s) + 1/2O_2(g) = ZnO(s) + S(s)$	-109.1
R14			$ZnO(s) + 2HCl(g) = ZnCl_2(s) + H_2O(g)$	-69.7

Table 4 Reaction of adsorbent / additive substance with $HgCl_2$ or various gases at 160℃

Reaction No.	Activated carbon	Adsorbent/ additive substance	Chemical reaction formula	ΔG (kJ/mol)
R15	C, D	KI	$HgCl_2(s) + 2KI(s) = HgI_2(s) + 2KCl(s)$	-88.4
R16	E	$FeCl_3$	$FeCl_3(s) + 3/4O_2(g) = 1/2Fe_2O_3(s) + 3/2Cl_2(g)$	-48.8
R17			$FeCl_3(s) + 3/2H_2O(g) = 1/2Fe_2O_3(s) + 3HCl(g)$	-5.0
R18	-	ZnS	$HgCl_2(s) + ZnS(s) = ZnCl_2(s) + HgS(s)$	-28.0
R19			$ZnS(s) + 1/2O_2(g) = ZnO(s) + S(s)$	-109.1
R20			$ZnO(s) + 2HCl(g) = ZnCl_2(s) + H_2O(g)$	-69.7

filter drops significantly due to the presence of an excess of slaked lime it is possible that some of the mercury would not be sufficiently removed, as it could pass through the bag filter as Hg^0. We propose that the amount of slaked lime sprayed should be reduced, not only in terms of ensuring the reliable removal of mercury but also to reduce the generation of fly ash and prevent the high alkalization of landfill sites. In addition, $FeCl_3$ is effective in dry treatments of mercury because it can be expected to change Hg^0 to $HgCl_2$ even when HCl is not present.

CONCLUSIONS

This research clarified the following points:

(1) $CaCl_2$, $FeSO_4$, KI, S, I_2, and $FeCl_3$ were identified as the chemical form of AC adsorbents that remove mercury using X-ray diffraction and scanning electron microscopy-energy dispersive x-ray analysis.

(2) Thermodynamic equilibrium calculation was used to estimate the form in which the mercury existed. It was presumed to be mainly aqueous $HgCl_4^{2-}$ at temperatures lower than 168℃ and mainly gaseous $HgCl_2$ when the temperature was higher.

(3) $FeCl_3$ and ZnS are effective at removing mercury used as an impregnating agent or additive substance; $FeCl_3$ can convert mercury into $HgCl_2$ even in the absence of HCl.

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INTRA- AND INTER-PARTICLE ELEMENTAL HETEROGENEITY IN COMPONENT MATRICES OF MUNICIPAL SOLID WASTE INCINERATOR FLY ASH PARTICLES

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ABSTRACT

Major treatment of municipal solid waste (MSW) in Japan is incinerator, with stoker incinerator around 74% and fluidized bed incinerator is 17%. Fly ash is byproducts of incinerator that recognized as homogeneous fine particles. However, there is no significant research explained about the homogeneity of fly ash particles. The objectives of this study are to analyze elemental heterogeneity of fly ash particles in component matrices and to compare heterogeneity of fly ash from stoker and fluidized bed combustor. By using SEM-EDS, we analyzed elemental composition in the surface of single particle fly ash. Beside surface, we analyzed inner matrices of fly ash by using Japan leaching test 19th (JLT 19), which were conducted to remove semi-soluble and soluble components of fly ash particles. Two kinds of heterogeneity were studied quantitively: heterogeneity in a fly ash particle (intra-particle heterogeneity), and heterogeneity among fly ash particles (inter-particle heterogeneity). Interparticle heterogeneity in the surface of fluidized bed fly ash larger than stoker combustor. In contrast, insoluble inner matrices of stoker incinerator fly ash have more interparticle heterogeneity than fluidized bed incinerator fly ash. Small particles of SiO_2 from bed materials could be carried to air pollution control devices and remained in most of the inner matrices fly ash particles that cause decreasing heterogeneity among fly ash particles of fluidized bed combustor.

Keywords: Municipal solid waste incinerator, Fly ash, Stoker incinerator, Fluidized bed incinerator, Elemental heterogeneity,

INTRODUCTION

Thermal treatment of municipal solid waste (MSW) started to spread in developed and developing countries. The thermal treatment can reduce the volume and mass of MSW, to destroy pathogenic agents and to recover energy (Wan et al., 2006). Thermal treatment technologies mainly use incineration, gasification, and pyrolysis. As a country that has leading incineration facilities in the world, Japan can treat about 80.3% of their MSW by the incinerator. Several types of incinerators are widely used in Japan: stoker furnaces, fluidized bed furnaces, and gasification fusion resource furnaces. About 74% of incinerators in Japan is stoker type, and 17% is a fluidized bed type. Those two types of incinerators are most widely used in Japan (MoE, 2017). Stoker incinerator operates by using a mechanical mixture of movable grate system. The fluidized bed has uniform gas-solid system that provided good stable mixing between waste and bed materials. Moreover, fluidized bed had more merits such as more efficiency of heat transfer and more contact probability for waste treatment. Different transportation and mixing system inside furnace influenced properties of bottom ashes and fly ashes (Chang et al., 2006).

Although there are several types of incinerators, all incinerator types generate residues containing bottom ash, which is the residue from combustor of incinerator, and fly ash, which is residue collected from air pollution control devices (APCDs). The quality of ashes can be affected by the type of incinerators and the operation condition – i.e., temperature, residence time, and disturbance time (Lu et al., 2015). Fly ash of municipal solid waste incinerator (MSWI) contains leachable toxic metals and hazardous organic compounds which cause potential hazard to the environment. Therefore, fly ash should be treated before its final disposal in landfill (Chang et al., 2001). In Japan, there are several methods used to treat fly ash before disposal, and these include melting, cement solidification, chemical immobilization and acid extraction (Ecke et al., 2000). Chemical immobilization using chelate reagent solution has been a significant method because of its simplicity.

Geochemical characteristics of leaching behaviors of heavy metals of MSWI fly ash already has been investigated by numerous researches (Hyks et al., 2009). Comparative analysis between fly ash particles from stoker and fluidized bed combustor had been done by numerous researches (Li et al., 2004). From our research group, we have already done geochemically structural approach to stoker incinerator fly ash (Kitamura et al., 2016). Fly ash particles had specific geochemical structure that consists of soluble KCl/NaCl-based aggregates on the surface, Al/Ca/Si-based semi-soluble matrices and Si-based insoluble inner matrices. The incineration bottom ash was heterogeneous matrix because of the different nature of MSW burnt in the incineration system. However, MSWI fly ash is fine particles and regarded as homogeneous. We need further research about micro-characteristic of MSWI fly ash regarded as heterogeneous particles. Therefore, the objective of the study is to investigate the elemental heterogeneity of MSWI fly ash on the surface and inner structure of fly ash and to compare fly ash from stoker and fluidized bed.

METHODOLOGY

Fly ash samples

In this study, fly ash produced from two types of MSWI in Japan namely stoker and fluidized bed combustor. Fly ash was trapped to fabric filter for stoker incinerator and bag filter for fluidized bed incinerator; and injected lime and activated carbon into flue gas after decompression process. Both fly ash samples were collected after treated by chelate reagent in each incinerator plants.

Microscopic observation

Morphological characteristic of MSWI fly ash particles was observed using scanning electron microscope (SEM). The elemental composition of MSWI fly ash particles was analyzed using energy-dispersive x-ray spectroscopy (EDX) coupled to SEM. Surface elemental concentration was used to analyze elemental heterogeneity.

Leaching test

Japan leaching test 19th (JLT 19), which used hydrochloric acid as leaching medium with a liquid-to-solid ratio of 33.3, were conducted to remove semi-soluble and soluble components of fly ash particles, so inner matrices of fly ash could be analyzed.

Elemental heterogeneity

In this study, we divided into two types of heterogeneity: intra-particle heterogeneity and inter-particle heterogeneity. Intra-particle heterogeneity was analyzed by using CV values of surface elemental concentration by line profile analysis. Inter-particle heterogeneity was analyzed by area analysis of surface fly ash particles as described in Figure 1.

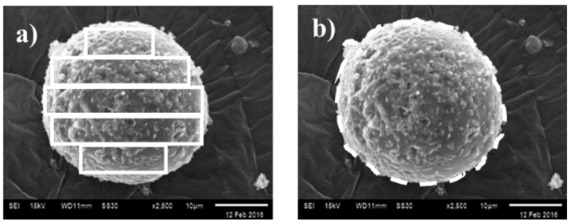

Figure 1 Elemental heterogeneity analysis : a) line profile analysis and b) area analysis

One hundred of chelate treated fly ash from stoker and fluidized bed incinerator and residue after JLT 19 test from both incinerators. Total 400 particles fly ash were analyzed for this study.

INTRA-PARTICLE HETEROGENEITY

Heterogeneity on fly ash particle's surface

To get dispersion of element distribution in a particle, we calculate the coefficient of variation of each element. It is one way to evaluate the heterogeneity of each particle. Coefficient variation is a measure of elements spread in fly ash particles that describe the number of variability elements relative to the mean. Major elements in fly ash particles show different dispersion in fly ash particles. The CV values of major elements in fly ash particles from stoker and fluidized bed as are shown in Figure 2.

The range of CV values of Ca, Al, and Si of fly ash particles from both combustors are almost from 0 to 1.7. Calcium in fly ash has less heterogeneity than other elements that made Ca concentrated in fly ash particle's surface. Detected Ca in fly ash due to neutralization reaction and remaining unreacted $Ca(OH)_2$. Silicate contained in fly ash from fluidized bed had the highest CV than other elements up to 1.7. Also, the weighted average of Si 42% higher than fly ash from stoker combustor. Silica in fly ash from fluidized bed could be derived from remaining small particles of SiO_2 from bed materials that carried to air pollution control. Generally, bed materials of fluidized bed are quartz sand.

The range of CV value of Na, Cl, and K almost from 0 to 1.6 that slightly beneath range CV value of Ca, Al, and Si. Compare between combustors, fly ash from stoker has lower weighted average CV values of Na and K than fly ash from fluidized bed around 15% and 49%, respectively. It is due to possibilities of the shape of fly ash from fluidized bed were more aggregates of small particles which are most of it consisted of soluble KCl/NaCl-based.

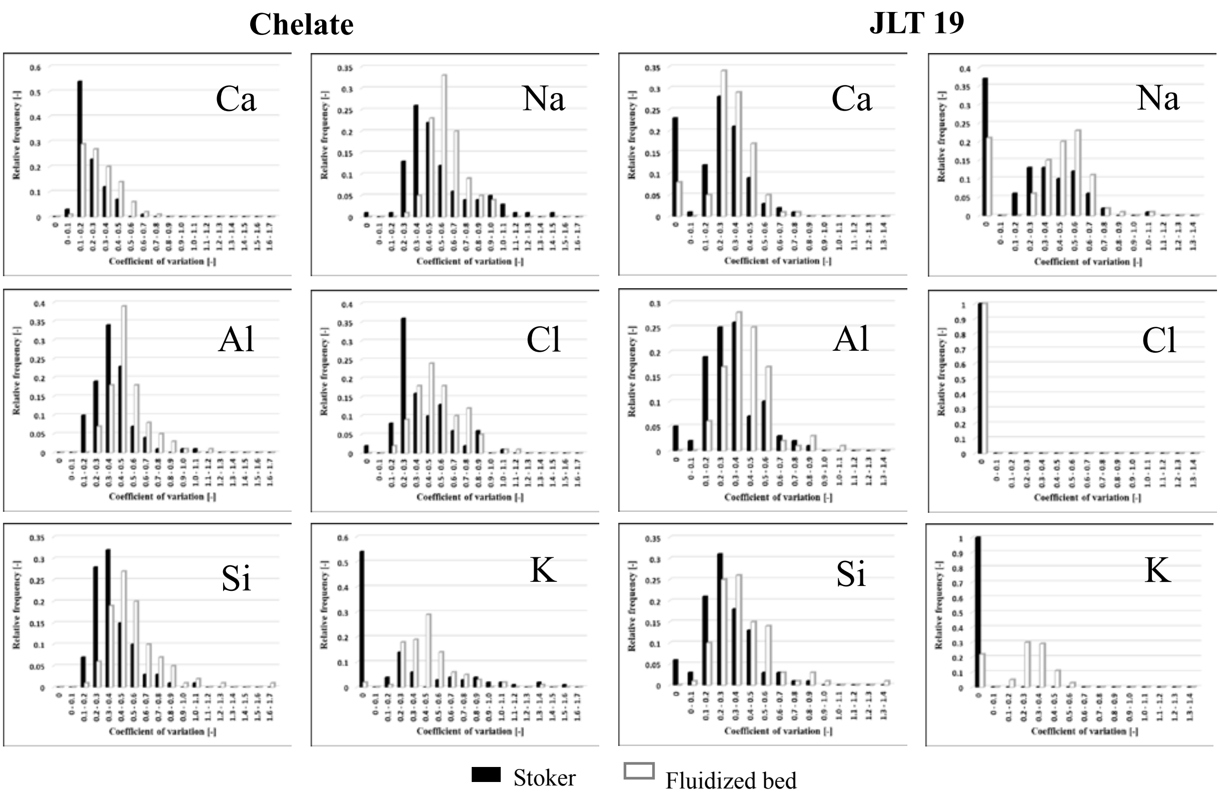

Figure 2 Relative frequency of coefficient variation of stoker and fluidized bed MSWI fly ash particles

<u>**Heterogeneity on inner matrices of fly ash**</u>

By using hydrochloric acid, JLT 19 aimed to remove soluble and semi-soluble matrices of fly ash. Figure 2 also shown histogram of CV values of major elements in the residue of JLT 19. The range of CV values in residual materials lower than in the surface of fly ash

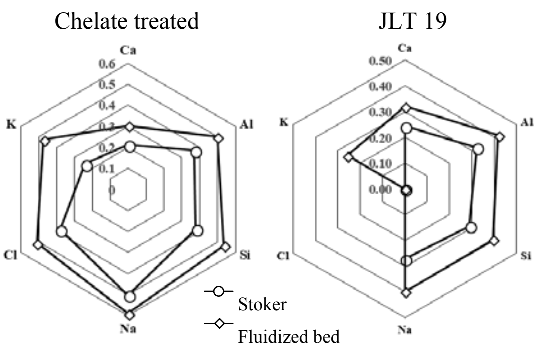

Figure 3 Weighted average of coefficient variation of major elements in all residue materials

which is from 0 to 1.4. Soluble components such as K and Cl wholly removed, and some Na remained in inner matrices. In fluidized bed fly ash, a few of K remained in inner matrices.

Weighted average CV values of chelate and after JLT 19 of fly ash that shown in Figure 3 explained fly ash from fluidized bed has higher intra-particle heterogeneity than stoker fly ash: 29% and 18%, respectively. It concludes a fly ash particle from fluidized bed has higher intraparticle elemental heterogeneity than fly ash from stoker despite surface or in the core of fly ash. Compared with surface of fly ash particles, weighted average CV value of significant elements in insoluble core of fly ash from stoker and fluidized bed is 36% lower. It implies major elements on surface of single particle fly ash more heterogeneous than on inner core of fly ash.

INTER-PARTICLE HETEROGENEITY

Heterogeneity on fly ash particle's surface

Average concentrations measured by area analysis using elemental mapping from EDS measurement. From area analysis, we could analyze the correlation and distribution of elements among fly ash particles. Elemental heterogeneity of fly ash particles was evaluated based on the variations of average concentration data among particles. The average elemental concentration is shown in Figure 4.

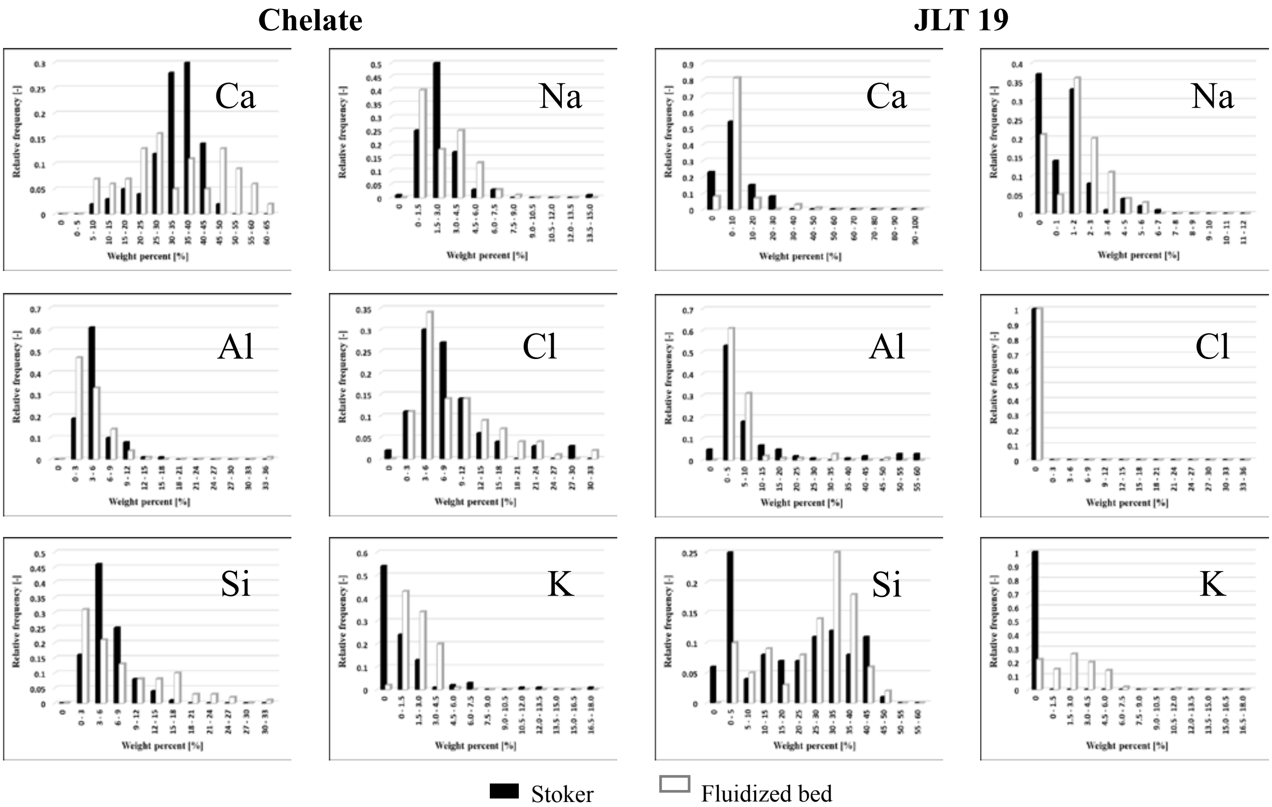

Figure 4 Relative frequency of major elements average concentration of fly ash particles (unit: weight percent)

Major elements in fly ash particles generated from both incinerators have broad distributions of elemental concentrations. On the other hand, there are no significant differences of elemental concentration distribution between both incinerator fly ash. Calcium has the most extensive distribution from 0 to 65 wt% and higher concentration than Al and Si for both combustors. Average concentrations of surface Ca, Al, and Si in fluidized bed fly ash has CV value 30% higher than fly ash from stoker combustor.

Calcite formation from fly ash lime, that form from decomposition of carbonates at temperatures more than 700 °C, reacting with humidity to form portlandite ($Ca(OH)_2$) during storage. Portlandite is reacting with atmospheric CO_2 to become calcite (Weibel et al., 2017). MSW that come to the incinerator plant has higher carbonates materials.

The elemental binary molar ratio among Ca, Si and Al were plotted in ternary diagrams to visualize interparticle heterogeneity as shown in Figure 5. Clearly shows from triangular graphs, that fly ash particles produced from stoker combustor concentrated in Ca area. On the other hand, fly ash of fluidized bed incinerator are dispersed more to Ca and Si sides. It means that fly ash of fluidized bed incinerator has larger interparticle elemental heterogeneity compared to stoker combustor fly ash although different waste streams might have caused this difference to some extent.

Heterogeneity on inner matrices of fly ash

Elemental concentration of residue after JLT 19 is also shown in Figure 4. As explained on "Intra-particle heterogeneity on inner matrices fly ash," after JLT 19 elements such as Cl and K wholly removed from surface of fly ash. The average concentration of Ca from both combustor decreased 27.15 wt% from before JLT 19 test had been done. In contrast, Al increase 3.26 wt% and Si increase 16.1 wt%. Moreover, Si disperses widely than other elements in insoluble matrices. It showed fly ash had Si-based insoluble core and also some particles have Al-rich and Ca-rich cores.

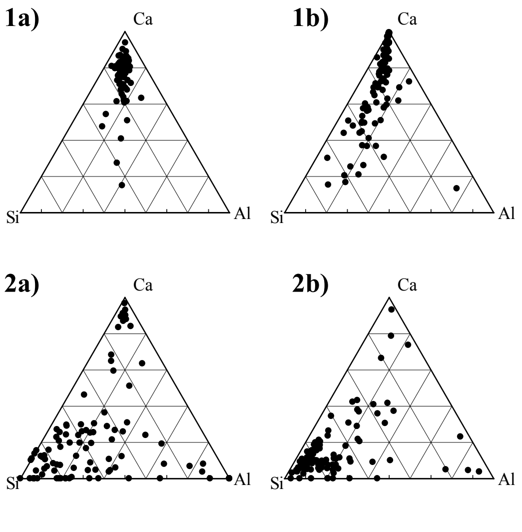

Figure 5 Ternary diagram of 1) chelate-treated and 2) residue JLT 19 of MSWI fly ash particles generated from a) stoker and b) fluidized bed combustor

Fly ash residue of JLT 19 tends to Si area based on ternary diagrams (shown in Figure 5). The author expected that most of residue samples would be plotted near Si area. However, some particles spread to Ca and Al areas. Moreover, fly ash from stoker more scatter than fluidized bed incinerator fly ash.

It shows that elemental distribution among fly ash particles is heterogeneous. Based on histogram results, fly ash from fluidized shifted to right. Fly ash from fluidized bed is likely more heterogeneous than that from stoker combustor. In contrast to interparticle elemental heterogeneity on fly ash surfaces, insoluble inner matrices of stoker incinerator fly ash have larger interparticle heterogeneity than fluidized bed incinerator fly ash.

CONCLUSIONS

Two kinds of heterogeneity are analysis in this study: intra-particle heterogeneity and inter-particle heterogeneity. Intra-particle heterogeneity is heterogeneity in a single particle fly ash, and inter-particle heterogeneity is heterogeneity among fly ash particles.

Elemental distribution among fly ash particles from both incinerators is seemed heterogeneous. Based on histogram results, fly ash from fluidized has tendency shifted to the right side. It implies fly ash from fluidized bed is likely more heterogeneous than fly ash from stoker combustor.

On the surface of fly ash particle showed fly ash from fluidized bed have more intra- and inter-particle heterogeneity than fly ash from stoker incinerator. Moreover, on inner matrices of fly ash from fluidized bed have more intra-particle heterogeneity than stoker fly ash. However, inter-particle heterogeneity on inner matrices of stoker higher than the fluidized bed. Fly ash from fluidized bed had more Si-based dominant as inner matrices owing to bed materials on combustor.

It implied different type combustor could affect distribution and variation concentration of elements in fly ash particles. Moreover, waste input also can affect heterogeneity to some extent. These analysis results would be useful for not only evaluation of fly ash heterogeneity but also considerations of fly ash formation mechanisms.

ACKNOWLEDGMENT

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DARK DISSOLUTION RATE COEFFICIENT OF ELEMENTAL MERCURY IN NATURAL WATERS

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ABSTRACT

Artisanal and small-scale gold mining (ASGM) is a major source of income in most developing countries. However, its sole dependence on elemental mercury (Hg^0) use is of great environmental and human health concern. Of note is the discharge of Hg^0-rich amalgamation tailings into aquatic systems. Though its solubility in waterbodies has been greatly explored, information on its dissolution rate coefficient is limited. Thus, the objective of this study is to determine the first order dissolution rate coefficient of Hg^0 in freshwaters and the factors influencing it. So far, investigations in a dark chamber have revealed that the Hg^0 droplet size greatly influences the dissolution rate. A rapid Hg^0 dissolution (0.00092 min^{-1}) was observed when a larger Hg^0 droplet volume (0.09 mL) compared to a smaller droplet (0.02 mL: 0.00046 min^{-1}). These results will be useful in estimating mercury (Hg) exposure to human bodies using Hg environmental fate and transport models. Further experiments will be conducted to determine the effect of other variables such as pH and Fe (III) concentration on the Hg^0 dissolution rate coefficient.

Keywords: Mercury, Artisanal and small-scale gold mining, Dissolution rate coefficient, Freshwater

INTRODUCTION

Elemental mercury (Hg^0) is a non-biodegradable and toxic transboundary pollutant widely used by Artisanal and small-scale gold miners (ASGMs) in developing countries to extract gold from ore. It is its ease of use under field applications, availability and low cost which makes it more attractive compared to conventional mining methods.

However, though it is a major source of income, Artisanal and small-scale gold mining (ASGM) has negatively impacted the environment and the normal function of the aquatic ecosystem. This is mainly due to the increased land degradation and the discharge of mercury (Hg)-rich amalgamation tailings into nearby waterbodies (Dreschler, 2001; Veiga et al., 2006).

Though the solubility of Hg in water bodies has been extensively investigated (Clever et al., 1985; Canela & Jardim 1997; Melamad et al., 1997, Amyot et al., 2005) there are several knowledge gaps on its dissolution rate coefficient. It has been estimated to be about 0.3 min^{-1}

(Amyot et al., 2005) in high salinity waters (0.5 M Cl^- concentration). However, the authors did not provide detailed information on how Hg^0 dissolution rate coefficient fluctuates with changes in environmental conditions. Therefore, the objective of this study is to determine how changes in the Hg0 droplet volume influences the Hg^0 first order dissolution rate coefficient.

METHODOLOGY

Experimental conditions

Dissolution experiments were performed in 250 mL Erlenmeyer flasks in which 150 mL of Milli-Q water was added.

The effect of initial Hg^0 droplet volume on its first order dissolution rate coefficient was investigated in a dark chamber at pH 3, constant shaking rate of 120 rpm. The droplet volume was varied from 0.02 to 0.09 mL and the dissolution tests were performed for 4200 min. At predetermined time intervals, 2 mL aliquots were extracted from the experimental solution. Of the 2 mL sample volume, 0.5 mL was placed in acid washed vials and made up to 5 mL using Milli-Q water and this was analyzed for total dissolved mercury (HgT) using an NIC-RA3 Mercury Analyzer (NIC, Japan). The dilution factor was taken into consideration in the final concentrations calculations. All experiments were performed in triplicates and nitrile gloves were worn during the course of the experiment.

In order to determine the Hg0 dark dissolution rate coefficient, experimental data was fitted on the Noyes-Whitney first order dissolution model (Noyes & Whitney, 1897

RESULTS AND DISCUSSIONS

Effect of initial Hg^0 droplet volume

The HgT concentration was proportional to the initial Hg^0 droplet volume used. An increase in Hg^0 droplet volume from 0.02 mL to 0.09 mL resulted in a six-fold increase in the equilibrium HgT concentration (Figure 1A).

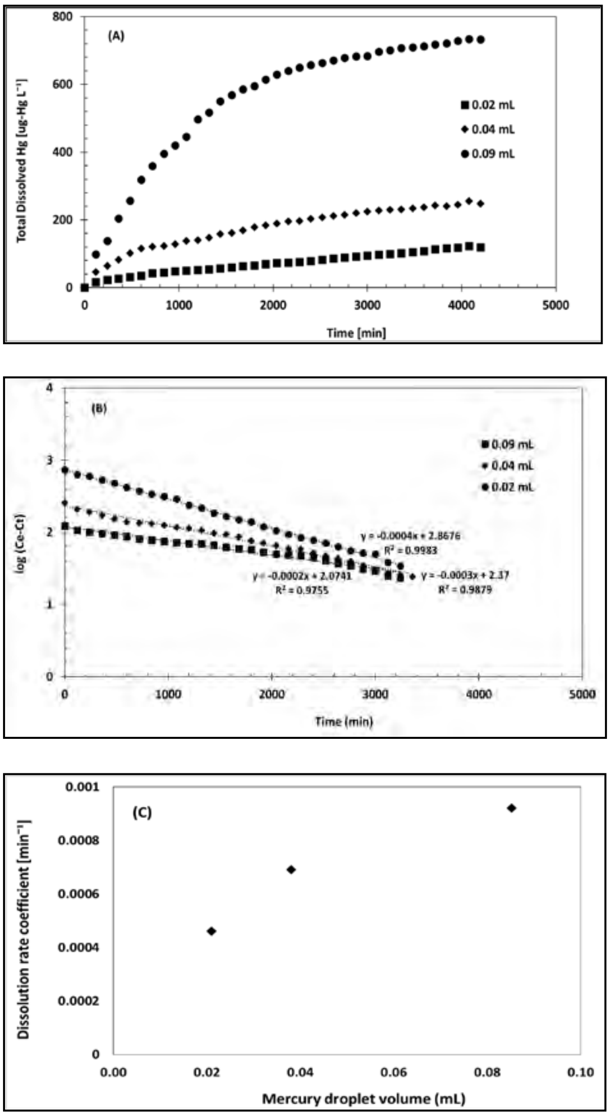

Figure 1 (A) Effect of Hg0 droplet volume on the HgT (B) Noyes-Whitney first order dissolution model (C) Dissolution rate coefficient as a function of Hg0 droplet volume.

The Noyes-Whitney first order dissolution model best fitted the experimental data (Figure 1B). A linear correlation coefficient > 0.97 was obtained for all three scenarios investigated.

As expected, the dissolution of Hg^0 droplets was faster in the presence of a larger Hg^0 droplet. A first order dissolution rate coefficient of 0.00046, 0.00069 and 0.00092 min^{-1} was obtained for 0.02, 0.04 and 0.09 mL droplets respectively.

CONCLUSIONS

The presence of a larger Hg^0 droplet volume resulted in a rapid dissolution of Hg^0 compared to a smaller droplet volume. These results will be useful in estimating mercury (Hg) exposure to human bodies using Hg environmental fate and transport models. Further experiments will be carried out to determine the impact of other variables such as pH on the Hg0 first order dissolution rate coefficient.

ACKNOWLEDGMENT

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Quantitative Mineral Phase Analysis for Reliable Waste Metal Stabilization and Recovery

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ABSTRACT

The ability of designing marketable products derived from waste to simultaneously prevent the environmental pollution and recover valuable material resources is a major technological challenge in the 21st century. Conventional inorganic product designs are often assisted by X-ray diffraction (XRD) technique to qualitatively identify the mineral phase types in the products. However, a further advancement in the quantitative capability of XRD technique is now available to further accurately control product quality. In this study, we will demonstrate the successful applications of the state-of-the-art quantitative X-ray diffraction (QXRD) on stabilizing the hazardous metals in ceramic products and on extracting metallic lead from waste electronics. The feasibility of stabilizing metal-laden waste sludge and ash materials by a wide variety of aluminum- and iron-rich ceramic precursors will be demonstrated by the high metal transformation efficiency and the significant reduction of intrinsic metal leachability. Our work of recovering metallic lead from waste cathode ray tube (CRT) glass will also reflect how the QXRD can assist the development of new resource recovery technologies. A method of reductively transforming the lead in CRT glass into its metallic form through the reactive sintering with zero-valent iron was invented and optimized by the QXRD technique. With the rapid progresses in materials science and characterization techniques, substantial new technological developments in the beneficial uses of waste materials are now spearheaded by the interdisciplinary environmental materials research.

Keywords: Hazardous Metals; Incineration Ash; E-Waste; Ceramic Materials; Thermal Treatment

INTRODUCTION

Heavy metals are toxic and their discharge into receiving waters is detrimental to human health and the environment. Many researchers have attempted to immobilize toxic metals via sorption, using natural or synthetic sorbents or cement, and then correlate their performance directly for metal leaching ability (Bolger & Szlag, 2002). In the immobilization processes, cementitious or pozzolanic materials have been received as an acceptable way to achieve solidification/stabilization with reduced environmental risks associated with their subsequent disposal (Viguri et al., 2001). The cementation method uses the binder to either chemically bind toxic waste matter into solid bulk or physically cut them off from the outside by forming a capsule. However, these solidification/stabilization technologies were not successful in preventing leaching in acidic environments, i.e., pH less than 4.0 (Yousuf et al., 1995).

Stabilizing hazardous sludge via thermal treatment has the potential to convert hazardous metal-laden sludge from the waste stream into reusable products, such as construction ceramics. After thermal treatment, the metal leachability of products via irreversible transformation of metal mineral phase can be significantly reduced (Hsieh et al., 2008). For examples, the simulated nickel sludge was sintered with alumina (Al_2O_3), hematite (Fe_2O_3) and kaolinite ($Al_2Si_2O_5(OH)_4$), and the formation of aluminate and ferrite spinels was found in the products (Shih et al., 2006a,b). The long-term nickel leachabilities were found to drop dramatically in its alumina and ferrite spinel phases, comparing to that in nickel oxide (Shih et al., 2007). Similarly, in the feasibility study of stabilizing simulated copper-laden sludge, copper aluminate spinel ($CuAl_2O_4$) was formed at a most efficient temperature of 1000 ^oC under 3-hour short sintering (Tang et al., 2010). The copper leachabilities of CuO and $CuAl_2O_4$ were evaluated by a pH 2.9 acetic acid solution, and $CuAl_2O_4$ was superior to CuO in metal immobilization over longer leaching periods. In a study attempting to observe the interaction of copper with the iron content in the chemically-enhanced primary treatment sludge, the $CuFe_2O_4$ was found. A low-temperature $CuFe_2O_4$ phase with tetragonal structure was detected at 750 ^oC, and the cubic $CuFe_2O_4$ developed at 1000 ^oC (Tang et al., 2016).

Management of electrical and electronic equipment waste (commonly known as e-waste) has been recognized as a great environmental challenge, and the obsolete cathode ray tubes (CRTs) is one of the main e-waste targets. A good strategy to dispose CRT glass is to extract lead content. In the literature, most of the lead extraction methods from glass matrix were found with very high energy consumption (Chen et al., 2009). In this study, metallic iron (Fe(0)) was used as the reducing agent to treat lead-containing glass to extract the metallic lead from the glass matrix at temperatures of 500-950 ^oC in the air.

Conventional material designs are often assisted by the X-ray diffraction (XRD) technique to identify the mineral phases in the products via matching the observed diffraction peak positions with those of standard mineral phases. In quantitative X-ray diffraction (QXRD) analysis using the Rietveld methods, relative weight fractions of crystalline phases in a multiphase sample can be calculated directly from scale factors of the respective calculated intensities. This technique is now available to further contribute to the accurate control of product quality.

In this study, the applications of QXRD on extracting metallic lead from waste electronics and on stabilizing the hazardous nickel and copper in ceramic products was investigated. The simulated metal-laden waste sludge and ash materials were thermally treated with a wide variety of alumina precursors. Our work of recovering metallic lead from waste CRT glass will also serve as a good example to reflect how the quantitative phase composition analysis can assist the development of new resource recovery technologies. A method of reductively transforming the lead in CRT glass into its metallic form through the reactive sintering with zero-valent iron was also invented and optimized by the QXRD technique.

METHODOLOGY

The hazardous metal (Zn and Cu) oxides were used as the simulated metal-laden waste sludge and ash materials to react with the aluminum oxide precursors. The γ-Al_2O_3 was derived from the fired boehmite (AlOOH) at 650 °C for 3 h. The hazardous metal (Me) oxide was mixed with aluminum oxide precursor at a Me:Al/Fe molar ratio of 1:2. The mixing process was carried out by ball milling the powder in water slurry for 18 h. The slurry samples were dried and homogenized by mortar grinding, pressed into 20 mm pellets at 650 MPa, and then fired from the temperature of 650 °C to 1450 °C. The leachability of single-phase samples was tested by means of a leaching experiment, with a pH 2.9 acetic acid solution as the leaching fluid. Each leaching vial was filled with 10 mL of TCLP extraction fluid and 0.5 g of powder, and rotated from 0.75 d to 22 d.

The CRTs glass was collected in Hong Kong and crushed into small pieces with the coating fully removed by the wet scrubbing method. The cleaned funnel glass particles were further dry ball milled and sieved to smaller than 45μm. The powder obtained was dried at 105°C for 24 h. The chemical composition of the glass powder was examined by X-ray fluorescence (XRF) with 21.5 wt. % of PbO. The waste funnel glass was mixed with metallic ion powder at different weight fractions. The mixtures were then homogenized by ball milling and pressed into pellets under a pressure of 650 MPa to ensure the consistent compaction of the samples. The pellets were then transferred to a muffle furnace preheated at the target temperatures (600-950 °C), and thermally treated with a dwell time ranging from 3 to 180 min in air.

All of the heat-treated samples were then quenched in the air and then ground into powder for X-ray diffraction scanning. Subsequently, the collected XRD patterns were conducted the qualitative XRD analysis by matching XRD patterns with the powder diffraction files (PDF) database of International Centre for Diffraction Data (ICDD) to investigate the phase composition of these samples. Furthermore, Rietveld refinement analysis was also conducted to quantitatively explore the weight percentages of the crystalline phases in the sintered products.

RESULTS AND DISCUSSION

The stabilization of copper and zinc through the formation of aluminate spinel

In order to investigate the reaction kinetics of the mixtures, the transformation ratio of Zn/Cu into spinel was defined as Equation 2. From Figure 1, about 20% of copper was transformed from CuO into $CuAl_2O_4$ when the mixture was sintered at 650 ^oC. The maximum TR of the CuO + γ-Al_2O_3 samples reached 80% at temperatures between 850 and 1000 ^oC, and then declined at higher temperatures because of the formation of $CuAlO_2$. Meanwhile, the TR values of zinc incorporated into $ZnAl_2O_4$ phase was strong and even reached over 60% transformation at 750 ^oC. The zinc transformation continued to increase with the elevation in sintering temperature and reached nearly full incorporation after sintering at 1450 ^oC.

$$TR = \frac{w_S/M_S}{w_S/M_S + w_{MeO}/M_{MeO}} \times 100\% \qquad (2)$$

Where w_s presents for the weight percentage of spinel ($ZnAl_2O_4$ or $CuAl_2O_4$); M_s is the molar weight of spinel ($ZnAl_2O_4$ or $CuAl_2O_4$); w_{MeO} is the weight percentage of residual ZnO/CuO; and M_s presents for the molar weight of ZnO/CuO.

Throughout the 22-d leaching experiment, the copper and zinc concentrations of MeO and $MeAl_2O_4$ leachates were shown in Figure 2a & b, respectively. Within the first 18 h, both copper and zinc ions increased substantially in leachates of metal oxides, and then they remained at approximately this value throughout the rest of the leaching period. When the leaching of $MeAl_2O_4$ was considered, the concentration of Cu^{2+} and Zn^{2+} kept slow increasing from the first 18 h to the end of this leaching procedure. However, even at the end of the leaching procedure, the concentration of Me^{2+} leached out from $MeAl_2O_4$ phase is much lower than that from MeO phase. The amount of leached copper and zinc in MeO leachate was about 3 orders of magnitude greater than that in the leachates of $MeAl_2O_4$. In comparison to metal oxides, the spinel demonstrated much higher inherent resistance to acidic attack, and thus the spinel incorporation strategy proved to be beneficial in stabilizing copper and zinc.

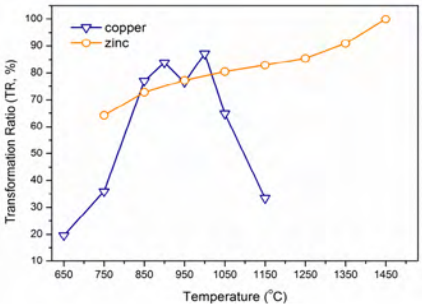

Figure 1. The transformation ratio (TR, %) of copper and zinc into the $MeAl_2O_4$ spinel structure.

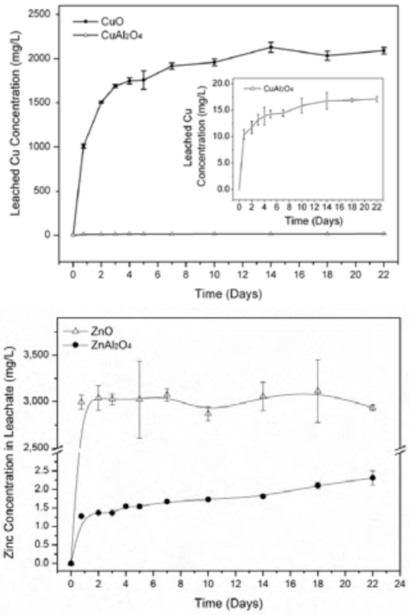

Figure 2. Variation of the (a) copper and (b) zinc concentrations of the leachates from MO and the as-prepared MAl_2O_4 powders.

The extraction of metallic lead from cathode ray tube (CRT) funnel glass

To further study the extraction efficiency of the Pb, the weight percentage of Pb related crystalline phases was refined by XRD quantitative method and then further converted into Pb Extraction Ratio as defined by Equation 1.

$$ER = \frac{m_T \times (w_{Pb} + w_{PbO} \times \frac{M_{Pb}}{M_{PbO}})}{m_O \times w'_{Pb}} \times 100\% \qquad (1)$$

Where m_O is the original mass of Fe + glass before thermal treatment; m_T is the mass of Fe+glass after thermal treatment; w_{Pb} and w_{PbO} are the weight percentage of metallic Pb and PbO; M_{Pb} and M_{PbO} are the molecular weight of metallic Pb and PbO; and w'_{Pb} is the weight percentage of Pb element in the mixture of Fe + glass before thermal treatment.

To optimize the Pb recovery process, the reaction between Fe and Pb-glass was investigated under various thermal treatment temperatures, time periods, and Fe/Pb-glass ratios. The Pb extraction ratio (ER) values of Fe+Pb-glass under different recovery conditions were shown in Figure 3. Figure 3 (a) summarizes the observed ER index values over the temperature range of 600-950 °C for the samples with Fe/ Pb-glass mass ratios of 1/1 and 0.75/1. At temperatures of 600-700 °C, substantial increases in the Pb extraction efficiency were observed for both mass ratios, and the lead extraction ratios increased significantly to 33% (Fe/Pb-glass of 1/1) and 54% (Fe/Pb-glass of 0.75/1). However, the curves also reflect a dramatic decrease in the lead extraction efficacy at higher temperatures (750-950 °C) for both the 1/1 system (a decrease from 33% to 0%) and the 0.75/1 system (a decrease from 56% to 12%). This finding demonstrates a particular condition for initiating the phase transformation of lead, and the results of the quantitative X-ray diffraction reveal 700 °C to be the most effective temperature for extracting the lead from the glassy network. In Figure 3 (b), the ER increases with the ratio increasing up to 1, and then maintains the ratio of 1.5/1. Therefore, the use of a Fe/Pb-glass mass ratio of close to 1/1 results in a more effective and economical extraction operation. In Figure 3 (c), the ratio of metallic lead extraction was enhanced by the use of prolonged heating time (180 min) to 37% at 600 °C. At 700 °C, the lead extraction efficiency first exhibited a significant increase to 56% after 30 min of heating, but then gradually decreased with prolonged heating time, dropping to 39% after 180 min of treatment. In contrast, a negative relationship between the lead extraction efficiency and thermal treatment time was found at 950 °C. The lead extraction ratio quickly reached 24% after 3 min of heating at 950 °C, but the extraction efficiency decreased continuously with prolonged heating. Therefore, the recovered Pb can be re-oxidized and over 30 min at 700 °C or over 3 min at 950 °C.

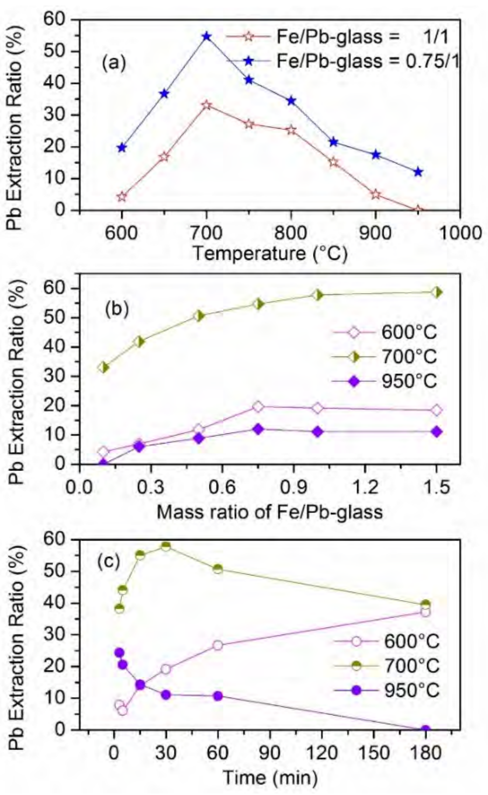

Figure 3. Extraction ratio (ER) values of Fe+Pb-glass (a) with the mass ratios of Fe/Pb-glass at 1/1 and 0.75/1 thermally treated at 600-950 °C for 30 min; (b) with different Fe/glass mass ratios treated at 600, 700, and 950 °C for 30 min; (c) with the mass ratio of Fe/Pb-glass at 1/1 treated at 600, 700, and 950 °C for 3-180 min.

CONCLUSIONS

The Pb in the Pb glass could be successfully recovered into metallic Pb by the oxidation of metallic ion. The reaction temperature, time, and the mass ratio of Fe/Pb-glass are significant to the Pb extraction efficiency. An optimal reaction condition is to sinter the Fe+Pb-glass with a mass ratio of 1/1 at 700 °C for 3 h, under which condition, about 56% of Pb could be recovered. The simulated hazardous metal (Zn or Cu) sludge and ash materials can be immobilized into spinel by Al_2O_3. Through the phase identification and quantification function of the XRD technique, copper and zinc were observed to be stabilized in the aluminate spinel ($MeAl_2O_4$).

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LANDFILL LEACHATE CHARACTERIZATION FOR SIMULATION OF BIOLOGICAL TREATMENT WITH ACTIVATED SLUDGE MODEL No.1 (ASM1) AND No.3 (ASM3)

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ABSTRACT

An appropriate design of a wastewater treatment plant should depend on the fractional composition of pollutants. Especially COD and nitrogen fractions play an important role in various wastewaters. This paper presents the results of studies concerning the COD and nitrogen fractionation for leachates. The COD fractions of Vietnamese leachates were determined including soluble biodegradable COD (S_S), soluble inert COD (S_I), particulate biodegradable COD (X_S) and particulate inert COD (X_I). The obtained results showed that the percent ratio (mean±SD) of COD fractions such as S_S, S_I, X_S and X_I in dry season equivalent to: 43.61±9.90%, 24.04±11.07%, 26.24±14.48% and 6.11±5.9%, respectively and rainy season were 45.63±9.87%, 19.65±10.62%, 25.4±13.81% and 9.32±3.55%, respectively. The methodology was also applied to characterize nitrogen fractions such as ammonia nitrogen (S_{NH}), nitrite and nitrate (S_{NO}), soluble non-biodegradable nitrogen (S_{NI}), particulate non-biodegradable nitrogen (X_{NI}), soluble biodegradable organic nitrogen (S_{ND}) and particulate biodegradable organic nitrogen (X_{ND}). The nitrogen fractions in this study were expressed as percentage ratio (mean±SD) of nitrogen fractions such as S_{NO}, S_{NI}, X_{NI}, S_{ND} and X_{ND} in dry season and rainy season. The achieved values were 67.77±9.95%, 0.16±0.05%, 6.18±2.84%, 8.01±5.46%, 16.25±5.52% and 1.63±1.35%, respectively in dry season and 72.71±12.67%, 0.16±0.05%, 7.25±4.41%, 15.41±7.21%, 2.74±2.03% and 2.69±2.52%, respectively in rainy season.

Keywords: Leachate, COD fractions, Nitrogen fractions

INTRODUCTION

Both biodegradable, refractory organic and inorganic as well as a number of pathogenic bacteria are contained in leachate (Melike YalılıKılıç 2007, Eka Sri *et al*. 2013, Eka Sri Yusmartini 2013). According to (Johansen *et al*. 1976, Robinson 2007, Barjinder Bhalla *et al*. 2012, Noor Ainee Zainol 2012) the main compounds are COD, BOD, ammonia, hydrocarbons, suspended solids and inorganic salts. As it is well known, leachate characteristics reflect biodegradation properties, and the age of landfill site. To treat leachate, several methods such as physicochemical and biological are often combined. Biological treatment methods are more common for leachate treatment (Lo 1996, Wiszniowski *et al*. 2006, Melike YalılıKılıç 2007, Salwa Mohd Zaini Makhtar *et al*. 2011). The efficiency of biological leachate treatment depends both on pollutant concentration levels and on their biodegradability. Usually biological treatments with activated sludge are capable to obtain high performances, due to bacterial colonies, particularly autotrophic bacteria for ammonia consumption and heterotrophs for the carbon fraction (Carlo Collivignarelli 1990, Spiros N. Agathos *et al*. 2003, Guibing Zhu 2008). The behavior of these micro-organisms can be mathematically described and models like the Activated Sludge Model's (ASM) family had proven to simulate it correctly, at least for municipal wastewater treatment conditions (I. Vadillo *et al.* 1999, Fall *et al*. 2014). Nowadays, a more detailed characterization of influent wastewater is needed because they are the relevant factors to the efficient operation of wastewater treatment plants. Moreover, the increasing utilization of simulation tools related to ASMs developed by IWA requires accurate and precise description of raw wastewater, especially organic and nitrogen matter present in the influent as those values are direct state variables of those models. Therefore, COD and nitrogen fractions play an important role in the design of wastewater treatment plants, especially in the case of leachates.

In ASM models focus is made on the compounds of wastewater as state variables of the models. These variables represent the organic matter present, measured as Chemical Oxygen Demand (COD) fractions and nitrogen forms, biomass, alkalinity and dissolved oxygen. Good model calibration requires knowledge of model parameters and influent wastewater characteristics which can significantly influence plant performance, especially for biological nutrient removal systems (Mogens Henze 1999, Szaja 2015). In the context of using activated sludge models, it was proposed that the COD can be described in Figure 1.

COD is selected as the most suitable parameter for defining the carbon substrates because COD is relevant to quantify the electron equivalents in the organic substrate, the biomass and oxygen utilized. There are seven COD fractions in the ASM1 based on solubility, biodegradability, biodegradation rate and viability (biomass). One of the most difficult parts to calibrate the ASM1 is the characterization of the wastewater fractions. Wastewater can be characterized either with physical-chemical methods or with biological methods. To be able to characterize all the fractions, the two methods must be combined (Petersen B. *et al*. 2000). The biological methods are based on the rates of degradation.

Nitrogen components in ASM are similar to the organic matter, total nitrogen can be subdivided based on solubility, biodegradability and biodegradation rate. Summarizing, the total nitrogen balance for the components in ASM is illustrated in Figure 2.

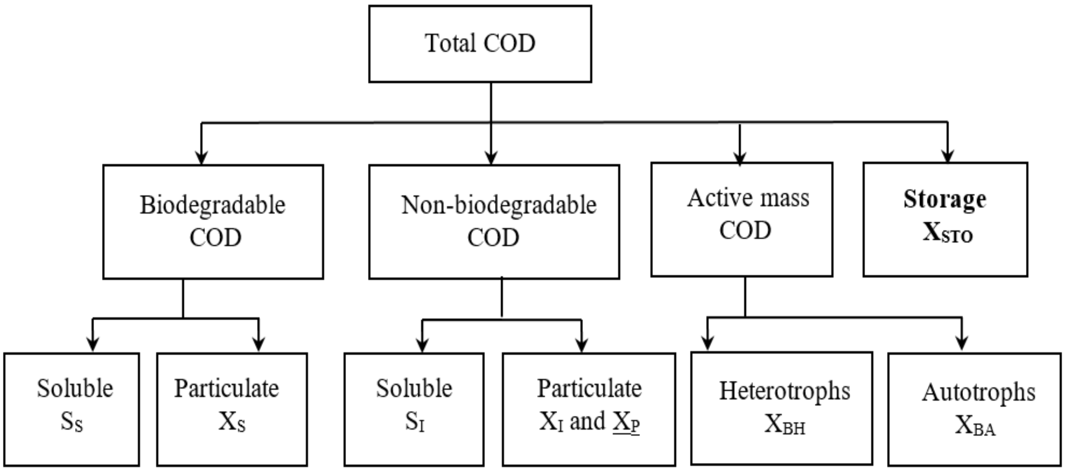

Figure 1 COD fraction in ASM1 and ASM3 (modified from (Nelson *et al*. 2009))

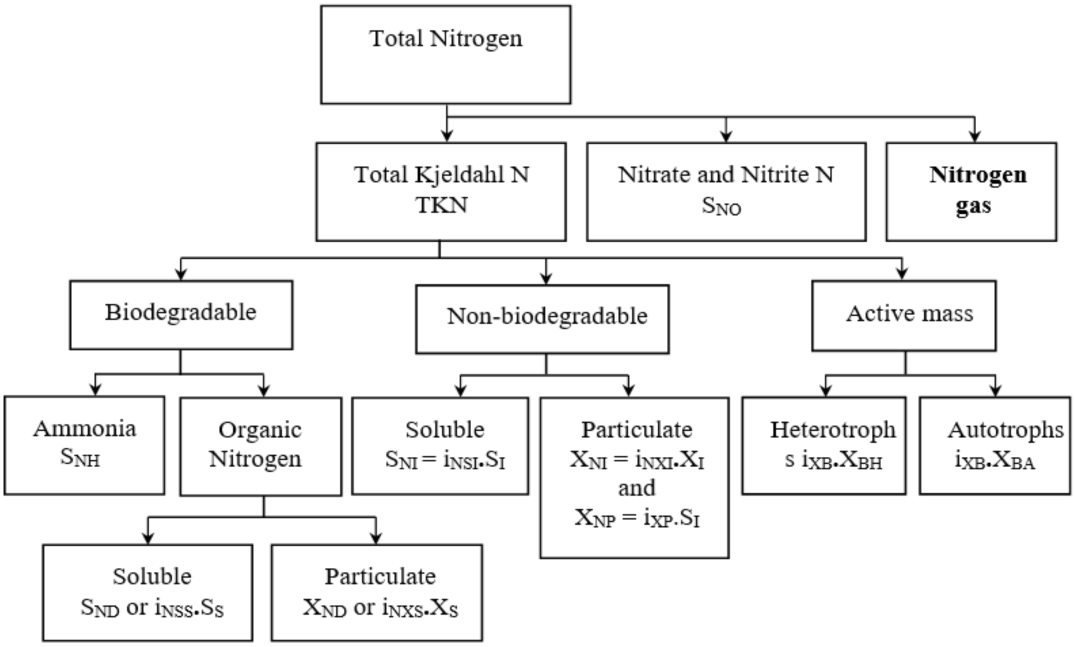

Figure 1 Nitrogen components in ASM1 and ASM3 (modified from (Mogens Henze 2000)

MATERIALS AND METHODS

Leachate sampling

Leachate was collected at Phuoc Hiep landfill, located in the North East Solid Waste Treatment Complex, Phuoc Hiep Commune, Cu Chi District, about 37 km distance from the center of HCMC. Phuoc Hiep landfill covers 50 ha and has been operated since 2003. The samples were collected and transported immediately to the laboratory. The samples were kept in the refrigerator at 4^{o}C to minimize biological and chemical reactions and analyzed within a day.

Methods

The goal of research was to determine the COD and nitrogen fractions in leachate. The characterization employed in this study is based on a physico-chemical method combined with a BOD analysis.

1) **S_S + S_I + X_S + X_I**: Total Chemical Oxygen Demand (COD) was determined following Method 5220.C of Standard Methods (APHA: 1998).
2) **S_S + S_I**: Wastewater was pretreated with coagulation, flocculation with $Zn(OH)_2$ and 0.45 µm filters and the COD of the filtrate was measured by Method 5220.C of Standard Methods (APHA: 1998).
3) **X_S + X_I**: After the determination of soluble COD fractions (**S_S + S_I**) the COD of the wastewater suspended solids was obtained by subtracting soluble COD from total COD (Bilgili *et al.* 2008).
4) **S_S + X_S**: BOD was performed by The Hach BOD Trak II Apparatus during 10 days and was calculated by Thomas method (Thomas 1950). As a certain amount of ammonia is present and this has to be considered during the BOD test where an appropriate amount of ATU (Allylthiourea) has to be added to inhibit nitrifying bacteria that would otherwise affect the oxygen consumption in the BOD bottle.
5) **S_I + X_I**: Non-biodegradable COD was obtained by subtracting biodegradable COD (**S_S + X_S)** from total COD.
6) **S_S**: S_S was performed by The Hach BOD Trak II Apparatus. The sample pretreatment procedure was performed the same to determination of soluble COD. Then soluble biodegradable COD is calculated by using Thomas method.
7) **X_S**: X_S was calculated via non-biodegradable COD and S_I in accordance with the COD balance. Meanwhile, non-biodegradable COD was calculated from difference in total COD and biodegradable COD.
8) **S_I:** S_I was obtained by subtracting soluble biodegradable COD from total soluble COD (P.J. Roeleveld *et al.* 2002, M. Zawilski 2009, Wu et al. 2014).
9) **X_I:** X_I was calculated from difference between total non-biodegradable COD and soluble inert COD (P.J. Roeleveld *et al.* 2002, M. Zawilski 2009).
10) **S_{NH}**: Sample was adjusted pH to 9.5 with 6N NaOH then it was boiled by Kjeldahl test system to use mixture to steam out. Distillate is collected in Erlenmeyer flask with boric acid. The Nessler method in which potassium, mercury, and iodine react with ammonium to produce a yellow brownish colored compound is called the Nesslerization. The wavelength for the light used in the measurement was set at 425nm (Bradstreet 1965, APHA: 1998, Heonsang Jeong 2013).
11) **S_{NO}:** Nitrite was measured by colorimetric method, in accordance to 4500.B of Standard Methods. Nitrate was determined by cadmium reduction method in 4500.E of Standard Methods (APHA: 1998).
12) **S_{NI}:** S_{NI} was estimated on the basis of filtered Kjeldahl nitrogen in effluent (after determining BOD without ATU) to determine soluble residual organic nitrogen.
13) **X_{NI}:** X_{NI} was calculated as difference between non-biodegradable organic nitrogen and soluble biodegradable organic nitrogen.
14) **S_{ND}:** S_{ND} = TNK filtered leachate - TNK filtered treated - S_{NH}.
15) **X_{ND}:** X_{ND} was calculated as difference between

total biodegradable organic nitrogen and soluble biodegradable organic nitrogen.

16) **X_{SS}:** The TSS was determined after filtration of sample on a Whatman glass micro filter. Dry weight was determined after the filter was dried at 105°C and weighted on a microbalance in accordance to 2540.D of Standard Methods (APHA: 1998).

17) **Alkalinity (S_{Alk}):** The alkalinity was measured by titration Method (2320 B).

18) **Dissolved oxygen (S_O):** measuring dissolved oxygen by using HANNA HI9147-04 equipment .

RESULTS AND DISCUSSION

COD fraction

The COD fractions in this study were expressed as percentage of the average and were reported in Table 1 and Fig. 3. The results of the research show that the main components in landfill leachate are fractions S_S and X_S.

Table 1. Results of COD fraction

COD FRACTIONS	DRY SEASON		RAINY SEASON	
	mg/L	%	mg/L	%
S_S	1963 ± 356	43.61 ± 9.90	1426 ± 283	45.63 ± 9.87
S_I	1089 ± 456	24.04 ± 11.07	630 ± 390	19.65 ± 10.62
X_S	1253 ± 719	26.24 ± 14.48	829 ± 477	25.4 ± 13.81
X_I	293 ± 159	6.11 ± 5.95	301 ± 150	9.32 ± 3.55

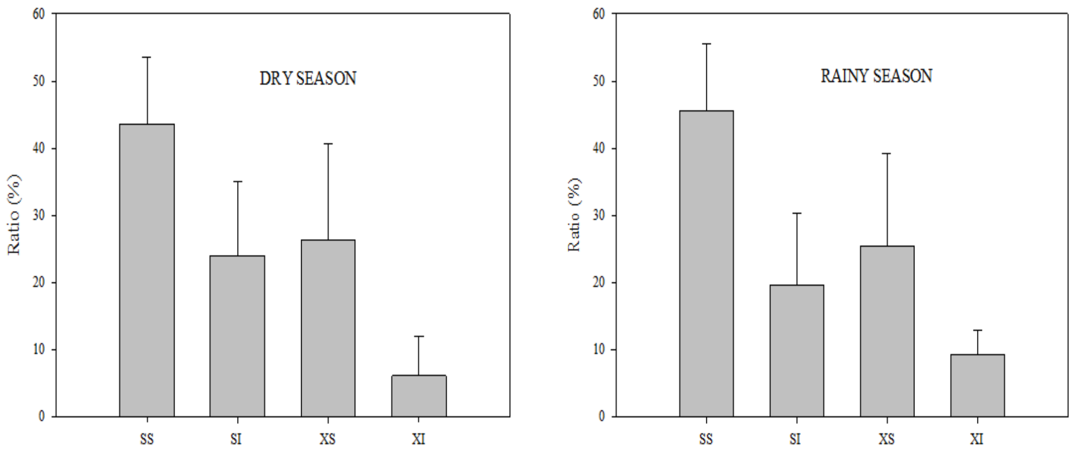

Figure 3 COD fractions

As shown in this table, the average of total soluble COD component in dry and rainy season was found approximately 67.65% and 68.28% of total COD corresponding to the average value of total particulate COD component of 32.35% and 34.72%, respectively

The average of readily biodegradable fraction in dry season and rainy season accounted for 69.85% and 71.03% of total COD, respectively. Whereas, the soluble readily biodegradable COD in dry season and rainy season accounted for 43.61±9.90% and for 45.63±9.87% total COD, respectively. Results of this study showed that the values of soluble inert COD were 24.04±11.07 % and 19.65±10.62% during dry and rainy season, respectively.

It can be seen from table 1 that evaluation of experimental study indicated 26.24±14.48% and 25.4±13.81% of total COD are biodegradable particulate compounds. The lowest mean value is particulate inert COD. The fraction of inert particulate compounds in this study in dry season and rainy season was found around 6.11±5.95% and 9.32±3.55% of total COD, respectively. Whereas Boubaker had observed that this fraction ratio was only from 0.4 to 1%. (Boubaker 2015). The reason of this difference is that the leachate from well operating sanitary landfill have passed the entire depth of deposits and a filtration has been done by the solid wastes.

To evaluate the effects of seasons to COD fraction, t-test value was calculated. The statistics showed that the season affected soluble COD ($p \leq 0.05$), especially S_S and S_I but not X_S and X_I.

Nitrogen fraction

Values for the major nitrogen fractions are listed in Table 2 and Fig. 4 together with similar results reported for leachate from former study.

Table 2. Nitrogen fractional ratios

NITROGEN FRACTIONS	THIS STUDY				REFERENCE
	dry season Mean ± SD		rainy season Mean ± SD		(Boubaker 2015)
	mg/L	%	mg/L	%	%
S_{NH}	1268±198	67.77 ± 5.95	945±305	72.71 ±12.67	5 – 68
S_{NO}	2.99±0.96	0.16 ± 0.05	1.98±0.69	0.16 ± 0.05	6 – 9
S_{NI}	115±53	6.18 ± 2.84	83±38	7.25 ± 4.41	0.4 – 3
X_{NI}	152±117	8.01 ± 5.46	187±66	15.41 ± 7.21	0.4 – 1
S_{ND}	307±123	16.25 ± 5.52	32±19	2.74 ± 2.03	11 – 85
X_{ND}	30±25	1.63 ± 1.35	34±33	2.69 ± 2.52	5 – 20

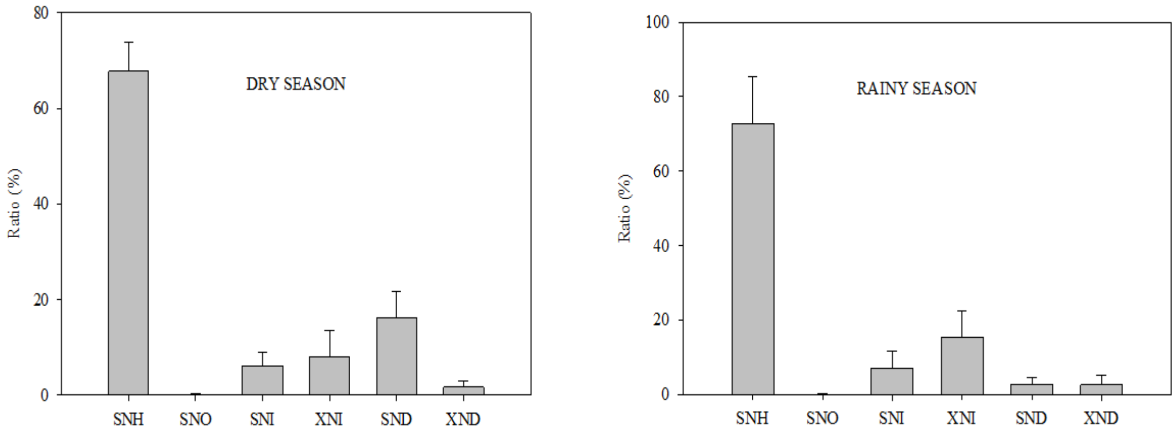

Figure 4 Nitrogen fractions

The data collected in Table 2 indicated that the highest percentage ratio is S_{NH} and the lowest is S_{NO}. The ammonia nitrogen achieved to 67.77±5.95% for dry season and 72.71 ±12.67% for rainy season. On the contrary, the S_{NO} fraction accounted for a very small proportion in leachate and was only 0.16±0.05% in both seasons. For domestic waste waters Boubaker found that S_{NO} fraction was higher than in this study (between 6 and 9% of TKN) (Boubaker 2015). The S_{NI} fraction in dry and rainy season was determined at 6.18±2.84% to 7.25 ± 4.41%, respectively. As it can be seen from the table 2, the particulate non-biodegradable nitrogen values are different between wet and dry season.

The organic nitrogen fraction was divided into two compartments as S_{ND} and X_{NI}. The fraction of soluble organic nitrogen biologically degradable, S_{ND} was determined at 16.25±5.52% and 2.74±2.03% for dry and rainy season, respectively. Meanwhile, this value was determined at 11 – 85% in domestic wastewater (Boubaker 2015). In the rainy season, the value of particulate non-biodegradable nitrogen was twice the one in dry season. The X_{NI} values were obtained at 8.01±5.46% and 15.41±7.21% of the total nitrogen in dry and rainy season, respectively.

In this study, the values of X_{ND} were 1.63±1.35% (dry season) and 2.69±2.52% (rainy season) rather different of the 5% to 20 % for domestic waste waters (Boubaker 2015).

The results of the statistical analysis (average comparison) showed an effect of season on S_{NH} and S_{NO}. On the other hand, the p value were > 0.05 for S_{NI} and X_{NI}. So and thus statistically significant.

<u>Others components</u>

Alkalinity (S_{Alk}): In this investigation, the Phuoc Hiep landfill was found to have significantly high alkalinity value. Alkalinity during the study period in the dry and rainy season varied from 8.403±1327 mgCaCO$_3$/L to 2.202±744 mgCaCO$_3$/L, respectively.

Total suspended solids (X_{SS}): X_{SS} value was determined 1.300±318 mg/L and 1802±633 mg/L in the dry and rainy season, respectively.

Dissolved oxygen (S_O): Dissolved oxygen concentration in landfill leachate is very low. The value of measured DO is close to zero because the leachate is flowing out of an anaerobic environment.

CONCLUSIONS

The analysis of fractional composition of COD and Nitrogen for a Vietnamese landfill leachate were performed for dry and rainy season. A significant decrease of the fractional ratio of inert soluble organic (p value of 0.04) in rainy conditions was recorded. Contrary, there is a significant increase for biodegradable soluble organic (p value of 0.003) was also determined in this study.

For nitrogen, the ammonia nitrogen fractional ratio (N-NH4) significantly increases during the rainy saison.

Such type of studies are important to characterize leachates in order to design and operate properly landfill leachate treatment plants. Also some seasonal effects have been observed and should be taken into account.

ACKNOWLEDGMENT

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STUDY ON THE DRYING PROCESS OF THE SOLID WASTE IN LANDFILL UNDER ARID CLIMATE

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ABSTRACT

In recent years, many mega-cities have formed in arid/semi-arid region such as Middle East and North Africa. Huge amount of waste generated from these cities are disposed of very simple landfill or dumpsite. As for the stabilization of waste, water is indispensable. However, in arid region, evaporation exceeds the rainfall. If the waste tends to dry, the stabilization process perhaps may hardly proceed. In this regards, drying of waste is considered to be the crucial process. In this study, to clarify the drying process of waste in landfill under arid climate, numerical simulations were performed by creating heat and water movement model based on the theory of the transport phenomena in porous media. Besides, basic water movement characteristics in waste were determined by laboratory experiments and model validity was confirmed by the drying experiment of waste using lysimeter. As the results, the following were obtained; 1) Moisture movement occurs even in waste having macropore through micropore existing in waste itself. 2) The created model could almost reproduce the results of lysimeter. 3) When the model is applied to the real scale landfill, the drying of waste only occurs near surface region even after 30 years and the drying rate of the waste gradually decreases as it progresses to inside. In addition, the water retention curve covering from 0% to 50% of volumetric water content was determined for simulated waste.

Keywords: Arid climate, Landfill, Simulation, Water characteristic curve

INTRODUCTION

The arid/semi-arid area on the earth occupies 41.3% of the land area, and about 35% of the world population lives in the area (World Resources Institute, 2005). Even in these arid regions, the amount of waste has been increasing recently due to population growth, urbanization, etc. and it results in serious social problems. Many of the countries located in arid regions are developing countries, and open dumps and simple landfilling are still the mainstream of waste disposal. However, there is little knowledge about the mechanism of long-term stabilization of waste in landfills under such climates. Therefore, suitable management strategy of the landfill doesn't exist.

Under arid climate, evaporation exceeds rainfall so that net water balance becomes negative. For stabilization of the waste, moisture is crucial because biodegradation of organic matter requires suitable moisture content and some inorganic salts must be washed off by precipitation. However, under arid climate, sufficient water supply cannot be expected. Therefore, when considering about waste stabilization under arid condition, drying process is thought to be important. Major questions are as follows;

In arid/semi-arid condition, how does the waste in landfill stabilize? Does the waste completely dry out? How long will it take for the waste to completely dry? How is the drying rate and how deep does it progress? Answer for these questions seems to be indispensable when thinking about the stabilization of waste under arid climate and proper management strategy for the landfill.

In this study, column drying experiments of the artificially synthesized waste were performed and coupled numerical model of heat, moisture, and vapor was created by considering internal evaporation and water retention curve up to absolute dry state. Through validation between the results of experiment and numerical model, real scale simulation with regard to the drying process of the waste was carried out.

MATERIALS AND METHODS

Confirmation of water movement in drying process of the waste

The waste layer is not composed of homogeneous substances like the soil layer. Compared to the soil layer, large particles and fine particles are mixed. In particular, the void between each waste and the void existing inside the waste differ greatly in void diameter. In the outer particle void having a large void diameter, liquid water is not easily movable at the low water content as in the drying process, or there is a possibility that liquid water cannot move, since the capillary force is quite small. On the other hand, the interstitial void spaces inside the waste material such as paper and fibers are thought to be fine voids, and there is a possibility that capillary water can move through the inside of the waste during drying process. However, it is a prerequisite that the particles of waste come into contact with each other and the continuity of capillary water is maintained. From this point of view, it is necessary to clarify the occurrence of liquid water movement when considering the drying process in the waste layer. Therefore, in this study, a column experiment using NaCl as a tracer was carried out to confirm the occurrence of liquid water movement during the drying process of the waste.

In this experiment, simulated artificial waste was created and used. Composition was determined with reference to Tanaka et al. (1993). Table 1 shows the composition of simulated landfill waste. Paper and cloths are hardly decomposable organic substances which influence water movement of waste layers in landfill and are used as substances having fine voids inside them. Plastic tubes were used to reproduce the coarse gaps present in the waste layer.

Table 1 Simulated artificial waste

Components	Mass %
Paper (Newspaper)	13
Paper (Printing paper)	18
Paper (Tissue paper)	4
Cardboard	30
Textiles	12
Plastic tube	23

The dried artificial waste was packed in a column having an inner diameter of 6.9 cm and a length of 50 cm, so as to have a porosity of about 80%. After immersing the column packed with the sample in a 0.8% NaCl solution for 1 day, drainage was performed from the bottom of the column for 3 days so that a natural drainage state was formed at the start of the experiment. Thereafter, the column surface was irradiated with an infrared ray lamp to promote drying process. During drying, the whole column was set in a thermostatic chamber set at about 25ºC. After drying for a certain period of time (after 7 days and 14 days), the sample was divided into 10 layers from the surface and then water content and NaCl content were measured.

Determination of water characteristics curve of the waste in a wide range of water content

For drying process, heat transfer, evaporation, vapor and water movements are involved. Since the occurrence of water movement was confirmed by the drying experiment described above, it was necessary to measure the relationship between volumetric water content and suction potential. In general, the water characteristic curve in soil has the lowest water content as the residual wetness, and the water content below that is not considered in water movement. On the other hand, voids exist both outside and inside of the materials comprising waste. At the natural drainage state, the capillary water in the void existing particle outer space is thought to be in an equilibrium state with the water content corresponding to the position. Besides, moisture in the interstitial void also exists at the same position. In the drying process, not only the moisture in the outside void but also the moisture in the interior void deems to be involved. Therefore, in order to consider the drying process, it is necessary to obtain a water characteristic curve leading to an absolutely dry state such that pore water in the waste material is completely dried. For that, in this study, the water characteristic curve covering the range up to the absolutely dry condition was measured for the artificially created waste. For this purpose, the soil column method, centrifugal method, and vapor pressure

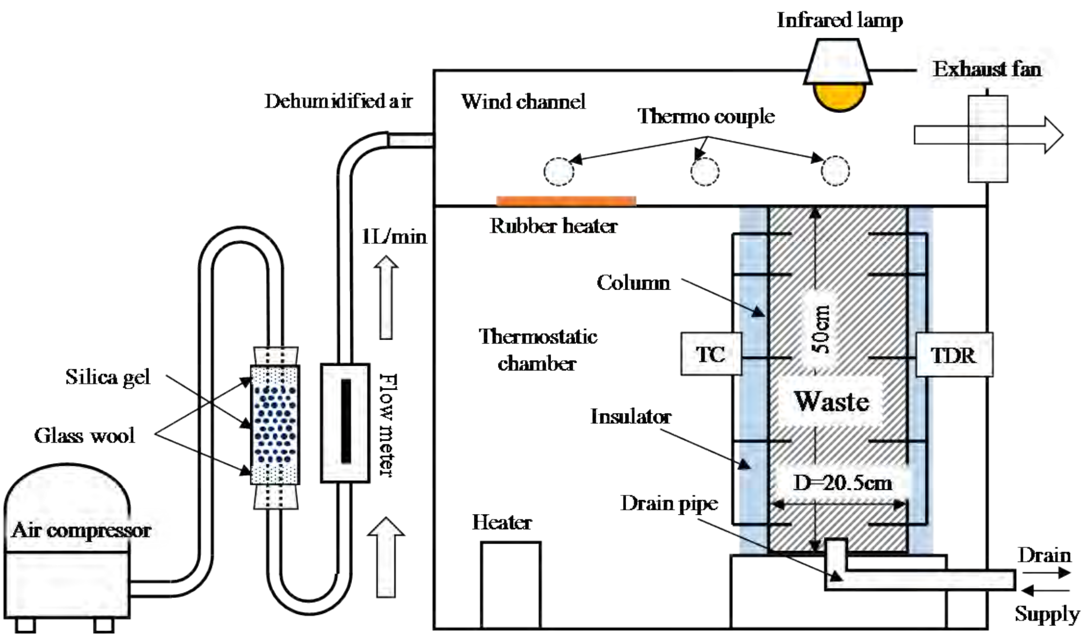


Figure 1 Experimental apparatus for drying experiment

method were applied.

Drying experiment

In order to reproduce the drying process of the waste in landfill, column experiments were conducted. Figure 1 shows experimental setup of drying experiment. The column was filled by artificially created waste of which composition is indicated in Table 1. The column is covered by insulator and the surface of the waste is irradiated by infrared lamp. At the top of the column was exposed to the wind tunnel and hot air was sent by blower to remove the vapor escaped from the waste. The column was set up in the thermostatic chamber. At constant interval, thermocouple and TDR was installed in order to measure temperature and volumetric water content. Both parameters were measured continuously after irradiation was initiated.

COUPLED MODEL OF WATER, VAPOR, AND TEMPERATURE MOVEMENT

To express the drying process of the waste, following transport phenomena were taken into account.

Water movement

In general, unsaturated water movement in porous media can be expressed by the following formula;

$$\frac{\partial \theta}{\partial t} = -\frac{\partial}{\partial z}\left(-K(\theta)\frac{\partial}{\partial z}(\psi_m + z)\right) - \frac{E_{in}}{\rho_w}$$

Here, θ: volumetric water content [-], t: time [s], z: vertical coordinate [m], $K(\theta)$: unsaturated hydraulic conductivity [m/s], ψ_m: matric potential [m], E_{in}: amount of phase change between liquid water and vapor by internal evaporation, and ρ_w: density of water [kg/m^3].

Vapor movement

Vapor diffuses due to the concentration gradient. Thus, it can be expressed by the following equation;

$$\theta_v \frac{\partial \rho_v}{\partial t} = -\frac{\partial}{\partial z}\left(-D_{soil}\frac{\partial \rho_v}{\partial z}\right) + E_{in}$$

Here, θ_v: gas phase ratio [-], ρ_v: concentration of vapor [kg/m^3], D_{soil}: diffusion coefficient of the media [m^2/s] calculated by diffusion coefficient of vapor in free space and tortuosity of the media (Moldrup, et. al. (1997)).

Heat transfer

Change of the temperature is calculated by the balance of input and output of heat conduction, sensible heat transfer by liquid water, and consumption of latent heat by internal evaporation. Therefore it can be expressed by the following equation;

$$\frac{\partial C_S T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z}\right) - \rho_w C_w q_L \frac{\partial T}{\partial z} - LE_{in}$$

Here, C_S: volumetric heat capacity of the media [J/(m^3·K)], T: temperature of the media [K], λ: thermal conductivity [W/(m·K)], C_w: heat capacity of water [J/(m^3·K)], q_L: flux of liquid water [m/s], L: latent heat of water for evaporation [J/kg].

Internal evaporation

In subsurface, evaporation of liquid water occurs by volumetric water content and gradient of vapor concentration from saturated vapor concentration at the temperature (Zhang, J. and Datta, A. K. (2004)). Thus;

$$E_{in} = \frac{b(\theta - \theta_r)RT}{M_w}\left(\rho_{vs}(T)\cdot h_r - \rho_v\right)$$

Here, b: constant [-], R: gas constant [8.314 J/(mol•K)], M_w: molecular weight of water [0.018 kg/mol], $\rho_{vs}(T)$: saturated vapor concentration at temperature of T [kg/m^3], h_r: relative humidity [-].

RESULTS

Occurrence of liquid water during drying process

Although the results are not shown, the volume moisture content of the column surface decreases most greatly with time and reaches about 1% after 14 days. Other than the surface, the moisture content increased in the middle part of the column, and the moisture content in the bottom region was decreased. On the other hand, the amount of NaCl on the column surface sharply increased after drying. Other than the surface, the amount of NaCl decreased as the drying period became longer. This is because water existing inside the column moves upward as liquid water, NaCl is also carried upward by liquid water moving upward, and as it reaches the column surface, the amount of NaCl at surface increased conceivably. That is, it was confirmed that liquid water movement occurs during the drying process.

Water characteristic curve

Figure 2 indicates the relationship between volumetric water content and matric potential of the artificial waste used in this study. As can be seen, the relationship could be obtained in a quite wide range. The lowest water content reaches close to zero and its potential is near -10^6cm. The measurement was done assuming that two different void (i.e. outer space void and interstitial void) exist. Based on this assumption, water holding characteristics was thought to be

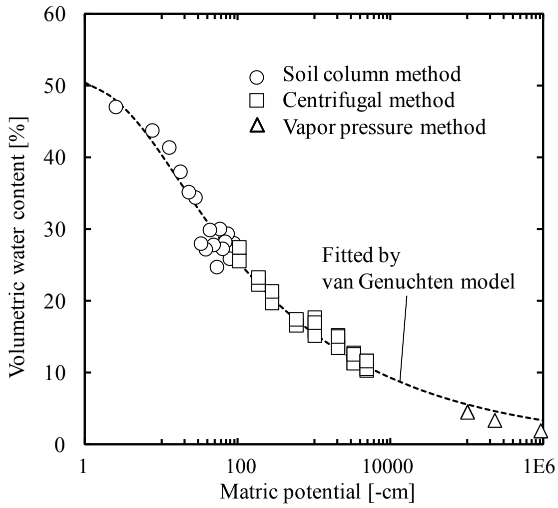
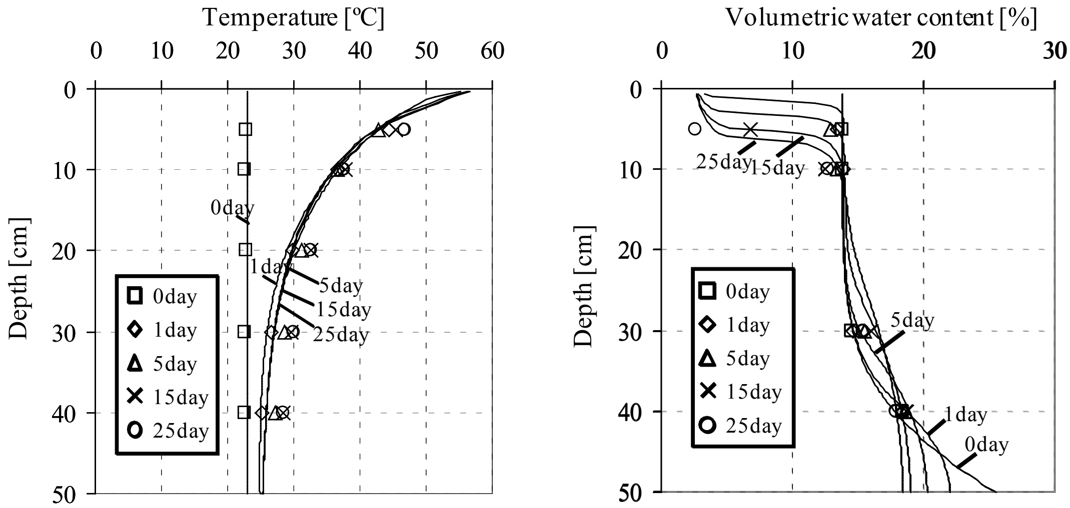


Figure 2 Water characteristic curve of the artificially created waste



(a) Temperature profile (b) Profile of volumetric water content

Figure 3 Results of the column drying experiment and comparison to the calculated results by coupled model of heat, vapor, and water movement

different for each void and the curve might be discontinuous. However, as indicated in the figure, these data points seemed to be continuous and they seemed to exist along with a continuous line. Therefore, data points are fitted by van Genuchten's model (van Genuchten, M.Th. (1980)).

Drying experiment and validation of the model

Figure 3 shows the results of the column drying experiment and the calculation results by the model created. Figure 3(a) shows the evolution of the temperature profile and 3(b) shows the change in volumetric water content. As shown in Figure 3(a), the temperature inside the column was 23 ºC over the whole area at the beginning. After 1 day, the temperature exceeded 40 ºC at a depth of 5 cm from the surface. Although the temperature rises remarkably near the surface, it can be confirmed that the temperature rises also inside gradually. In the water content profile shown in Figure 3(b), reduction of the water content at 5cm from the surface was particularly notable. It drastically decreased with the time, and became 5% or less after 25 days. On the other hand, the decrease in water content in the area deeper than 10cm was small. The calculation results indicated by the solid line almost reproduce the tendency of temperature increase from the surface to the depth. However, although the observed value continues to rise with the lapse of time, the calculation result doesn't show the same tendency. The temperature rise in calculated result seems to converge, even time progresses. The calculation result of the water content is almost consistent with the experimental result. It is confirmed that the temperature near the surface sharply drops and the drying region gradually moves to downward. In addition, the water content decreases remarkably at the deepest part, and the moisture content tends to increase near the central part. The experimental result also shows that the moisture content slightly increases with the time at around 30 cm. Thus, both observed results and simulated results are harmonious. This is because the liquid water moves upward from the bottom as the surface dries. From the above, it seems that the coupled model of heat, vapor and liquid water created in this study can mostly reproduce the drying process of waste.

Drying experiment and validation of the model

Since the model created in this research was able to reproduce experimental results roughly, calculations of drying process in real scale landfill were performed by using this model.

The landfill site to be calculated is shown in Figure 4. Landfill was assumed to be a form where waste was directly stacked on the ground surface, and the height was set to 10 m. For the analysis, considering the system that cut out from a part of the landfill, coupled model was applied to the vertical one-dimensional system. As for the environmental conditions around the landfill, radiation intensity of the sun, atmospheric temperature and humidity were assumed to be steady

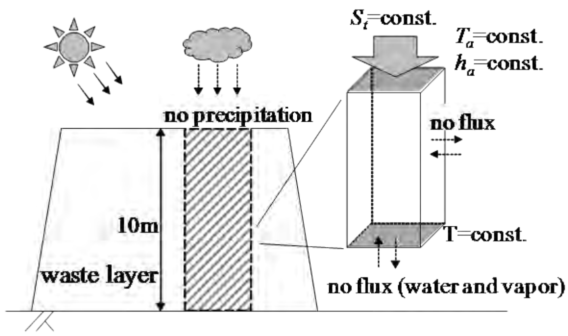
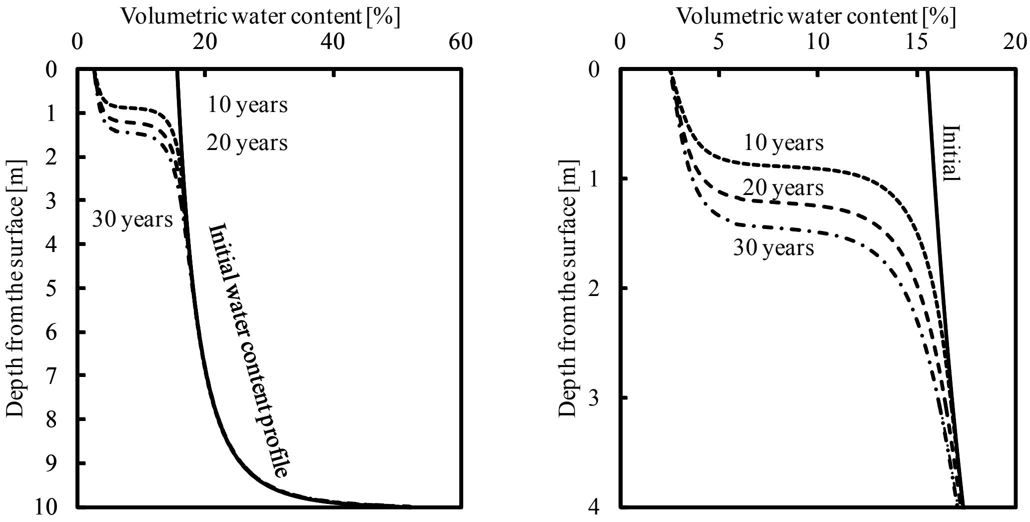


Figure 4 Assumed real scale landfill subjected for the simulation



(a) Entire depth

(b) Near surface region

Figure 5 Simulated results on drying process for real scale landfill

state. Rainfall was not taken into account in this simulation because it was aimed at emphasizing the promotion of drying. Temperature of the ground surface in contact with the bottom of the landfill was set always constant because input and output of heat was thought to be negligibly small when considering big heat capacity of the ground. For calculation, COMSOL Multiphysics® was used. The landfill with a height of 10 m was divided into 1920 elements. The calculation period was set to be 30 years considering the length of the management period of the landfill.

Changes in the water content distribution of the waste layer are shown in Figure 5. Figure 5(a) indicates water content profile at entire depth and 5(b) shows only the region near surface. Reduction in the water content can be confirmed only in the vicinity of the landfill surface up to 3 m in depth. The water content of the waste below the depth of 3 m does not change from the initial water content. The size of the drying zone (the area at which the water content rapidly decreased is referred to as the drying zone in this paper) has increased with time and it spreads to the point of 1.5 m after 30 year. If the spreading speed of this drying zone is a measure of the drying speed of the waste, the drying speed of the waste is the fastest during fist 10 year, and its speed is about 8 cm/year. Then, drying speed gradually declines with time. It becomes about 3 cm/year from 10th to 20th year, and about 2 cm/year from 20th to 30th year. Based on the result, it can be concluded that the drying rate of the waste decreases with the lapse of time and it takes quite a long time for waste in landfill to completely dry.

This is explained as follows. At the stage of relatively high water content after natural drainage, there is enough unsaturated hydraulic conductivity that allows liquid water to move. However, with the progress of drying, the unsaturated hydraulic conductivity decreases exponentially, and the flux of liquid water in the drying zone decreases sharply. Instead of liquid water movement, the movement of vapor becomes dominant. However, as the drying progresses further, the location at where internal evaporation occurs also moves to the deeper region. As consequences, the resistance of the vapor movement increases and the overall drying speed decreases.

CONCLUSIONS

In this research, the objective was set to clarify the mechanism of drying of waste in the landfill under arid/semi-arid climate. A coupled model on heat transfer, and movement of liquid water and vapor was created. The validity of the model was confirmed by lab-scale column experiments. Then, the model was applied to the real scale landfill. The major results are as follows;

1) In drying process of the waste, it was found that even in the waste layer having the coarse voids, the liquid water moves through fine voids existing inside the waste materials.

2) The water characteristic curve of the waste was measured for the wide water content range leading to absolute dryness. It was found that simulated waste used in this study shows a continuous shape of the water characteristic curve in which the volumetric water content gradually decreases as the matrix potential decreases.

3) Results of column drying experiment on artificial waste and results of its numerical simulation made by the coupled model coincide mostly. However, in order to improve the accuracy of the model, it is necessary to study various parameters further.

4) Numerical analysis assuming a real-scale landfill using the model revealed that the progression of drying reaches only the vicinity of the landfill surface even after a long period of time. It was also found that the drying rate of waste decreases with time due to the decrease of water and vapor flux near the landfill surface.

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EMISSIONS OF HIGH GLOBAL WARMING POTENTIAL GASES OVER LIFECYCLE OF LANDFILLS

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ABSTRACT

A parametric study was conducted to estimate emissions of high global warming potential and ozone depleting substance greenhouse gases from landfills in California, USA, during different life stages of the facilities. Emissions were estimated for halogenated hydrocarbons (chlorinated and fluorinated species), collectively termed (hydro)chlorofluorocarbons or F-gases that have mainly been used as refrigerants and foam insulation. Measured surface emissions data from an extensive field investigation at a Northern California landfill were used to scale changing landfill F-gas emissions due to varying landfill operational conditions and landfill life stage. Three scenarios were evaluated: active, closure, and post-closure by varying the relative surface areas of the three cover types, daily, intermediate, and final, used at landfills. The relative proportions of the covers were selected based on data obtained from 15 California landfills. The results of the analyses indicated that emissions decreased from active to closure to post-closure conditions and were primarily controlled by the type and relative areal extent of the different covers. Seasonal variations and waste in place had secondary effects on emissions. CO_2-equivalent emissions were up to 64,000 tonnes/year for a 100 ha landfill. Emissions reflecting spatial variations and time-dependent evolution of cover conditions need to be determined and adopted for use in representative estimates of emissions from landfills and larger-scale greenhouse gas inventories to inform landfill operations and regulatory decisions related to sustainable landfilling.

Keywords: Surface emissions, F-gas, Greenhouse gas, Landfill cover, Landfill

INTRODUCTION

Chlorinated and fluorinated halogenated hydrocarbons have been used in refrigeration and insulation foams since the 1920s to 1930s (Midgley and McCulloch, 1999). Chlorofluorocarbons (CFCs) were historically the first generation chemicals used in insulation applications. CFCs have been successively phased out and replaced by hydrochlorofluorocarbons (HCFCs) and then by hydrofluorocarbons (HFCs) under the Montreal and Kyoto Protocols. These chlorinated and fluorinated species collectively termed (hydro)chlorofluorocarbons or F-gases are high global warming potential (GWP) greenhouse gases (GHGs) as well as ozone depleting substances (ODSs). The global warming potentials (100-year basis) of the F-gases can be in excess of 10,000 relative to CO_2 and atmospheric lifetimes can range up to in excess 1000 years (IPCC 2013).

Global emissions of CFCs, HCFCs, and HFCs were estimated to be 0.73, 0.76, and 0.69 $GtCO_2$-eq./year, with decreasing, relatively stable, and increasing trends over the previous decade, respectively (Carpenter and Reimann, 2014). California, emissions of CFCs, HCFCs, and HFCs were estimated to be 9.9, 10.3, and 18.9 $MtCO_2$-eq. for 2014 (Gallagher et al., 2014). Similar to global trends the emissions were decreasing, relatively stable, and increasing over the previous decade for CFCs, HCFCs, and HFCs, respectively. With its large population and advanced industry, California is the fifteenth largest emitter of GHGs globally, accounting for 2% of global emissions (CARB, 2008). Approximately 2% of global F-gas emissions also are contributed by the state similar to total GHG emissions (Yeşiller et al., 2018). The physical and chemical characteristics of F-gases favor the accumulation of these chemicals in the atmosphere as opposed to the soil or groundwater, where accumulation is dependent on atmospheric retention times (higher for CFCs than HCFCs and HFCs) (Scheutz et al., 2003 and Tsai, 2005). The tropospheric concentrations are in ppm for CO_2, in ppb for methane, and in ppt for F-gases (AGAGE, 2018).

Discarded appliances; construction, demolition, and refurbishment wastes; and discarded heating/cooling units, transport refrigerated units, marine foams, fire suppressants, medical aerosols, and cleaning agents are main sources of F-gases entering landfills (Deipser et al., 1996). The fate and emissions of these gases in the landfill environment are dependent on biochemical conversion processes such as degradation in the waste mass and oxidation in covers. Additional chemical processes including sorption of the chemicals to the wastes and dissolution in the leachate also affect emissions from landfills. Alternative materials used for daily covers such as auto shredder residue (i.e., auto fluff), construction and demolition waste, and foam products may contain F-gases and contribute directly to F-gas emissions from landfills (Yeşiller et al., 2018).

While F-gases are trace components in landfill gas, which mainly consists of methane and carbon dioxide, emissions of F-gases are of concern due to their high GWP and ozone depleting characteristics. Due to the long lifetime of F-gases in various products such as the insulation foams past the useful service life of both appliances and building materials, as well as relatively slow degradation processes encountered within landfill environments, banks of CFCs, HCFCs, and HFCs are generated. With approximately 400 $MMTCO_2$-eq. of F-gases estimated to be banked in appliance and building insulation foam waste in landfills in California (CARB, 2008) and 1.4 $MMTCO_2$-eq. of four main F-gases in insulation foams estimated to enter landfills in the future (based on data from Yesiller and Hanson 2016), predicting, measuring and quantifying emissions are critical for managing current and future sources of ozone depletion and global climate change.

In this study, analysis was conducted to investigate F-gas emissions from landfills in California during different life stages of the facilities represented by changing the relative proportions of the typical cover systems used in landfills: daily, intermediate, and final. Analysis was conducted for three life stages: active, closure, and post-closure phases.

SURFACE EMISSIONS

Experimental Data

Field emissions of 12 F-gas species were investigated in an extensive study conducted at a municipal solid waste landfill located in northern California in a temperate climate zone (Yeşiller et al., 2018). The types and relevant characteristics of the F-gases investigated are provided in Table 1 (from Yeşiller et al. 2018). Spatial and temporal variations of flux of the F-gases were measured using static flux chamber tests. Data were obtained from three types of daily covers, three types of intermediate covers, and one type of final cover for a total of seven measurement locations across the landfill. At each measurement location, four large-scale (1x1 m area; 0.4 m depth) chambers were deployed for data collection. Measurements were repeated over the two main seasons in California (wet and dry) to investigate seasonal variations.

The results of the investigation conducted by Yeşiller et al. (2018) indicated that F-gas fluxes were generally positive and varied over 7 orders of magnitude across the cover types in a given season with variations of 10^{-8} to 10^{-1} g/m^2-day and 10^{-9} to 10^{-2} g/m^2-day for wet and dry seasons, respectively. F-gas flux decreased from daily to intermediate to final covers with larger decreases from daily to intermediate covers than intermediate to final covers. Flux and variability of flux were both significantly influenced by cover characteristics. Flux decreased with the order: coarser to finer cover materials; low to high fines content cover soils; high to low degree of saturation cover soils; and thin to thick covers. For a given cover type, fluxes were approximately one order of magnitude higher in the wet than the dry season, due to combined effects of comparatively high saturations, high void ratios, and low temperatures in the wet than the dry season.

Estimation of Emissions

Emissions of the 12 F-gas species are estimated using the flux data obtained in the previous study. Average flux data by cover type obtained in the prior investigation is presented in Table 2.

Table 1 F-Gas Characteristics

Replacement History	Name	Structural Formula	Principal Use	Atmospheric Lifetime (year)	GWP (100-year)
Compounds already phased out under Montreal Protocol	CFC-11	CCl_3F	Foam blowing agent	45.0	4660
	CFC-12	CCl_2F_2	Refrigerant	100.0	10,200
	CFC-113	$C_2F_3Cl_3$	Solvent	85.0	5820
	CFC-114	CF_3CFCl_2	Propellant	190.0	8590
Compounds currently being phased out under Montreal Protocol	HCFC-21	CH_2FCl_2	Refrigerant blends	1.7	148
	HCFC-22	CHF_2Cl	Refrigerant	11.9	1760
	HCFC-141b	CH_3CFCl_2	Foam blowing agent	9.2	782
	HCFC-142b	CH_3CF_2Cl	Foam blowing agent	17.2	1980
	HCFC-151a	CH_3CHFCl	Refrigerant blends, foams	NA	NA
Alternatives controlled under Kyoto Protocol	HFC-134a	CH_2FCF_3	Refrigerant blends, foams, fire suppressant, and propellant in metered-dose inhalers	13.4	1300
	HFC-152a	CH_3CHF_2	Refrigerant blends, foam blowing agent, and aerosol propellant	1.5	138
	HFC-245fa	$CF_3CH_2CHF_2$	Foam blowing agent and possible refrigerant in the future	7.7	858

Table 2 Average F-Gas Fluxes

Cover Type	Flux (g/m^2-day)	
	Wet Season	Dry Season
Daily	2.34E-02	1.76-03
Intermediate	1.67E-05	2.22-05
Final	3.41E-06	2.30-07

Emissions are determined by scaling the measured fluxes to an entire landfill by using the relative surface areas of the specific cover types: daily, intermediate, and final. Detailed flux data (presented in full in Yesiller and Hanson, 2016) obtained from the four chambers by chemical species and cover location are used in the analysis. The fluxes from a given cover type are multiplied with the area of the cover to determine surface emissions for a given day and then converted to an annual basis. The results are reported in tonnes/year by assuming that the area of the landfill used in the analysis is 100 ha. Analysis is conducted for the three scenarios representing the life stages of a landfill: active, closure, and post-closure. In active landfills, all three cover types are used, whereas intermediate and final covers are present at the time of closure of a landfill site and only a final cover is present at post-closure (i.e., in the long term) over an entire site. As the life stage is progressed from active to closure to post-closure conditions, the relative areas of the covers are redistributed accordingly over the waste placement footprint of the landfill.

For the investigation, a total of 33 simulations are conducted to investigate the emissions corresponding to the three scenarios. The relative distributions of the cover types are established based on data collected from 15 landfills across California representing small, medium, and large landfills with waste-in-place (WIP) categories of less than 4,000,000 m^3, between 4,000,000 and 40,000,000 m^3, and over 40,000,000 m^3 of wastes, respectively. The areal extents of the covers were between 0 and 37% for daily covers, between 48 and 100% for intermediate covers, and 0 and 41% for final covers.

The analysis was conducted using two steps. First, the relative areas of the cover types are established for active conditions using the data collected from the California field sites for a total of 16 cases. Next, the active landfills are progressed through the closure and post-closure stages for these 16 cases for the analysis of a total of 33 simulations. The simulations conducted are presented in Table 3. Simulations A1-A16 represent active conditions, closure conditions with no daily covers corresponding to these active cases are included under simulations C1-C16. Finally, a single post-closure simulation (PC) is conducted with no daily or intermediate covers and only a final cover. Simulations A10 and A11 represent average cover conditions based on the field data used directly and by taking a weighted average with regard to the WIP of the sites, respectively. In A1-A16, progressively more daily covers are included in the simulations with areal representations based on field data. The intermediate cover areas are set at 25, 50, 75, or near 100% based on the field data and the balance is distributed to the final covers. Simulations are conducted separately for wet and dry seasons. Total annual emissions are determined for each simulation. Then further analysis is conducted to convert the calculated emissions to CO_2 equivalent values to estimate the contributions of the F-gases to climate change. The CO_2 equivalent emissions are calculated by multiplying the F-gas specific emissions with the corresponding GWP for the chemical using data presented in Table 1.

Table 3. Landfill Life Stage Scenarios Investigated

Scenario	Simulation	Cover Type		
		Daily (%)	Intermediate (%)	Final (%)
Active	A1	0.1	25	74.9
	A2	0.1	50	49.9
	A3	0.1	75	24.9
	A4	0.1	99.9	0
	A5	1	50	49
	A6	1	75	24
	A7	1	99	0
	A8	5	75	20
	A9	5	95	0
	A10	7.05	83.66	9.29
	A11	8.57	76.05	15.38
	A12	10	75	15
	A13	10	90	0
	A14	20	75	5
	A15	20	80	0
	A16	37	63	0
Closure	C1	0	25.03	74.97
	C2	0	50.05	49.95
	C3	0	75.08	24.92
	C4	0	100	0
	C5	0	50.51	49.49
	C6	0	75.76	24.24
	C7	0	100	0
	C8	0	78.95	21.05
	C9	0	100	0
	C10	0	90.01	9.99
	C11	0	83.18	16.82
	C12	0	83.33	16.67
	C13	0	100	0
	C14	0	93.75	6.25
	C15	0	100	0
	C16	0	100	0
Post Closure	PC	0	0	100

RESULTS

The results of the simulations are presented in Figure 1. The total emissions are provided in Figure 1a and the converted CO_2 equivalent emissions are in Figure 1b. Large differences, up to three orders of magnitude, are observed for CO_2 equivalent emissions compared to baseline values indicating the significant contributions of F-gases to global warming with GWP values of the gases ranging from 138 to 10,200 (Table 1). For an individual F-gas, the highest CO_2 equivalent emissions were consistently associated with CFC-11 across the entire set of simulations, even though the manufacture and use of the chemical has been banned under the Montreal Protocol. CFC-11 is one of the earliest chlorofluorocarbons developed and used for foam blowing and refrigeration applications. Significant banks of CFC-11 remain in landfills and continue to be emitted to the atmosphere.

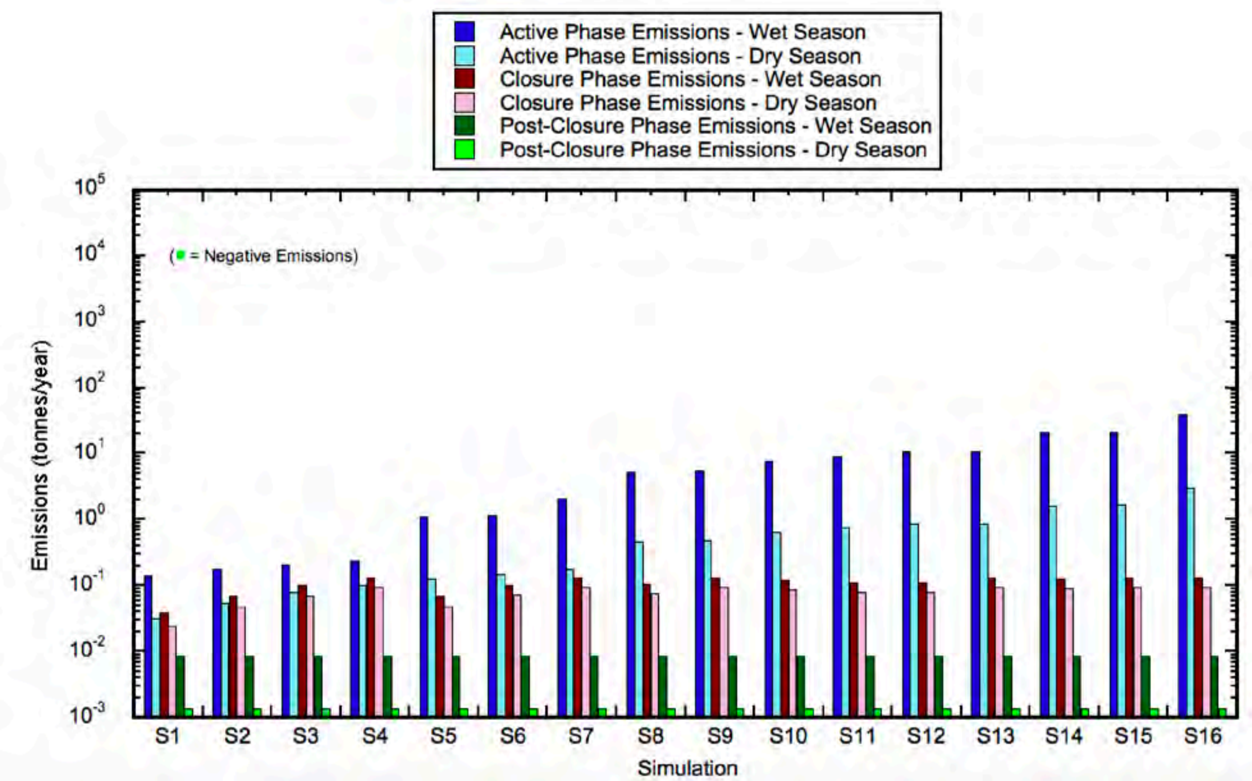

Figure 1 Summary of F-gas emissions

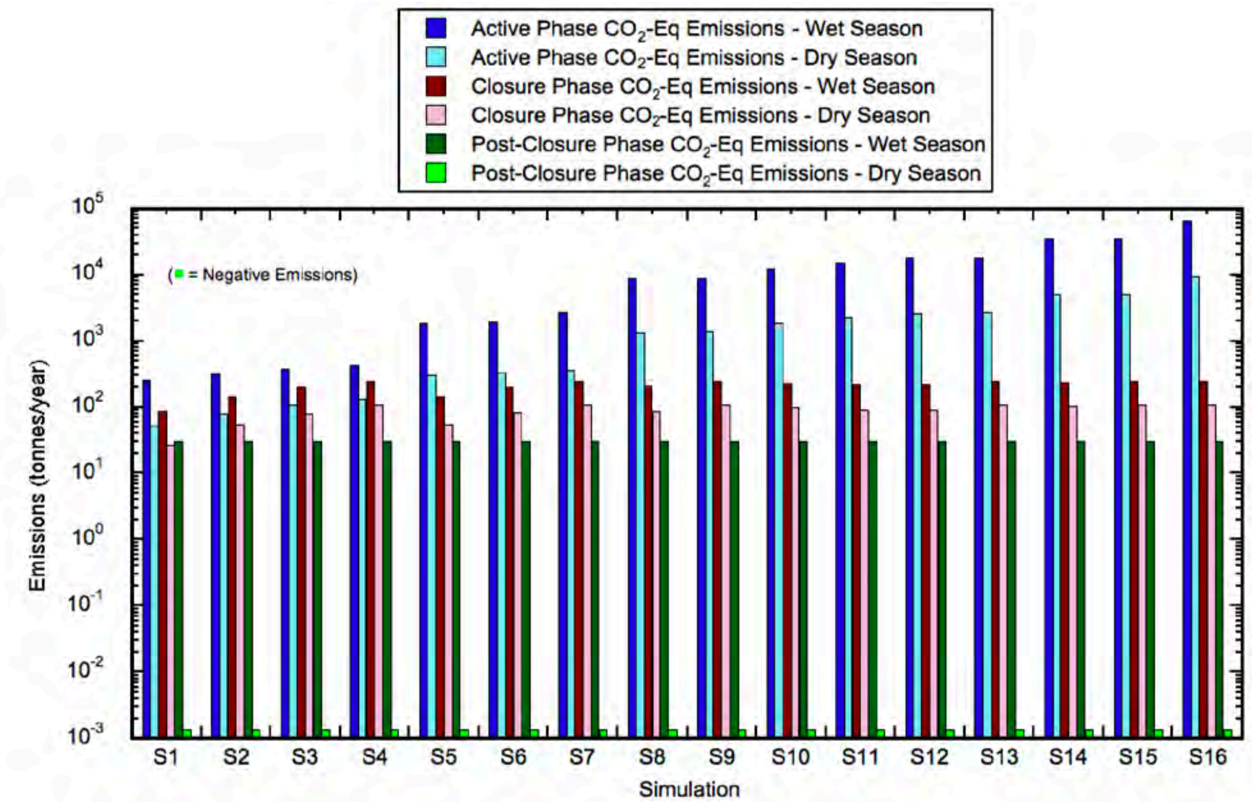

Figure 2 Summary of CO_2-equivalent emissions

For active conditions, higher variations occurred in emissions as the relative area of daily covers increased (with the order A1, A5, A8, A10, A11, A12, A14, A16) compared to increasing intermediate cover areas (e.g., A1 to A4). As the daily cover areas varied from 0.1 to 37%, the total emissions varied from 0.14 to 39.0 tonnes/year (direct data) and from 258 to 64,000 tonnes/year (CO_2 equivalent data), respectively (based on wet season results, with similar trends observed for dry season). The variation in emissions between A1 and A16 was more than two orders of magnitude, whereas the variations with increasing intermediate cover area for a given daily cover area was less than one order of magnitude (e.g., between A1 and A4).

For closure conditions, intra-simulation variations were low and well under one order of magnitude. The absence of daily covers in closure scenario prevented development of large differences between simulations even though the intermediate cover areas varied as much as from 25 to 100% (C1 to C4).

The analysis conducted for average cover areas for the 15 landfills investigated in California (A10) and the weighted average considering WIP at the sites (A11) resulted in similar results (Figure 1). The variations in cover areas in these analyses are within 2% for daily cover and 8% for intermediate and final covers (Table 3), which did not significantly affect the emissions.

Emissions for both cases (Figure 1a and 1b) decreased with the order active to closure to post-closure scenarios. The differences between paired active and closure cases (e.g., A1 vs. C1) were generally similar with somewhat lower values than the differences between the closure simulations and the post-closure simulation. The largest differences were for cross-simulation cases progressing from active cases with high daily cover areas to closure cases with high final cover areas to the post-closure case.

The seasonal variations were within one order of magnitude for direct as well as CO_2 equivalent emissions. The effects of seasonal variations were less than the variations of the different types of cover materials and life-stage scenario.

CONCLUSIONS

Direct and CO_2 equivalent emissions were estimated for high global warming potential, ozone depleting substance F-gases for different life-stages (active, closure, and post-closure) using cover type/area data from 15 California landfills. The significantly higher CO_2 equivalent emissions compared to the baseline values indicate the need to consider the global warming potential of these gases in emissions calculations as well as the significant level of emissions for F-gas constituents that are trace gases in landfill gas and yet are significantly more potent than the main landfill gases methane (GWP=28) and carbon dioxide.

The emissions decreased from active to closure to post-closure conditions and were primarily controlled by the type and relative areal extent of the different covers. Seasonal variations and waste in place had secondary effects on emissions. For active conditions, emissions are minimized by minimizing the amount of daily covers. Closure with high areal coverage of final covers also minimizes emissions. Good operational practices should consider use of the lowest possible extent of daily covers and timely closure of landfill facilities.

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DEVELOPMENT OF A METHANE (CH_4) SURFACE EMISSION MAP: A CASE STUDY AT KARADIYANA DUMP SITE, SRI LANKA

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ABSTRACT

Municipal solid waste (MSW) landfills and dumpsites generate mainly methane (CH_4) and carbon dioxide (CO_2) among many other tracer gases. Quantification of methane emission from dumpsites is an important aspect of disposal site management. In Sri Lankan context, quantification of gas emission is rarely done in large-scale dumpsites. This study was conducted to develop a landfill surface gas emission of Karadiyana dumpsite which is a larger dumpsite in the country with extend of 37 acres and daily receiving 500 tons of MSW. First, a contour map of dumpsite was developed through a comprehensive topographic survey and a grid of 150 sampling points at 10 m distance was marked. Sampling tubes were installed to depth of 1 m on each grid point and passively vented methane concentration was measured using a portable gas analyzer (Gas board-3200P). The measurements were continued for six times at each location for four weeks. The methane measurements were developed to a concentration map using ArcGIS software. The average surface emission of methane was 13.8% (volume %) that varied from 0% to 65.9% at different locations. Maximum emission rates were observed above the places where organic wastes are dumped. The developed emission map can be used to identify "hot spots" at dump site, to identify high risk and low risk areas during the operations and to install gas wells for methane recovery and greenhouse gas emission control.

Keywords: Landfill gas; Open dump; Surface emission map

INTRODUCTION

Open dumping of municipal solid waste in disposal sites is the most common and major municipal waste disposal method practiced in Sri Lanka and many other developing countries. There are numerous studies to show the public health risk and environmental pollution caused by open dumping. Similarly, ground water and leachate pollution from dumpsites in Sri Lanka have been shown in several research studies (Sewwandi et al., 2013). However, only a limited number of studies are available on quantifying the gas emissions from dumpsites, particularly in Sri Lanka (Nagamori et al., 2016).

The decomposition of biodegradable materials under anaerobic conditions produces a mixture of hundreds of different gases, primarily containing 50% – 60% CH_4 and 30–40% CO_2 by volume (Abushammala et al., 2012). The rate and volume of landfill gas produced at a specific site depend on the characteristics of the waste and a number of environmental factors (ATSDR, 2001). A reasonable quantitative and qualitative assessment of landfill gas can be done using well recognized numerical models such as LandGEM by US-EPA and EPER model (Scharff and Jacobs, 2006). However, knowledge on landfill configuration, physical and chemical characteristics of waste, geographic information, climate and weather data, and landfill operation and closure plans is needed for accurate and precise estimation of emissions from landfill. Such information is often not available for open waste disposal sites.

The uncontrolled dumping of waste on unlined ground dramatically increases the heterogeneity of dumpsite that is often reflected by variable surface emission rates reported (Jha et al., 2008). Thus, a systematic combination of on-site emission measurements with available information such as geographical features, waste quantity and quality has been identified as the most reliable method of dumpsite emission estimation.

This study aimed at developing a methane emission map on a large municipal solid waste dumpsite in Sri Lanka by combining measured surface emission concentrations and dumpsite geographical configurations. This enables the identification of surface concentrations and its correlation with waste disposal and dumpsite management practices.

MATERIALS AND METHODS

Study site

The studied dumpsite is situated approximately 15 km south of Colombo, approximately 5 km inland to the Indian Ocean (6° 48' 56" N and 79° 54' 16" S). The available records showed the dumpsite was first started in year 1996 and it is estimated that approximately 3 million metric tons of municipal waste has been disposed at the site up to date. As shown in Figure 1, the site consists of two major disposal areas, active dump A and B, which expand over 15 hectares and approximately 10 hectares have already been filled by waste. The site lies on a riverine floodplain (Weras Ganga), thus surrounded by abandoned paddy fields and marshy lands.

At present, site is managed by Waste Management Authority-Western Province, thereby site receives 500-600 metric tons of municipal solid waste collected from 7 urban and semi-urban local authorities in Western Province. All the receiving waste are weighted at the entrance and mixed waste and partially sorted waste as degradable and non-degradable are disposed in different areas.

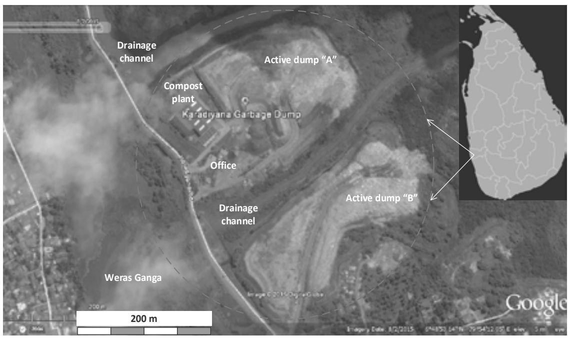

Figure 1 Location and main features of Karadiyana Municipal Solid Waste Dumpsite, Sri Lanka

(Source: Google Earth)

Establishment of base map and sampling points

The study was limited to active dump A that is the largest and most active filling area at Karadiyana dumpsite. First a baseline was marked on the surface of the dump and entire area was separate into 10 x 10 m grids. The intersection elevations of each grid were measures along with plan coordinates using a Theodolite (Model DT103). Totally 200 grid elevation points were recorded. The measured data was used to develop contour map and three dimensional projection of the site using software Surfer ver. 12.

A small sampling well was drilled at intersections of each grid using a precast steel pipe (2.54 cm diameter) and steel hammer. Once the steel tube reached the desired depth, the steel pipe was removed and a PVC sampling pipe was inserted to the drilled hole. As shown in Figure 2, a 2.54 cm diameter, 100 cm length section of perforated PVC pipe was used as the casing of the sampling well.

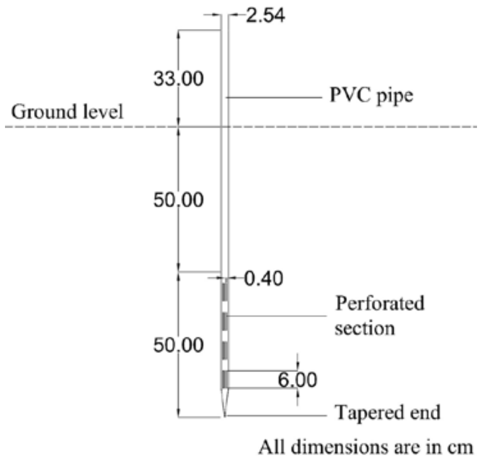

Figure 2 Sectional view of sampling well

Sampling wells were 10 m away from each other and it was assumed that the radius of influence is 5 m covering an area of 78.5 m^2. Once installed, each sampling pipe was sealed around the sides at ground level by firming the soil around the outside (Rosa et al., 2013) to avoid leakages. It was assumed that landfill gases freely flow from deep in the landfill and readily migrate to the surface (Hilger and Humer, 2003) due to concentration and pressure differences.

Measurement of gas emission

The gas sampling tube (5 mm diameter) of a pre-calibrated portable gas analyzer (Gas board 3200P) was tightly fixed to the opening of the gas well header and gas composition was measured until it reached steady value. The concentrations of methane and carbon dioxide from each sampling well were simultaneously measured in sampling event.

Emissions from each sampling well was measured for six times during a period of 30 days. Accordingly, six surface emission maps were developed using software ArcGIS ver. 10.2 and an average concentration map was developed using average values of six reading.

RESULTS AND DISCUSSION

The site contour map was developed with an arbitrary benchmark of 100 m. As shown in Figure 3, the site has irregular landform with several peaks. The highest elevation of the dumpsite is at 108.69 m elevation (8.69 m height from base).

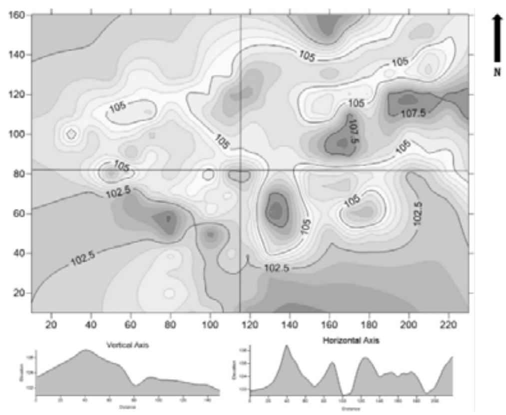

Figure 3 Contour map of Karadiyana dump (Site A)

The methane surface concentration maps developed over a span of 30 days at 6 days' intervals are shown in Figure 4. It was observed that the composition of methane and carbon dioxide in each sampling well did not changed over period of 30 days indicating that temporal emission changes are not significant. However, changes of environment conditions, particularly rainfall and extreme changes of temperature and wind were not recorded during the entire period.

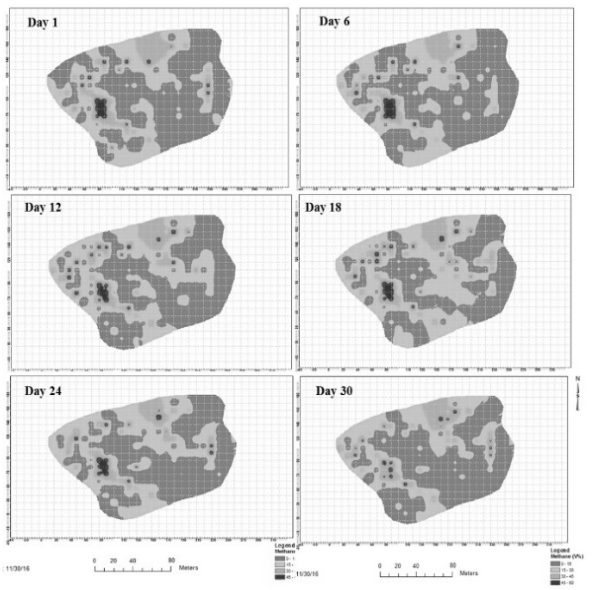

Figure 4 The developed methane concentration maps of Karadiyana dumpsite for 6 measurement events during a span of 30 days

The minimum and maximum recorded methane emission values for any of the well or measurement event were 0% and 65.9% by volume, respectively. The average surface methane emission map as shown in Figure 5 was developed using average values of six emission measurements.

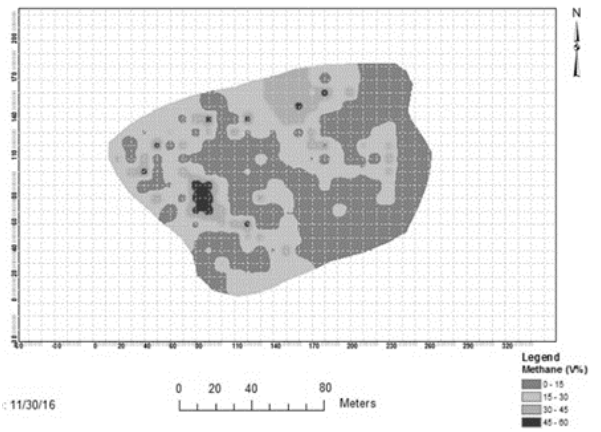

Figure 5 Average surface methane emission concentration map of Karadiyana dumpsite (*n=6*)

The average methane emission across all 150 measurement wells were 13.8% by volume. Methane emissions are not spatially uniform due to the variation of the underlying waste composition and the methane oxidation activity, which differs due to variations in the cover waste layers. Hot spot is a smaller, discrete area where methane emissions significantly differ from the surrounding areas. Hot spot emissions in conventional landfill may result from variation in cover soil thickness and cracking of cover soil (Abushammala et al., 2012).

It was observed that certain areas of the dump emit higher concentrations while some other adjacent areas having lower surface emissions. Therefore, the site infrastructure facilities and dedicated waste disposal areas were overlaid on the methane concentration map (Figure 6).

It was found that methane hotspots (45-60% by volume) which are shown in dark colors in Figure 6 coincide with the areas where organic waste are disposed and covered with a thin soil layer (~10 cm). Moreover, side slopes of the same area are also covered by a thin soil layer to prevent mal odors and worming.

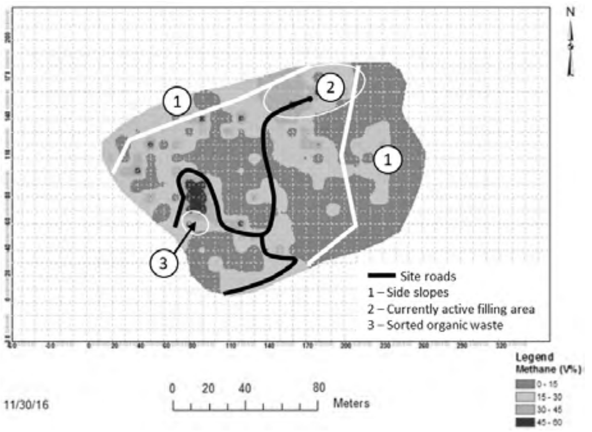

Figure 6 Layout showing site infrastructure and disposal pattern overlapped on methane emission map

Thus, it is assumed that higher perishable organic content of waste is undergoing rapid anaerobic decomposition resulting an elevated methane emission. Also, most of other areas where moderate methane emission was recorded are also covered with a soil layer that make the area more anaerobic and emit more methane (Scheutz et al., 2004).

However, a noticeable feature is that irrespective of nature and age of waste, methane emission concentrations are comparatively lower in areas where there is no soil cover. This is assumed to be caused by enhanced passive ventilation and methane oxidation. The assumption is supported by previous studies that have found methane oxidation processes in landfill cover soils as an efficient strategy for methane emission mitigation (Stern et al., 2007).

Most of the low emission areas are coincide with the site roads and currently active filling areas. Site road are having thick soil cover and highly compacted due to vehicle movement with heavy waste loads. The lead might have compacted the areas higher than that of surrounding, thus creating a barrier for gas migration. In addition, type of cover materials is also may have an effect on variations in methane emissions (Jugnia et al., 2008). In Karadiyana dump site, the emission from side slopes were varies 0-15% similar to what have been reported elsewhere (Abichou et al., 2006). Also, some areas of capping can be more permeable than others such as portions of a side slope (Di Trapani et al., 2013).

CONCLUSION

A topographic map of the Karadiyana dump site was developed in order to locate a series of near surface gas well on the dumpsite. The methane concentration in near surface sampling wells were successfully measured and developed to a methane concentration map of the entire dumpsite. The developed map showed that temporal variation over a span of 30 days is not significant; however, the spatial methane emission variations are very high. It was found that all the methane hot spots (45-60% methane by volume) coincides with the areas where organic waste are dumped. The overall emission map will help dumpsite managers and designers to identify high risk and low risk areas during the operations. Further, the developed emission map can be used to install gas wells for methane recovery and emission control.

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TECHNICAL AND SOCIAL FACTORS OF DUMPSITE COLLAPSE IN DEVELOPING COUNTRIES AND ITS CONSEQUENCES: CASE STUDIES IN MOZAMBIQUE AND SRI LANKA

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ABSTRACT

In recent years, severe collapse incidents have frequently occurred at solid waste final disposal sites in urban areas of developing countries. Many of these incidents have occurred at open dumpsites or insufficiently controlled dumpsites, where solid waste increasingly accumulates on limited available land, and sudden collapse is triggered by rainfall. These incidents give rise to casualties, particularly in developing countries. The following factors have been associated with urban dumpsite collapses: rapid urbanization and urban sprawl, rapid increase of solid waste volume, increasing gap between rich and poor among the urban population, formation of informal groups of waste pickers, inadequate technology for disposal site management, and difficulty of building consensus for siting landfills. These factors form a complex chain of problems and are interrelated. In this presentation, the technical and social factors that lead to dumpsite collapse, as well as the consequences of these collapses, are discussed using case studies of dumpsite collapse incidents that occurred at Maputo City, Mozambique in March 2018, and at Colombo City, Sri Lanka in April 2017.

Keywords: Dumpsite collapse incident, Developing countries, Informal waste pickers, Gas, Leachate

INTRODUCTION

In recent years, severe collapse incidents have frequently occurred at solid waste final disposal sites in urban areas of developing countries. In only seven months, from December 2015 to June 2016, The International Solid Waste Association (ISWA) recorded more than 750 deaths related to poor waste management in dumpsites, and several incidents with important health impacts (ISWA, 2016). Many of these incidents have occurred at open dumpsites or insufficiently controlled dumpsites, where solid waste increasingly accumulates on the limited available land, without any planning. These incidents give rise to casualties, particularly in developing countries. Table 1 summarizes widely reported dumpsite collapse incidents that have occurred in developing countries since 2000.

Table 1. List of reported dumpsite collapse incidents in developing countries since 2000

Year	Month	Area, Country	Name of dumpsite	Causalities	Reference
2000	July	Metropolitan Manila, Philippines	Payatas dumpsite	200<	Koelsch (2007)
2005	February	Bandung City, Indonesia	Leuwigajah dumpsite	143	Koelsch (2005), Lavigne et al. (2014)
2015	December	Shenzhen, China	Hongao dumpsite	77	Xu et al. (2017), Yin et al. (2016), Yang et al. (2016)
2016	April	Guatemala City, Guatemala	Guatemala dumpsite	24	Reuter (2016)
2017	March	Addis Ababa, Ethiopia	Qoshe dumpsite	113	WHO (2017), Reuter (2017), Kolinjivadi (2017)
2017	April	Metropolitan Colombo, Sri Lanka	Meethotamulla dumpsite	34	JDR (2017)
2017	September	Metropolitan Delhi, India	Ghazipur landfill	2	Hindustan Times (2017)
2018	March	Maputo City, Mozambique	Hulene dumpsite	16	JICA Survey Team (2018)

These waste dumpsite collapses have been considered to be due to unsound geotechnical engineering risk controls and practices, inappropriate site selection and design, and inadequate operation and management.

The author had the opportunity to participate with emergency disaster relief teams at dumpsite collapse incidents in Sri Lanka in April 2017 and in Mozambique in March 2018. In this paper, the author reports on the results of preliminary field surveys and discusses the technical and social factors that resulted in these incidents.

THE CASE IN MOZAMBIQUE

Background

The Hulene waste dumpsite receives approximately 850 tons/day of municipal solid waste, collected from Maputo City, the capital city of Mozambique (Figure 1). The dumpsite is the only final disposal facility for municipal solid waste generated in the city. It is currently managed by the Waste Management Department of Maputo Municipality, and dumping and partial compaction are conducted by heavy equipment.

Incoming waste is measured using a weighbridge for collecting a tipping fee. There are hundreds of waste pickers who are informally working to collect recyclables, such as metal, plastic, paper, and clothes, from the dumpsite. In the open places around the dumpsite, these pickers illegally built huts to live in.

A huge solid waste mound on the western margin of the Hulene waste dumpsite collapsed on February 19, 2018 (see Figure 1). According to the Maputo Municipality, 16 people died, and six people were injured by the dumpsite collapse.

The collapsed part was a mass of solid waste approximately 30 m high, composed of waste that was disposed more than five years before. That area had not been used in the five years before the collapse happened. The waste debris covered houses that had been illegally constructed by local people (mostly dumpsite waste pickers), according to the Maputo Municipality (Figure 3).

Figure 1. Index map and satellite image of Hulene dumpsite, Maputo. The scale of the horizontal frame is 400 m. (JICA Survey Team, 2018).

Figure 2. Collapsed cliff of the Hulene dumpsite.

Figure 3. Debris covered area in front of the cliff of the Hulene dumpsite.

Field Observations

Immediately after the dumpsite collapse, Maputo Municipality conducted emergency operations, and the waste debris covering the collapse site was removed by heavy equipment. The western part of the collapsed location is a lowland, which flooded above the floorboards, causing inhabitants in the area to be evacuated (Figures 2, 3). The water was composed of rainwater and leachate, generated within the waste dumpsite, creating unsanitary conditions.

Field observations showed several secondary cracks along the collapsed surface, indicating a possibility of secondary collapse of the remaining solid waste mound (Eguchi et al., 2018).

On-site gas concentrations, measured with a COSMOS XA-4400, for combustible gases (mainly methane), hydrogen sulfide (H_2S), and carbon monoxide (CO), were below the detection limits of the meter, indicating no immediate risk of gas hazards, such as fire or explosion, in or around the collapse area. However, the oxygen (O_2) reading was 20.7% along the exposed cliff face of the remaining waste mound, which is lower than the standard O2 concentration of 21.0%. This indicates that some oxygen depletion occurred around the collapse site.

Figure 4. Gas emission from water pool at the collapse area, Hulene dumpsite.

In-situ generation of gases, such as methane and carbon dioxide, caused by the microorganic decomposition of organic waste, was indicated by bubbling that was observed on the surface of standing water[1] in the collapse area (Figure 4). These gases were probably dispersed quickly due to windy conditions in the area.

The solid waste in the collapse area was accumulated in a pile, with a 38 to 52 degrees slope and 30 m average height (Figure 2). No soil covering was observed. At the top surface of the waste pile there was a rainwater pond, which indicates that water is constantly flowing into the dumpsite and creating leachate. The lowland in front of the collapse site has no water outlet, leading to extensive flooding in that area.

<u>Probable Causes of Collapse and Recommendations</u>

The steeply angled pile of accumulated solid waste collapsed due to the effects of gravity and additional rainwater. It is likely that heavy rainfall was a triggering event for the collapse. There are many cracks in the exposed cliff of the remaining waste mound that make it likely that the remaining mound will collapse further as additional water runs into and through the mound. A secondary collapse would not be expected to cause human damage because a larger space (70 m width, 40 m length) is available as a buffer zone in front of the exposed cliff face of the collapse site as people were evacuated after the first collapse. In order to avoid a secondary collapse of the dumpsite, water control is essential.

Figure 5. Waste pickers informally work to collect recyclables at the dumpsite.

THE CASE IN SRI LANKA

<u>Background</u>

The Meethotamulla waste dumpsite is located in Kolonnawa, in the Colombo District of Sri Lanka. It has been a solid waste open dumpsite for the last two decades. The land was originally marshy, as it was abandoned paddy land. Surrounding local councils and the Colombo Municipal Council began depositing municipal solid waste at the site in the early 1990s. The ownership of the site falls under the Urban Development Authority of the Ministry of Megapolis and Western Development (MoMWD).

[1] Water presents a dark brown color, perhaps a mixture of leachate and rainwater.

Prior to the collapse, the Meethotamulla waste dumpsite had been receiving over 900 tons of municipal solid waste per day. The dumpsite currently covers over 8.1 ha. The site is cut off from the surrounding area by a drainage canal and gravel ring road and was used solely for waste dumping purposes.

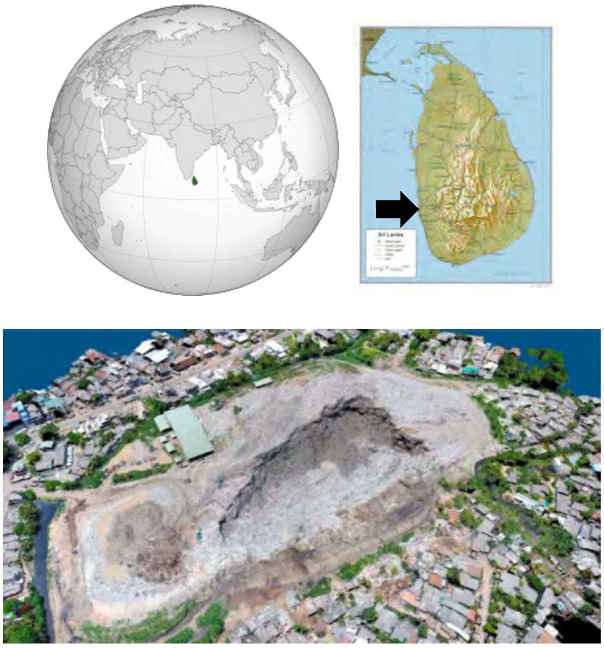

Figure 6. Index map of Sri Lanka and an overview of the Meethotamulla dumpsite. (drone photo taken by MoMWD, 2017).

Figure 7. Collapsed cliff and waste debris.

The total waste volume at Meethotamulla, as per data collected in April 2017, via drone based topographic survey, is estimated to be in excess of 1.2 million cubic meters. The perimeter of the site is 1,150 m, and it is surrounded by densely built, low-income settlements (MoMWD, 2017).

The authorities using the dumpsite were concerned about the risk of dumpsite collapse, but they could not find suitable alternate final disposal site. The continuous dumping of solid waste at this location resulted in layers of solid waste building into a mound with steep slopes, greater than 38 to 52 degrees in many places.

Field Observations

The collapse of the solid waste mound at Meethotamulla on April 14, 2017, affected a large number of people, including loss of lives, injuries, and property damage. According to the Government of Sri Lanka, 32 people died, 11 people were injured, and approximately 1,782 people were affected by this collapse.

Figure 8. Bubble of methane gas observed on the surface of standing water in the collapse area.

The Japan Disaster Relief (JDR) team was dispatched to Sri Lanka, and they surveyed the dumpsite in collaboration with a Sri Lankan team. A preliminary gas survey was conducted in the collapse zone of the Meethatamulla dumpsite using an MSA Altair 5X Multigas Detector. The results indicated that the oxygen concentration in the collapse zone was normal, and most areas of the site showed very low levels of hazardous gases, such as combustible gases (COMB), CO, and H_2S. However, at two locations along the base of the collapsed cliff face, COMB was detected at 16% and 26% of the Lower Explosive Limit (LEL). The combustible gases were probably generated in the waste deposit layers by microorganic decomposition activity, and released when the subsurface layers were exposed by the sudden collapse of the waste mound. The release of these combustible gases creates a fire risk.

Figure 9. Inclined ground and crushed houses caused by the dumpsite collapse.

The JDR team strongly recommended the prohibition of any open flames or ignition sources in the collapse zone, including lit cigarettes, to avoid a dumpsite fire. Dumpsite fires are notoriously difficult to extinguish, which would inhibit recovery and stabilization operations at the collapse site. The team also recommended prohibiting parking of vehicles or heavy equipment on the site to avoid unintentional accumulation of hazardous gases in engine or operator/passenger compartments. The team recommended that Sri Lankan authorities plan to continuously monitor hazardous gas concentrations at the site to maintain a safe working environment[2].

Probable Causes of Collapse and Recommendations

When considering stabilization of the waste mound, the angle of the slope formed after the collapse must be less than the angle of repose for the waste. The angle of repose is the maximum slope angle for the solid waste mound to be stable. The angle of the slope, as reconstructed was between 25 and 35 degrees, which is within the angle of repose for the solid waste mound. Since the mound had a stable slope, the risk of a surface collapse was low. Rapid drainage of liquid from the solid waste mound is key to avoid increasing the weight of the waste and to prevent the entire mound from failing. Construction of a trench is an effective emergency measure to achieve rapid drainage (JDR Expert Team, 2017).

Figure 10. Collapsed cliff and secondary cracks (drone photo by JDR Expert Team, 2017).

The main cause of the collapse appeared to be the

[2] Later on, MoMWD made detailed gas survey using a methane gas sensor and no explosive level of gas concentration was observed.

failure of the soft layer beneath the waste mound that was composed of semi-consolidated marsh sediments. This theory is supported by the facts as follows: (i) heaving of the soft layer was observed in front of the toe of the collapsed solid waste mound, (ii) the top of the sliding mass of solid waste had a terraced shape, and (iii) the soft layer was thickened in the southwestern direction where the landslide-type collapse occurred (JDR Expert Team, 2017).

DISCUSSION

Technical Aspect

According to the USEPA and Isenberg (2003), landfill stability can be assessed by its Factor of Safety (FS). FS is defined as:

FS = (Peak shear strength (or, residual)) / (Shear strength for equilibrium)

When the FS is less than 1.0, the landfill slope becomes unstable.

The value of FS for a landfill, is mainly controlled by the composition of the solid waste, its water content, topography (slope), and the distribution of gas in the waste. It is not easy to identify the FS value for solid waste due to its heterogeneous nature. A triggering mechanism, unique to each site, is then applied, resulting in an FS<1.0.

It is widely accepted[3] that the landfill slope should be less than 50 %, which means the slope angle is $\tan^{-1}(0.5) = 26$ degrees. However, in Hulene dumpsite, the slope angle is between 38 and 52 degrees, and in Meethotamulla dumpsite, it ranges between 37 and 50 degrees (see Figure 11). These data show that both dumpsites are unstable (FS<1.0) due to very steep slope.

[3] For example, Guideline value defined by Ministry of Environment, Japan (1998)

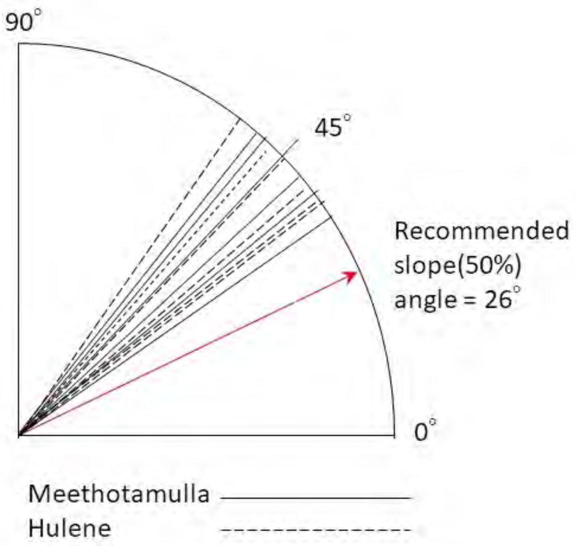

Figure 11. Distribution of slope angles of solid waste mound before the collapse estimated from the pictures of Hulene and Meethotamulla dumpsites.

Research has shown that triggering mechanisms are generally liquid related, such as leachate buildup within the solid waste mass, wet clay beneath the landfill bottom geomembrane, or an excessively wet foundation beneath the solid waste layers (Koerner, 2000).

Observations at the dumpsite collapses in Maputo, Mozambique in 2018 and Colombo, Sri Lanka in 2017, indicate that the collapses were caused by the following technical factors: (i) a steep slope of accumulated solid waste layers, often reaching more than 45 degrees, (ii) insufficient rolling pressure of dumped solid waste, (iii) inadequate drainage system for rainwater and leachate, and (iv) insufficient surface soil covering and compacting.

Under these unstable conditions, when rainwater infiltrated into the solid waste layer of the dumpsite, the water caused a change in weight balance, and a decrease in shear strength of the waste mass (FS<1.0) occurred, triggering the dumpsite collapse.

Social Aspect

In addition to the technical factors mentioned above, various social factors have also been recognized as contributing to waste dumpsite collapse. One of the most significant social factors contributing to dumpsite collapse is rapid increase in population and waste generation in cities, which has created urban sprawl. It means that residential areas have pushed closer to dumpsite areas where people are at greater risk of being affected by a dumpsite collapse.

Another factor is the lack of capacity to accommodate the rapid influx of solid waste at existing solid waste final disposal sites, and the limited ability to construct a new facility because of difficulty in obtaining land. This factor is exacerbated by the difficulty of public consensus building with local residents. Further, the urban poor, specifically the informal waste pickers who collect recyclables from the dumpsite, build slums, or low-income residential settlements, around the dumpsites. Inadequate administrative oversight of dumpsite operations can also be a contributing factor.

Figure 12 shows the causal relationship between these social factors of dumpsite collapse and its consequence.

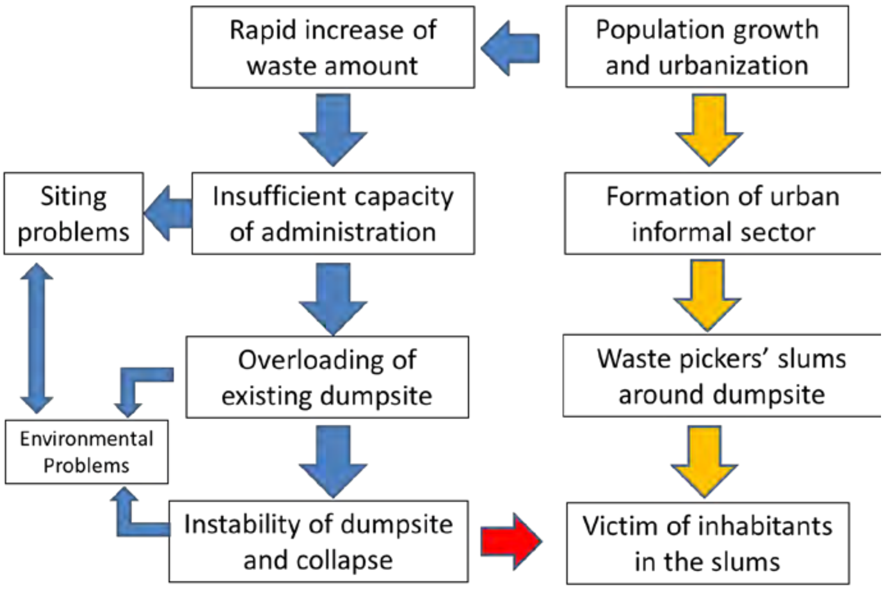

Figure 12. Hazard cycle for waste dumpsite collapse from a social perspective.

CONCLUSIONS

Dumpsite collapse incidents occur due to a combination of technical and social factors. The technical factors are: (i) A steep slope of waste layers, (ii) insufficient rolling pressure of dumped solid waste, (iii) inadequate drainage system, (iv) insufficient surface soil covering. The social factors are (1) Rapid increase of population and waste generation, (ii) Limited land for waste disposal site due to difficulty of public consensus building, (iii) Uncontrolled informal waste pickers activities in the dumpsite, and (iv) Inadequate dumpsite operations.

In order to avoid dumpsite collapses and the loss of lives caused by these incidents in the future, it is necessary to address both the technical causes and the social cause behind them.

The surveys in Mozambique and Sri Lanka were aimed at emergency relief, and research on detailed collapse mechanisms is a future subject.

ACKNOWLEDGMENT

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FUNCTION TEST AND EVALUATION CASES OF THE SEMI-AEROBIC LANDFIL

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ABSTRACT

In Japan, industrial waste landfill sites basically have a semi-aerobic structure that functions as a bioreactor using natural purifications and degradation mechanisms. Their functions give us a good work environment and a good quality leachate. The underlying technologies are very important for operating a landfill site, as well as to effectively and quickly stabilize the landfill, and to decommission a site after it has been closed. In this study, we measured the quantity of outside air that flowed into the landfill site via the leachate pipes from the pit, and determined that it keeps the landfill in a semi-aerobic condition. Moreover, we also figured out an easy and effective way to improve areas of the landfill site where some of the degassing pipes were emitting hydrogen sulfide. Intermittently feeding air for a short time with a portable blower accelerates and spontaneously progresses oxidation. Furthermore, using biological response testing at the leachate treatment plant, we found that the leachate is safe and that TRE/TIE (Toxicity Reduction Evaluation/Toxicity Identification Evaluation) can lead to energy-savings and lower costs by not using excessive treatment processing and reducing chemical dosing. This paper reports on aforementioned works.

Keywords: Controlled type of landfill site, Leachate, semi-aerobic, Biological response test, TRE/TIE (Toxicity Reduction Evaluation / Toxicity Identification Evaluation)

INTRODUCTION

In Japan almost all landfill sites have a semi-aerobic structure, but there are few cases of this evaluation study on an actual plant as opposed to laboratory equipment. This study is based on a real plant that has been operating since December 2005. The landfill capacity is around 930,000 m^3 and now the plant has made progress to about half capacity. We have been gathering and considering a large amount of data, such as flow of outside air into the landfill, each individual concentration of gas and leachate quality during daily maintenance. Figure 1 shows the semi-aerobic mechanism. The collecting drainage pipe, or leachate pipe, is situated at the bottom of the landfill and the degassing pipes are connected to the drainage pipe. Both pipes have several openings so they can get water and gas. The rainwater becomes leachate through the landfill and the leachate is led to the pit quickly. On the other hand, the generated gas in the waste quickly exits out of the landfill. Also, outside air enters the landfill by updraft due to rising temperatures while the organic matter in the waste decomposes. Therefore, the landfill maintains its aerobic state through natural power. When this mechanism works, unpleasant odors such as hydrogen sulfide gas are not generated and the leachate maintains its good quality.

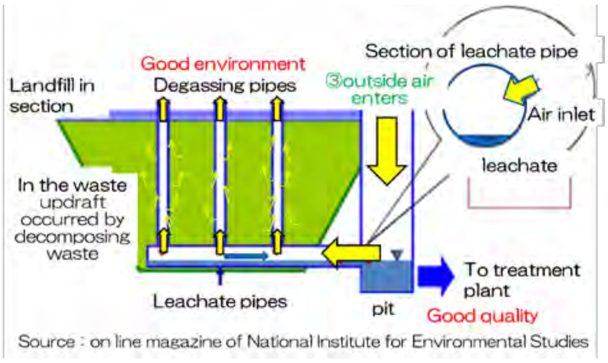

Figure 1 semi-aerobic conceptual diagram

We have conducted four EVALUATIONS of the landfill while maintaining the semi-aerobic function.

EVALUATION 1: AIR FLOWRATE INTO LANDFILL[1)]

Figure 2 and Table 1 show the air flow into the landfill by measuring at the end of the collecting drainage pipe at the pit. The air flow increases along with the filling progress. Regarding the relation between air flow and waste amount, Dr. Hanashima showed that it was 1.5 L/min at 1 m^3 of garbage. In our experiment, average air flow in 2014 was 26.7m^3/min. At that time, the amount of waste was about 380,000m^3. The air flow divided by the amount of waste is 0.07L/min. Our data (0.07L/min), comparatively totaling about 5% of Hanashima's experiment (1.5L/min) indicated that the landfill worked as a semi-aerobic function. This is due to the difference in the amount of organic substances between our plant and Hanashima's experiment, which used higher amounts of organic material.

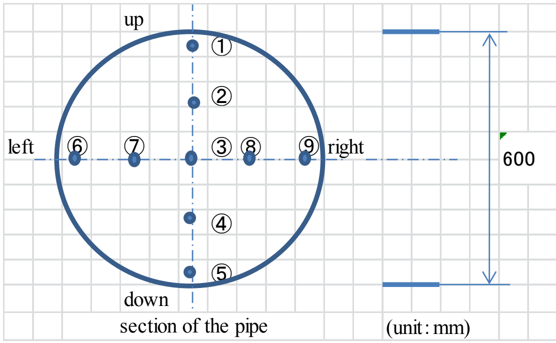

Figure 2 measurement position

Table 1 air flow measurement result

(unit : m/s)

month \ position	①	②	③	④	⑤	⑥	⑦	⑧	⑨	average	air flow m3/min
August in 2011	1.15	0.85	0.61	1.05	0.59	0.71	0.70	0.70	0.65	0.78	13.2
December in 2011①	1.05	0.40	0.60	0.20	0.30	0.20	0.80	0.40	0.60	0.51	8.6
December in 2011②	0.60	0.70	0.70	0.60	0.10	0.40	0.70	0.60	0.40	0.53	9.0
December in 2011③	0.80	0.90	0.90	0.90	0.30	0.50	0.90	0.80	0.80	0.76	12.8
March in 2012①	1.25	1.40	1.55	1.10	1.65	1.05	1.20	1.45	1.10	1.31	22.1
March in 2012②	1.40	1.51	1.32	0.95	0.63	0.78	1.47	1.20	0.80	1.12	19.0
November in 2012	1.30	1.45	1.75	1.20	0.60	1.25	1.40	1.70	1.25	1.32	22.4
February in 2014	1.30	1.20	1.50	1.10	0.90	1.20	1.40	1.30	1.00	1.21	20.5
December in 2014①	1.82	2.40	1.90	1.60	0.90	1.25	2.10	2.30	0.80	1.67	28.4
December in 2014②	1.60	1.80	1.80	1.50	1.20	1.55	1.80	1.70	1.30	1.58	26.8
average	1.23	1.26	1.26	1.02	0.72	0.89	1.25	1.22	0.87	1.08	18.3

EVALUATION 2: SHEET CAPPING[1)]

The landfill is located at an area where it rains about 3,000 mm a year. Generally speaking, the sheet capping is conducted after the landfill is full. But we continue sheet capping during filling in order to exclude rainwater. When you conduct sheet capping, a concern is that the landfill stabilization will be delayed because the sheet shuts out the air and the rainwater from the landfill surface. It was thought that the microbe activity would decrease. However, according to our study, we found some areas where there is no difference between the capping and non-capping for gas concentration. Rather, there were some capping areas that were better than the non-capping areas as shown below.

Figure 3 shows the state of landfill by showing gas concentrations, hydrogen sulfide and oxygen, temperature and rainfall. For the terms of sheets capping, there is no hydrogen sulfide despite rainfall being more than 300mm/month.

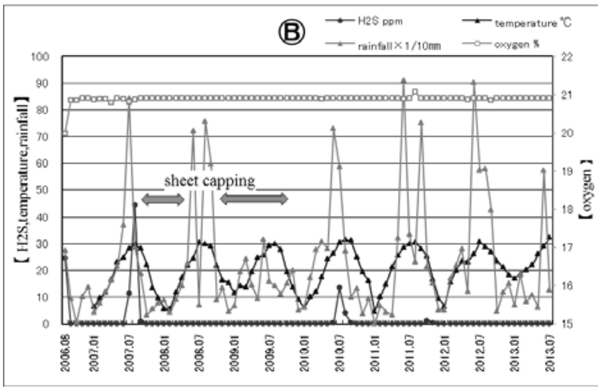

Figure 3 landfill condition

EVALUATION 3: IMPROVING LANDFILL WITH PORTABLE BLOWER[2)]

We have been monitoring the landfill by measuring gas concentrations (hydrogen sulfide, oxygen, methane) and gas temperatures. There are 24 main gas pipes in one half of the landfill. Of these, there are a few pipes that are emitting hydrogen sulfide due to a kind of waste, or a large presence of organic matter. In order to improve the area generating hydrogen sulfide, we supplied air into the gas pipes by 60 m^3/min, 3 to 4 hours, 2 or 3 times/day, with a portable blower and a bellows-shaped hose to connect to a gas pipe. As Figure 4 shows, the hydrogen sulfide was reduced after air feeding. This occurs due to the nature of the semi-aerobic landfill. The cause of emitting hydrogen sulfide is the lack of air. So, once the air is fed into the gas pipe, aerobic decomposition occurs. This phenomenon allows the updraft to occur because of rising temperatures. Thus, feeding air for a short time accelerates and spontaneously progresses oxidation.

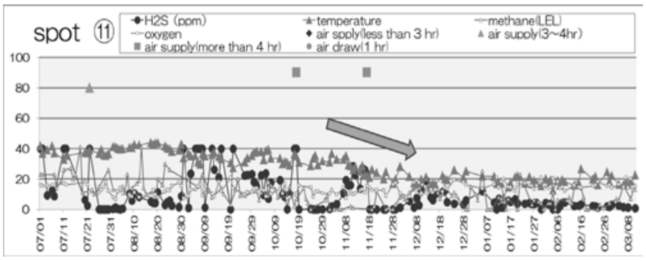

Figure 4 air feeding effect

EVALUATION 4: BIOLOGICAL RESPONSE TESTING[3)]

In this landfill, the leachate is treated as follows:

Raw water (leachate) in the pit

⇒ flow equalization tank (intermittent aeration)

⇒ bioreactor

⇒ coagulation-sedimentation

⇒ sand filter

⇒ first RO(reverse osmosis)

⇒ second RO

(1) INSTRUMENTAL ANALYSIS RESULT

Figure 5 shows each instrumental analysis result, BOD, COD, SS, T-N at each processing line. The inflow section water quality, also known as raw leachate, satisfies treated water reference value for the waste disposal law. This means that the semi-aerobic system is functioning. Considering the whole figure, it is certain that each concentration decreases as treatments advance.

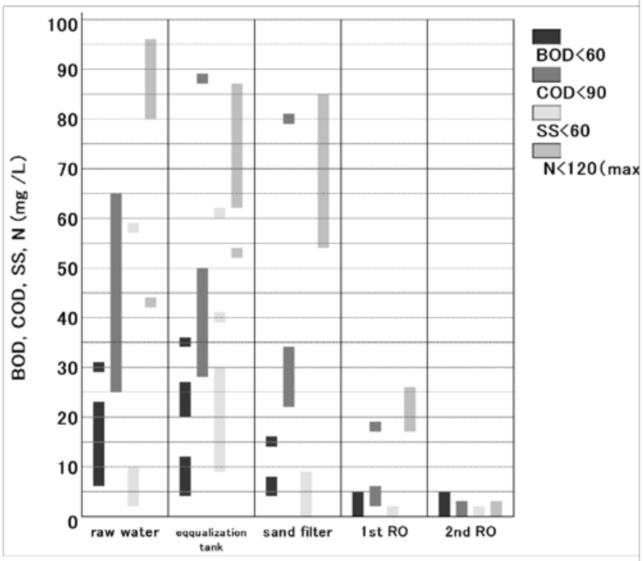

Figure 5 Instrumental analysis result

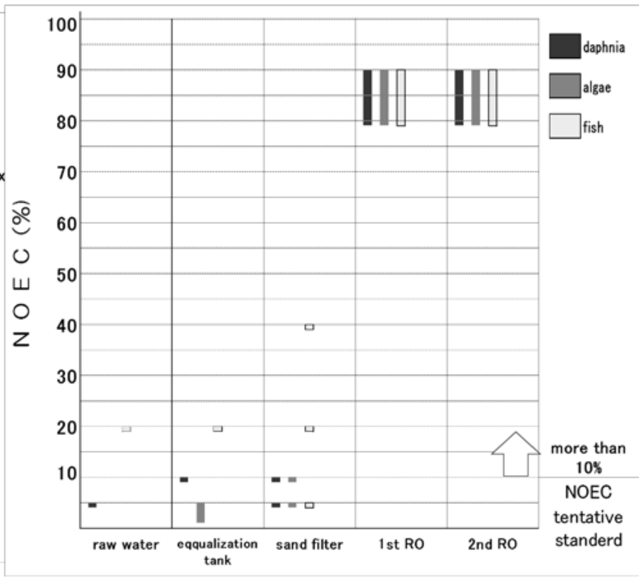

Figure 6 Biological response test result

(2) BIOLOGICAL RESPONSE TEST RESULT

We confirm the leachate quality not only by using equipment analysis but also using a biological response test, called WET (Whole Effluent Toxicity), using aquatic organisms like daphnia *(Ceriodaphnia dubia)*, algae (*Pseudokirchnerie subcapitata)* and fish (*Danio rerio)*. Figure 6 shows NOEC (Non Observed Effect Concentrations) of each processing line. When NOEC numbers are higher, this indicates a safer leachate. A figure of NOEC that is more than 10% is the tentative safe value. The safety-level of the first RO is the same as the second RO notwithstanding the second RO's concentration being less than the first RO. This means that the first RO is enough for this treatment, and that the second RO does not need to be done.

(3) TRE/TIE

On the other hand, when observing the sand filter, the fluctuation band is large. So, we have studied TRE/TIE (Toxicity Reduction Evaluation / Toxicity Identification Evaluation) to know the reason and make improvements. NOEC of the daphnia and algae are lower than fish's one. The cause here is from metal.

There is a coagulation process before the sand filter. Thus, we studied the coagulation and sedimentation process where the aluminum (Al) is dosed as the coagulant. Table 2 shows the test of the coagulation and sedimentation, what we call the jar test.

We confirmed that the result depends on pH values, 4.0 and 6.5. At pH 4.0, an acidic condition, Al concentration in treated water is 6.5mg/L, which means around 60 % of dosing Al. But at pH 6.5, an almost neutral condition, Al concentration is 0.22mg/L, which means about 2% of dosing Al. From this result, the cause of the low NOEC can be assumed Al by dosing at low pH. So, we improved the pH adjust system. As a result, we reduced the dosing by half of the conventional amount. We not only improve the safety for aquatic conditions but also can conduct a low dosing operation.

Table 2 coagulation & sedimentation test result

pH	PAC dosing mg/L	Al dosing mg/L	Al consentration of treatment water mg/L	NOEC	
				daphnia (%)	arge (%)
4	200	10.6	6.5	less than 5	less than 5
4.5	200	10.6	4.0	-	-
6.5	200	10.6	0.22	10	10

The biological response test helps us to notice the excess treatment, second RO, and the existence of too much dosing.

CONCLUSIONS

Based on the experiments reported here, we made the following determinations:

1) We evaluated the semi-aerobic mechanisms by measuring air flow with natural power.
2) The sheet capping during landfilling has a good effect that not only excludes rainwater, but also prevents emission of hydrogen sulfide.
3) We showed that by feeding air using a portable blower for a short term effectively improves the area emitting hydrogen sulfide. This method takes advantage of the semi-aerobic function's natural processes.
4) The leachate quality is good due to the semi-aerobic landfill. The biological response test and TRE/TIE are effective for the landfill maintenance and leads to energy-savings and low-cost operations.

In conclusion, maintaining the landfill's semi-aerobic system is essential.

ACKNOWLEDGMENT

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LANDFILL MINING – INVESTIGATION OF A SUSTAINABLE MINING OF A BOTTOM ASH LANDFILL

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ABSTRACT
The mining of untreated waste deposited on MSW landfills is in operation worldwide for over 60 years. In the past, relatively small material flows were purposefully recycled; usually the main material flows have only been relocated to other areas. Overall, a steady increase in the number of landfill mining projects can be observed over the last years worldwide. A completely different picture show landfills on which residues from waste incineration plants (bottom ash and filter dusts) were deposited. Due to the lack of a complete processing chain for the recovery of valuable metals up to the finest grain area, this resource potential is currently only insufficiently recovered or even not recovered at all. Especially in bottom ashes which had been deposited in the past – due to the less advanced treatment technology – very high amounts of recyclables in the landfill bodies are to be expected. A landfill mining (LFM) at a bottom ash landfill has not yet been carried out worldwide. Investigations at these landfills relate mainly to the long-term behavior of the bottom ash and the long-term emission behavior. The recovery can be enabled through a conventionel method for the coarse fraction (particle diameter > 4 mm) and a special hydrometallurgical method called „RENE-process“, (developed at TU Clausthal, Germany) for the fine fraction (particle diameter < 4 mm).

Keywords: bottom ash, landfill mining, metal recovery, resource recovery

INTRODUCTION

The results presented in this paper are part of the joint research project "TÖNSLM" for developing innovative methods for the recovery of resources out of landfills for municipal waste and bottom ash, funded by the German Ministry for Education and Research from 2012 to 2016. The project aimed the deconstruction of landfills with the primary goal of maximum recovery of secondary raw material (Enhanced Landfill Mining ELFM), under consideration of technical, economical and ecological aspects. The recovery of untreated and deposited waste on municipal solid waste landfills is in operation worldwide for over 60 years. In the past, relatively small material flows were purposefully recycled; usually the main material flows have only been relocated to other areas. Overall, a steady increase in the number of LFM projects can be seen over the last years worldwide. A completely different picture show landfills on which residues from waste incineration plants (bottom ash and filter dusts) were deposited. A large part (ca. 90 mass-%) of the residues are nowadays used in the construction industry after treatment. So there is only a relatively small amount (≈10 mass-%) which ends up on landfills. The deposited material is the fine fraction (< 4 mm), which is not further treated. In the last years there is a growing awareness that this fine fraction contains substantial amounts of valuable metals, such as copper, lead or aluminum. The share of the non-ferrous metal fraction vary in the fine fraction between 25 – 50 mass-%. Thus, up to 50 mass-% of valuable metals are lost in landfills (Eberhard and Züst, 2017). By the recovery of aluminum, the focus is not on the substitution of the metal, but the cumulative energy expenditure (relative to fossil energy sources) for the production of raw aluminum from bauxite. According to a study by the Federal Environment Agency of Germany (2007) the cumulative energy expenditure for the production of aluminum is 31.1 $MWh/t_{raw\ aluminum}$. According to the study by Wiemer and Gronholz (2011), an extensive treatment of the bottom ash achieves an energy saving of approx. 91 % with recovered aluminum and a CO_2 saving of approx. 87 %. Due to the lack of a complete processing chain for the recovery of these valuable metals up to the finest grain area, this resource potential is currently only insufficiently recovered or even not recovered in certain fractions at all (Alwast and Riemann, 2010), (Lukas et al, 2008), (Deike et al, 2012), (Breitenstein et al, 2013) and (Grünbein et al, 2015). Especially in bottom ashes which had been deposited in the past - due to the less advanced treatment technology – a very high value of recyclables in the landfill bodies is to be expected. LFM at a bottom ash landfill has not yet been carried out worldwide. Investigations at these landfills relate mainly to the long-term behavior of the bottom ash and the long-term emission behavior (Kieser et al., 1995), (Speiser, 2001) and (Klein, 2002). One focus of the investigations in the research project was the landfill mining of landfills where only bottom ashes were deposited. In order to get more detailed information on the proportion and concentration distribution of ferrous and non ferrous metals in the landfill body boreholes were drilled on a German bottom ash landfill in Offenbach to obtain solid samples and to analyze the concentrations of valuable metals over the deposition depth. In addition, the gas composition (O_2, CO_2, CH_4 and H_2S), and the temperature in the landfill body were measured during drilling, also the emissions (gas and dust) on the surface were analyzed.

RESOURCE POTENTIAL BOTTOM ASH

Due to the incineration process of MSW and the associated mass reduction, the substance concentrations in the remaining bottom ash are many times higher than in the original waste. The composition is strongly influenced by the composition of the input material in the incinerator, the firing conditions, the residence time on the grate and the bottom ash discharge (wet or dry bottom ash removal). Only with the beginning of the mechanical treatment of the bottom ash, ferrous and non-ferrous metals were recovered. Also the waste management measures in the area of waste prevention have improved significantly over the last 20 years. Nevertheless, the variations and concentrations of metals in bottom ash are very high even today. The literature data show that not only iron (max 150,000 mg/kg DS) but also copper (8,240 mg/kg DS) and aluminum (72,800 mg/kg DS) is present in very high concentrations. In particular, the concentrations of copper are in the range of poor copper ores, which are mined to lower levels of 0.3 mass-% copper. Although the state-of-the-art ferrous and non-ferrous metals are only partially recovered, so that a considerable amount of these metals remains in the mineral fraction, which is supplied to a further utilization. This means that around 17,000 t of copper are lost every year in landfills or with the mineral fraction in various construction measures in Germany (Alwast et al, 2010). It becomes clear that the bottom ash - in the past deposited on a mono-landfill or built-in documented profiling layers - should be considered for a landfill mining to recover valuable metals in the future.

MONO BOTTOM ASH LANDFILL OFFENBACH

The subject of the investigation was the mono-landfill for bottom ash in Offenbach in the southwestern part of Germany. From 1970 to 1990, only incineration residues from the waste incineration plant Offenbach were deposited on the landfill. The waste incineration plant had no downstream magnetic separator. The bottom ash was deposited after the wet removal and cooling directly to the landfill, which is divided into an old and a new area. The old area – sealed at the base – was in operation from 1970 to 1985. On this area there were disposed around 890,000 t of incineration residues, including scrap, filter dusts and bottom ash. After commissioning of the new landfill area with a combined bottom layer (according to the state-of-the-art at this time in Germany), subsequently, the landfill was filled to the final height (170,000 t bottom ash). Until 2009, a complete final profiling and recultivation of the landfill site took place.

ON-SITE INVESTIGATIONS OF THE LANDFILL BODY DURING DRILLING

The results of the gas concentrations, temperature values in the landfill body over the deposition depth and the emissions (gas and dust) during the drilling, are described in Zeiner, et al. (2018).

BASIC CHARACTERIZATION OF THE BOTTOM ASH

As a result of the thermal treatment, barely individual waste components can be recognized in the bottom ash. In addition to the bottom ash, construction waste, metal parts, ceramics, glass and soil as well as unburnt material could be detected. The total bottom ash - without the consideration of individual coarse components - usually has a gray color. Only a few deep areas of the boreholes show a brown color. The bottom ash samples were sieved as a mixed sample over the entire profile of the boreholes (figure 1), or individual layers were sieved separately. Overall, the determined share of the fine fraction (< 4 mm) with about 61 mass-% is very high. Compared with fresh bottom ash from 2017, there is a significantly higher proportion of fine fraction in the middle sieving cuts. The contents of selected metals were determined in the solid samples in mixed samples from every boreholes and in samples over the deposition depth from every borehole. It should be noted that for the analyzes, larger pieces of metal (cables, screws, structural steel, sheet metal, etc.) were sorted out bevor analyzing the metal contents. Figure 2 shows the metal contents in the solid of the mixed samples for boreholes BK01 - BK05.

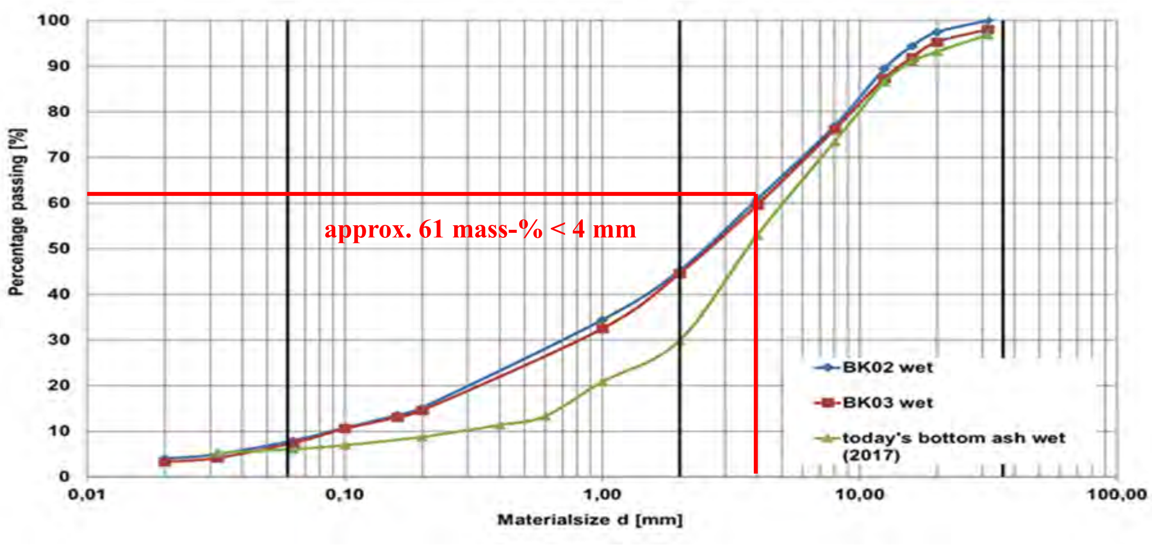

Figure 1: Comparison of wet sieving of mixed samples from BK02 and BK03 with today's bottom ash

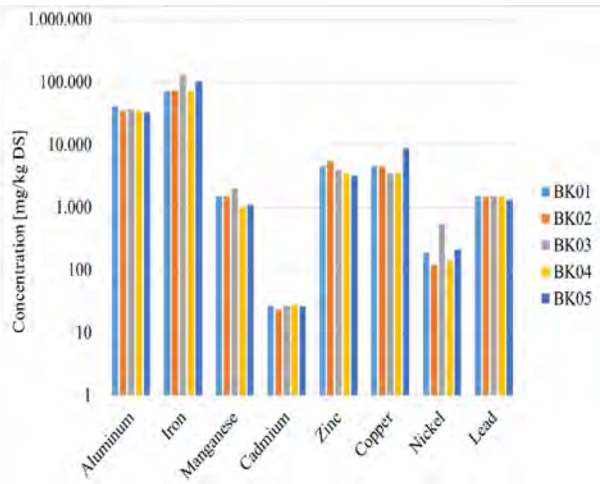

Figure 2: Heavy metal concentrations in the mixed samples of the boreholes BK01 - BK05

The distribution of the concentrations in the landfill body over the height is different for the individual metals (figure 3 - 5). Noticeable in the distribution of copper concentrations (figure 3) in the top layers of the landfill is the value of 30,000 mg/kg DS, which is almost a factor of 11 above the values of the other layers.

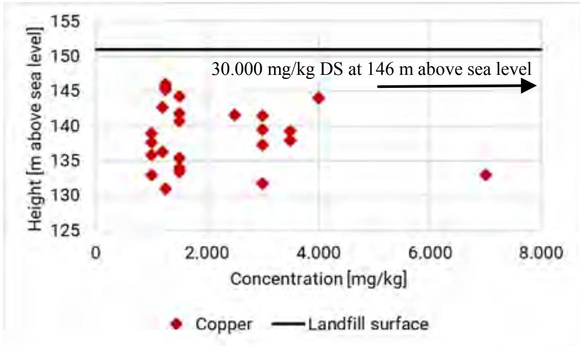

Figure 3: Copper concentrations over the deposition depth

The distribution shows that selectively very high copper concentrations are present, which can be caused for example by small cable particles. This is also the reason for significantly increased concentration of 7,000 mg/kg DS in the lower landfill area compared to the otherwise relatively narrow range of approx. 1000 - 4000 mg/kg DS. A clear correlation between concentration of copper and the age of the bottom ash is not recognizable. The values also show that the concentrations are for the most part below the value of 3,000 mg/kg DS, which describes an economically acceptable copper ore mining. The distribution of copper concentrations across the material sizes class is very unequally. A correlation of the concentration and the material size class can not be recognized. The aluminum concentrations (figure 4) show a slight decrease over the landfill depth.

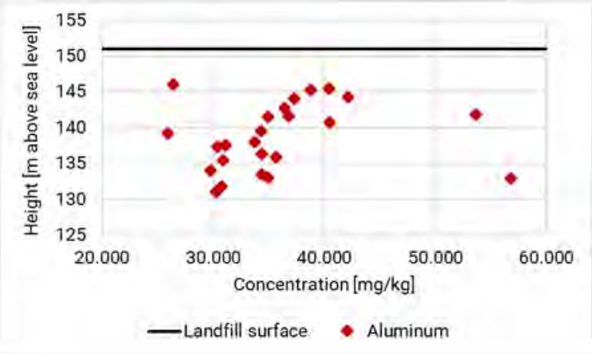

Figure 4: Aluminum concentrations over the deposition depth

The majority of the measured concentrations are in the range of 30,000 - 42,000 mg/kg DS. Also here high concentrations of up to 56,750 mg/kg DS can be seen. One reason for the higher concentrations of aluminum in top layers of the landfill may be due to the strong increase in the share of aluminum-coated composite materials in the younger residual waste in Germany. The aluminum concentrations over the material size classes clearly show an upward trend below a material size of 4 mm. That means there is an accumulation of aluminum in the fine fraction up to a maximum level of 59,400 mg/kg DS (material size 0.032 - 0.02 mm). As already shown with the analyzes of the mixed samples, iron has the highest concentrations in the bottom ash over the height (figure 5). From a height of approximately 137 m above sea level, a significant increase in the concentrations across the depth can be seen. Iron concentrations of up to 155,000 mg/kg DS were determined in the lowest layers of the landfill body. One reason may be that filter dusts have been deposited with the bottom ash in the lower layers of the landfill body.

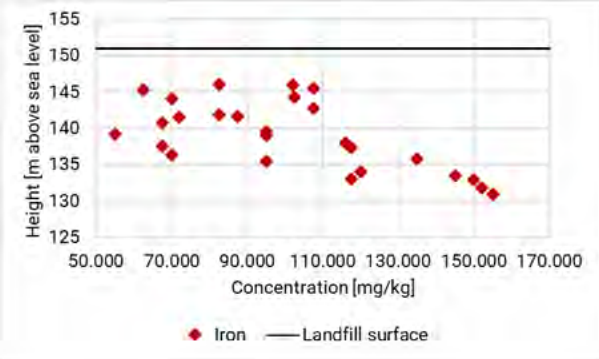

Figure 5: Iron concentrations over the deposition depth

Such a clear correlation can not be found in the concentrations over the different material sizes. In the mixed samples of BK02 and BK03 the maximum iron concentration is 260,000 mg/kg DS (coarse fraction 20 - 31,5 m) in the other material size classes the values are approx. around 100,000 mg/kg DS. Detailed analyses of the basic characterization of the landfilled bottom ash are described in Zeiner, et al. (2018).

ESTIMATION OF THE RECOVERABLE VALUBALE METALS AND STATE OF THE ART RECOVERY

A first estimation of the valuable metals – contained in the deposited bottom ash –, based on the coarse and fine fraction, is given in table 1. It can be seen that a numerous amount of valuable metals are in the fine fraction not only because the proportion of the fine fraction is very high, also because the concentrations of these metals are higher in the fraction < 4 mm.

Table 1: Estimation of the recoverable metals of the deposited bottom ash

[t]		< 4 mm	> 4 mm	Total	[mass-%]
Iron	MIN	34,154	19,894	54,049	5.10
	MAX	86,810	54,226	141,036	13.31
Copper	MIN	1,539	803	2,342	0.22
	MAX	2,073	1,368	3,441	3.25
Aluminum	MIN	45,859	17,352	63,211	5.96
	MAX	56,533	22,110	78,643	7.42

There are a large variety of different technical solutions for the recovery of these metals. Today the most common treatment techniques in Germany are dry-mechanical processes. In state of the art treatment facility for bottom ash, the maximum processing depth is 2 mm - 4 mm. By separating the fine fraction, a part of the total mass is separated and not further processed before the actual treatment starts. By doing so, a significant amount of valuable metals is lost (Grünbein et al., 2015). In dry mechanical processing, the following techniques are usually used:

- Drum sieve for particle size separation,
- impact crushers or other shredders for a better separation of the bottom ash,
- magnetic separator for Fe-fraction,
- eddy current separator for NFe-fraction,
- air classifier for the separation of unburnt material.

Depending on the processing target and depth, these techniques are arranged differently and repeated several times. In table 2 the increase in the efficiency of recovering valuable metals over time is shown. The main part is the Fe-fraction. On the other hand, the NFe-fraction has a smaller share, but because of its higher value, it is of particular importance. It can also be seen that the output of the different fractions could be increased from year to year through adaptation and development of the processing technology.

Table 2: State of the art of recovery of the valuable metals from bottom ash in Germany

	Alwast a. Riemann, 2010	Deike et al, 2012	Kuchta a. Enzner, 2016
	Mass output [mass.-%]		
Fe-fraction	7,27	7,27	7,65
NFe-fraction	0,67	0,80	1,26
Mineral-fraction	92,06	91,93	89,89

According to the state of the art, recovery rates of about 82 % for ferrous metals and about 56 % for non-ferrous metals can be achieved today (Kuchta and Enzner, 2016). Nevertheless, there is clear a potential for improvement in the recovery of non-ferrous metals. According to Breitenstein (2017), the amount of non-ferrous metals still to be recovered is distinctly above 30,000 t/a. especially in the fractions < 6 and < 2 mm an amount of non-ferrous metals in the range of > 10,000 t/a are lost, because of the non-existing treatment steps for this material.

SUSTAINABLE LFM SCENARIOS FOR MINING THE BOTTOM ASH LANDFILL

The technical implementation of a LFM requires the following four steps:

- Excavation of the deposited bottom ash,
- preconditioning of the excavated bottom ash,
- material flow separation into a coarse and a fine fraction,
- material flow-specific treatment.

One aim of the investigations was to integrate various technologies and to cover the widest possible range of treatment depths. The choice of a certain sustainable LFM concept influences the extent of the treatment of the deposited bottom ash and also the number, quality and quantity of the resulting products and residues, which can subsequently placed on the market or must be sent to a utilization or safe disposal. The choice of a LFM concept significantly influences the economic and ecological advantages of LFM compared to landfill closure and after-care. Table 3 shows 5 possible LFM scenarios for the bottom ash landfill in Offenbach. Depending on the processing and treatment depth of the individual scenarios, different fractions are produced, which can be used in different ways (table 4).

Table 3: Possible sustainable LFM scenarios

Scenario	Description
1a	Mobile treatment concept for the coarse fraction and re-deposition of the fine fraction of the bottom ash
1b	Mobile treatment concept for the coarse fraction and application of the „RENE-process“ for the fine fraction
2a	Co-treatment of the coarse fraction in the bottom ash treatment plant near to the landfill and re-deposition of the fine fraction
2b	Co-treatment of the total excavated bottom ash in the bottom ash treatment plant near to the landfill
2c	Co-treatment of the coarse fraction in the bottom ash treatment plant near to the landfill and application of the „RENE-process“ for the fine fraction

Table 4: Recovery options for the produced fractions

Fraction	Recovery option
Fe-fraction	Iron smelting industry
NFe-fraction	Copper / aluminum smelting industry
Coarse mineral-fraction (> 4 mm)	Use in road construction and earthworks
Fine mineral-fraction (< 4 mm)	Use in construction raw materials and cement industry

LANDFILL MINING SCENARIOS 1a AND 1b

Figure 6 shows LFM scenario 1a, with a low treatment effort, which can be realized at the location of the bottom ash landfill in Offenbach. It shows also the LFM scenario 1b, which is a combination of the LFM concept 1a with the "RENE process" for the treatment of the fine fraction (< 4 mm). At first, the bottom ash is excavated and transported to the treatment area on the landfill site with excavators, wheel loaders, dump trucks. After sorting out the extraneous material, the bottom ash is sieved into the following material sizes:

- > 12 mm
- 12 mm - 8 mm
- 8 - 4 mm
- < 4 mm

Based on experience from practice, a jigging screen with a sloping grate and two sieve decks as well as three discharger belts are used for sieving the bottom ash. The material flow > 12 mm is manual pre-sorted to get unburnt material out of the process and back again into the waste incineration plant. In the case of scenario 1a, the fine fraction (< 4 mm) is not further treated and is deposited again, according to the German landfill ordinance and its limit values for a save disposal. Based on practical experience, a combination unit consisting of magnetic and eddy current separators is used to separate the ferrous and non-ferrous fractions. For LFM

Scenario 1b, scenario 1a is extended by the "RENE-process" for the treatment of the fine fraction (< 4 mm). The process focuses primarily on the recovery of copper, aluminum and zinc. It is a three-step special hydrometallurgical process.

1st step: Recovery of non-ferrous metals > 1 mm with a dry mechanical treatment.

2nd step: Recovery of non-ferrous metals > 0.2 mm with a wet mechanical treatment.

3rd step: Recovery of non-ferrous metals < 0.315 mm with a hydrometallurgy treatment.

Detailed information about the "RENE-process" are given by Breitenstein, et al. (2013).

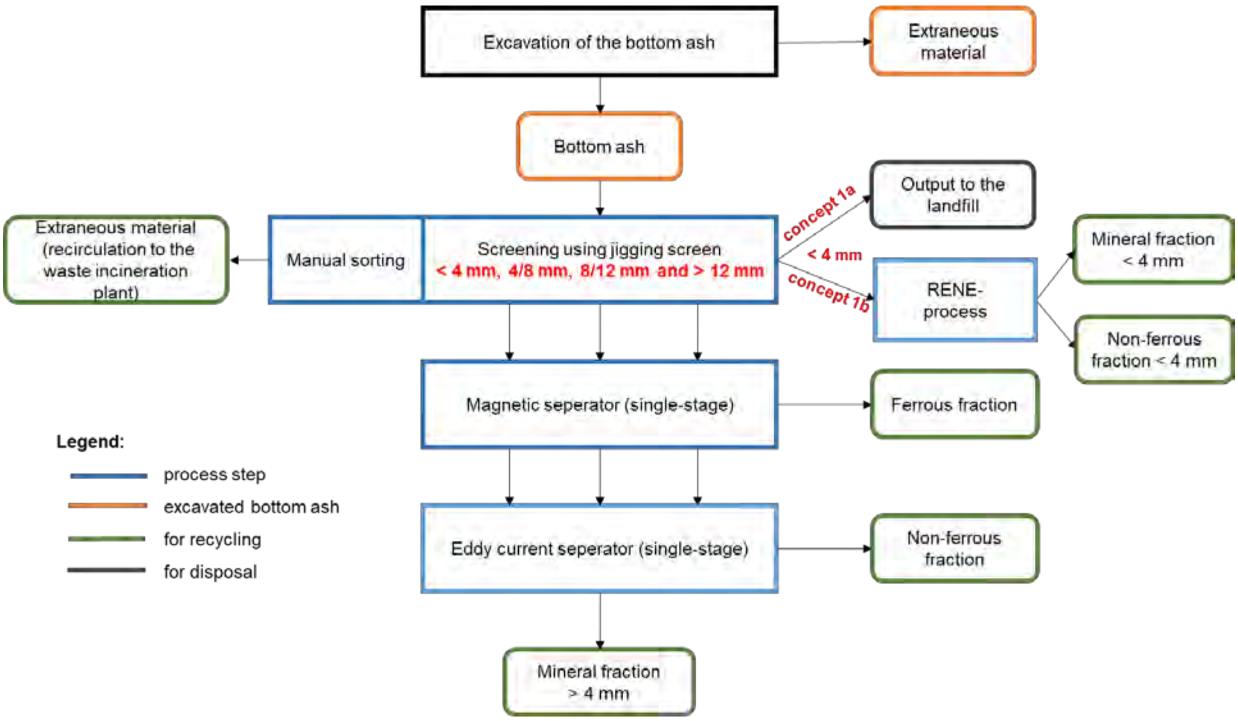

Figure 6: LFM scenarios 1a and 1b

QUANTITATIVE YIELD OF RECYCLABLE MATERIALS OF THE LFM SCENARIO 2b WITH THE "RENE-PROCESS"

Due to the lack of experience regarding the treatment of bottom ash which has been deposited and aged over a long period of time, a technical scale separation carried out to separate the bottom ash and to calculate the mass output of the different fractions (Table 5). Taking into account the literature data on the individual mass outputs (Table 2) and the results of the technical scale separation, mass outputs for magnetic separation and eddy current separation were set up (table 6). In order to make the widest possible statement about the recovery, a distinction was made between minimum and maximum mass output.

Table 5: Results of the technical scale separation of the bottom ash

Fraction	Mass output [mass-%]
Fe-fraction	7.17
NFe-fraction	0.35
Mineral fraction	92.48

Table 6: Basis of calculation of the mass output for the magnetic separator and eddy current separator (based on the total input mass)

Fraction	MIN	MAX	MV
	[mass-%]		
Fe-fraction	5	7	6
NFe-fraction	0.7	1.5	1.1

The results of LFM Scenario 1b are shown in Table 7. Those of the "RENE-process" are based on a laboratory scale test by the TU-Clausthal with mixed samples of all boreholes from the bottom ash landfill in Offenbach.

Due to the very high fine fraction (< 4 mm) of approx. 61 mass-%, approx. only 2 mass-% of the Fe-fraction and 0.4 mass-% of the NFe-fraction could be separated during the treatment of the coarse fraction. Through the 1st and 2nd step of the "RENE-process", an additional copper output of 0.38 mass-% (based on total input) could be generated. The relatively small amount of aluminum compared to the copper output is because in the analysis, also mineral aluminum was analyzed, but only metallic aluminum can be recovered. The ammoniac leaching in the 3rd step of the "RENE-process" can increase the copper output up to > 85 mass-%.

Table 7: Estimated recovery results of LFM scenario 1b (in relation to the total input of 1,060,000 t)

Fraction	MIN		MAX		MV	
	[t]	[mass-%]	[t]	[mass-%]	[t]	[mass.-%]
	Coarse fraction (> 4 mm)					
Fe-fraction	19,716	1.86	27,560	2.60	24,6638	2.32
NFe-fraction	2,650	0.25	5,512	0.52	4,028	0.38
Coarse mineral fraction	37,1954	35.09	36,1248	34.08	381,754	34.7
Fine fraction processing with the RENE-process (< 4 mm)						
			[t]	[mass-%]		
Total concentrate (3 %[1])	1st + 2nd step RENE-process		19,430	1.83		
Total copper output (Copper concentration of 284.409 mg/kg and copper yield of 73%[1])			4,034	0.38		
Total aluminum output (Aluminum concentration 328.439 mg/kg and aluminum yield of 15%[1])			957	0.09		
Fine mineral fraction (97 %[1])			628,230	59.26		
increase of the copper output	3rd step RENE-process		> 85 %[1]			
zinc output			34 %[2]			

[1] Results from a pilot plant test of the TU-Clausthal with mixed samples of all boreholes of the landfill Offenbach

[2] Results from Breitenstein (2017) from the application of the RENE process on 12-year aged bottom ash

FURTHER INVESTIGATIONS

Based on the presented results, additional analyses are currently being carried out to assess the environmental impact of the deposited bottom ash, the quality of the utilization as a substitute construction material and the recycling potential of the bottom ash with regard to the contained valuable metals. Finally, the LFM scenarios 1a and 1b will be ecologically and economically balanced and evaluated under a variation of a sensitivity analysis.

CONCLUSIONS

The investigations have shown that with the state of the art treatment of the coares fraction a certain amount of metals can be recovered from the bottom ash. Nevertheless, a large amount of valuable metals remains in the fine fraction. To recover these valuable metals, the “RENE-process” could be applied. With the two mechanical steps of this process, a considerable quantity of copper and aluminum can be recovered from the bottom ash. Nevertheless the largest output through the whole treatment is the fine mineral fraction. For the recycling of this mineral fraction, new mineral applications have to be found due to the very fine grain sizes. In particular, the use in construction raw material and cement industry is pursued since, the Ca-Al-Si-ratio is advantageous (Zeiner et al., 2018) and an enormous contribution to carbon dioxide saving can be achieved.

ACKNOWLEDGMENT

The authors like to thank the German Ministry for Education and Research (BMBF) for the financial support.

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EFFECT OF CARBONATION TREATMENT OF INCINERATOR ASH ON THE STABILIZATION OF OFFSHORE LANDFILL

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ABSTRACT

While securing landfill sites is becoming more and more difficult, offshore landfills in Japan play an important role in the disposal of not only daily domestic and industrial waste but also disaster waste which is usually generated in huge amounts within very short period of time. However, since highly alkaline incinerator ash is mainly landfilled under anaerobic conditions, the pH and the organic matter of the leachate can continue to be above the emission standards for a long time, resulting in delaying the stabilization of offshore landfill. Therefore, column experiments were carried out to evaluate the effect of carbonation treatment of incinerator ash on the stabilization of offshore landfills, especially focusing on the pH and concentration of organic matter in leachate.

As a results of these experiments, the carbonation-treated incinerator ash showed a marked decrease in TOC although there was not much difference in either leachate pH during the experiment period. This implies that calcium carbonate surface coating by the carbonation treatment retards the release rate of organic matter from incinerator ash. In addition, it was observed that the concentrations of cations (such as K and Na) of the carbonation-treated incinerator ash were significantly lower than those of untreated ash, suggesting that the carbonation treatment change the chemical property of the surface of incinerator ash to adsorb cations such as K and Na in leachate water.

Keywords: Incinerator Ash, Organic Matter, Carbonation, Stabilization, Offshore Landfill

INTRODUCTION

According to the Ministry of the Environment, Japan (FY2015), the remaining years of landfill capacity of municipal solid waste (MSW) are only 20.4 years. One of the main reasons is that the siting of new landfills is becoming more and more difficult due to the so-called NIMBY (Not In My Back Yard) syndrome, which is a pejorative characterization of opposition by residents to siting of locally undesirable but socially beneficial facilities. In fact, the number of new MSW landfills in 2000 was 56, but it has decreased every year, to only 5 in 2016. For offshore landfill sites, the influence of

NIMBY is relatively small, and large capacity can be secured. Furthermore, offshore landfill sites play an important role in disposal facilities not only of MSW but also of disaster waste generated by natural disasters such as earthquakes and floods, which can create large volumes of debris and waste in a very short period of time. Currently, about 80 offshore landfill sites for domestic waste (MSW) and industrial waste are in operation. Among them, offshore landfills for domestic waste are 34 that dispose of about 28% of MSW in Japan (FY 2013).

An offshore landfill is surrounded by a water barrier wall (made of concrete or steel) that separates it from the open ocean. When waste is put into the internal seawater in the landfill, the water level of the internal seawater rises, so that excess water is discharged to the outside sea after purification treatment at the wastewater treatment plant.

However, due to the structure of the offshore landfill, a large amount of water retained within the landfill makes it anaerobic. In addition, since landfill waste in Japan consists mainly of incinerator ash which includes a high porportion of alkaline components, the pH of water in the landfill maintains a very high (pH around 11) for a long period, resulting in delaying the decomposition of organic matter even after the landfill is completed. In fact, according to a report[1)], a certain offshore landfill that has passed more than 15 years after the completion of landfilling has been around pH 11, and it is estimated that it will take more than 100 years to meet discharge standards of pH (below pH 9) for “final storage quality”, or a situation where active environmental protection measures are no longer necessary and the leachate is acceptable in the surrounding environment. As a result, stabilization after the completion of landfill may be prolonged, which may make problems that the risk of environmental pollution and the burden of maintenance expenses become large.

Therefore, in this study, experiments simulating offshore landfills were carried out to examine the effect of carbonation treatment mainly on pH and organic matter in leachate, which are major problems in stabilizing an offshore landfill.

MATERIALS AND METHODS

Carbonation treatment

Figure 1 shows the outline of experimental equipment for carbonation treatment of incinerator ash. As shown in Figure 1, the standard carbon dioxide gas (CO_2 10%, N_2 90%) was injected through the incinerator ash of 20% moisture content until there was no difference between the CO_2 concentration of the inlet and outlet.

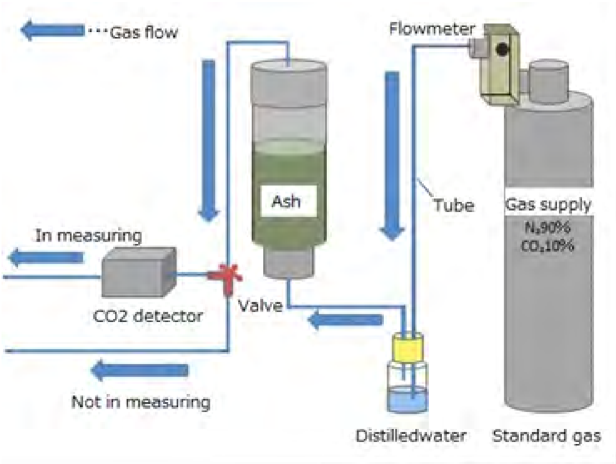

Figure 1. Experimental equipment for carbonation

Experiments simulated offshore landfill

Three samples for simulated offshore landfill were prepared; untreated incinerator ash, carbonation-treated incinerator ash, and mixed waste of carbonation-treated incinerator ash and compost (9:1) to clarify the change in organic matter. Each device (acrylic container) had a solid content of 1.1 kg and L/S was adjusted to 4.

As a sample for analysis, each 200 mL of water above and below the sample layer were sampled every week, and a new 400 mL of ion exchange was added.

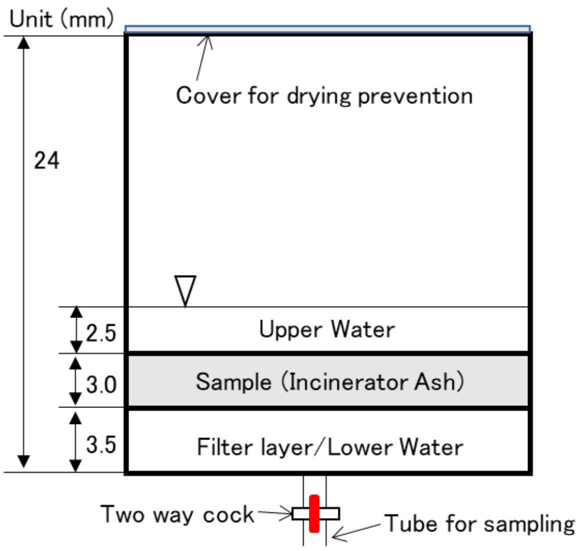

Figure 2. A device simulated offshore landfill

RESULTS

pH

Figure 3 shows the pH of the upper and lower water taken from each experimental device. In the case of untreated samples, the upper water decreased from the initial pH of 12.9 to pH 11.3 after 108 days due to the influence of atmospheric CO_2, but the lower water leveled off above pH 13. Compared with the untreated sample, the pH of the carbonated sample decreased by about 1, but there has not been much change since then.

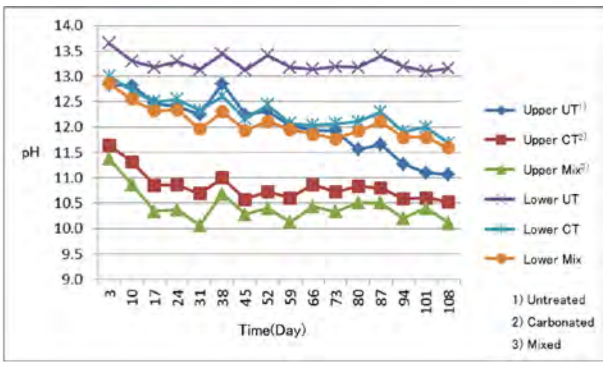

Figure 3. Change in pH in each sample

TOC

Figure 4 shows TOC (Total Organic Carbon) of the lower water taken from each experimental device. The untreated sample continued to increase from the initial 250 mg/L to 400 mg/L, whereas the carbonated sample decreased from the initial 180 mg/L to 25 mg/L. The compost mixed sample also decreased from the initial 400 mg/L to 80 mg/L, suggesting that the carbonation treatment reduces the TOC.

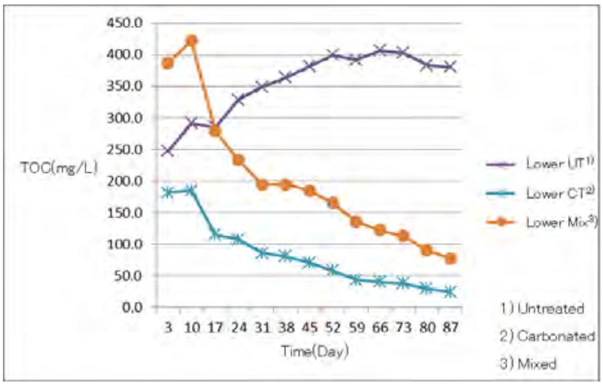

Figure 4. Change in TOC in each sample

As shown in Figure 3, although the activity of microorganisms in the treated sample can not be expected due to high pH, only the carbonated samples are obviously low. Thus it is highly probable that the calcium carbonate coating by the carbonation treatment inhibited elution of organic matter from the sample.

Na, K, and Cl

Figure 5 shows the Na, K, and Cl of the lower water taken from each experimental device. They decrease at a certain rate by injecting new water. However, as for Na and K, the concentrations in the carbonated samples were lower than that of the untreated sample at the earlier stage, and there was also a clear difference thereafter, whereas as for Cl, there is little difference from the untreated sample during the entire experimental period.

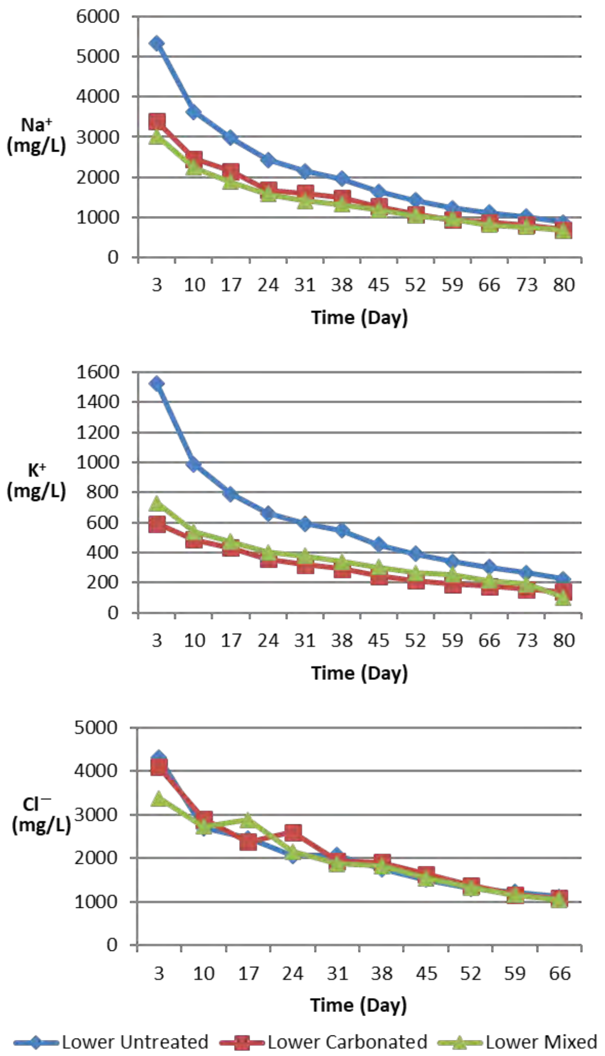

Figure 5. Change in Na^+, K^+, and Cl^- in each sample

From the above results, it is presumed that the coating formed on the surface of the ash by the carbonation treatment has a property of adsorbing positive ions as shown in Figure 6.

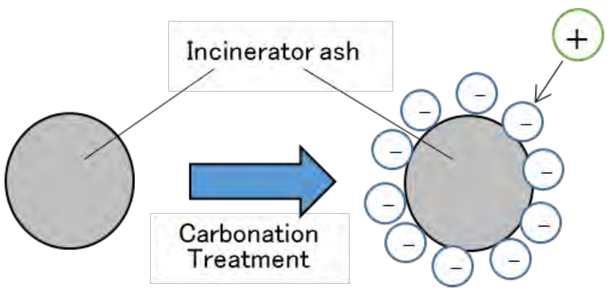

Figure 6. Chemical change of ash surface by carbonation

CONCLUSIONS

It was found that the carbonated incinerator ash was markedly lower in TOC than the untreated incinerator ash, although there was not much change in the pH of the carbonated sample compared to that of the untreated sample. It is expected that a greater reduction of pH by carbonation treatment could lead to a greater reduction of organic matter by highly active microorganisms.

It was also observed that the concentrations of cations (such as K and Na) of the carbonation-treated incinerator ash were significantly lower than those of untreated ash, suggesting that the carbonation treatment change the chemical property of the surface of incinerator ash to adsorb cations in leachate water such as K and Na.

ACKNOWLEDGMENT

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EXCAVATED WASTE CHARACTERISTIC FROM YOGYAKARTA CITY LANDFILL

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ABSTRACT

Yogyakarta City is one of the metropolis in Indonesia brimming with people from all over the country. It produces 2953 tonne of waste per day with volume around 11996 m3/day. Piyungan Dumpsite, the only active dumpsite available, has received municipal waste without going through any separation, even intermediate treatment. This research investigates the characteristic of excavated waste from Piyungan Dumpsite. Spindle inti drilling rig was used to obtain a sample from the landfill up to 12m depth. Then the sample was separated according to combustible, non-combustible, soils and rocks. Soils and rocks are the most material found in the dumpsite. They are mostly from degraded organic waste and material for top layer cover. The second most found material was combustible materials which consist of plastic, wood, paper, fabric and other organics. Proximate analysis was used to understand the moisture, volatile, ash and fixed carbon of the combustible material. From Principal Component Analysis (PCA), the depth of the dumpsite shows a higher correlation to the fixed carbon. It is because of the decomposition process in the landfill. As we are going deeper, we will found more carbon stable material. The results show that the average moisture content was 32.83%, volatile content was 23.58%, ash content was 58.42% and fixed carbon content was 18%.

Keywords: landfill mining, waste characterization, reclamation

INTRODUCTION

In the early 90s the concept about landfill mining has been developed because of the stricter regulation by the US government about solid waste management. The regulation was required a final disposal to have environment barrier, final enclosure and post-operation monitoring and management. Recovering and utilization of dumped waste was seen as an alternatives to reduce the post-operation cost and increase the land value of the ex-landfill area (Dickinson, 1995). On the next decade researchers began to doubt towards this concept because it is not economically viable without obtainable high quality recyclables and government incentives (Hull, Krogmann, & Strom, 2005). Recently, the issues were start to get more attention because of the Closing the Circle (CtC) project in Europe. The issues related to material conservation, appropriate technology, environmental impact, social aspect and final sink were assessed (Enema & Asce, 2014). In Indonesia, landfill mining research was still focus on reducing the environmental contamination from landfill. There are on going research about integrated landfill mining in several big cities in Indonesia (Wahyono, 2012).

Yogyakarta is one of the big city in Indonesia. With hundreds of universities in the city, Yogyakarta hold the title of Education City of Indonesia. Most of its residence is young adults coming from all over Indonesia to study for higher education. The tourism industry also growing fast in this city. As ancient capital of Indonesia, they still hold the culture and tradition of our ancestor which attract tourist all over the world. Those condition leads to high waste generation up to 2,953 tonne per day (Putra, 2016). They still depend so much on landfilling but the number of available land is very limited. Several systems and technologies for Indonesian waste utilization was developed previously, but only a few which could be implanted (Damanhuri, 2017; Lokahita, Aziz, & Takahashi, 2017; Lokahita, Yoshikawa, & Takahashi, 2017; Putri, Fujimori, & Takaoka, 2018).

Most of the waste generates in Yogyakarta City goes to the Piyungan Landfill (PL) in the outskirts of the city. For the Piyungan Landfill to become sustainable, material recovery and utilization of excavated material are required. Piyungan landfill has the potential for material recovery thru landfill mining. Various waste such as plastic, wood, organic, soil which can be utilized, came every day since decades ago. Waste to energy could be one of the solution for utilization of excavated material. In this case, excavated material from landfill site will be separated for combustible and non-combustible fraction. The combustible part could be processed further into RDF (refuse-derived fuel) to increase its energy recovery quality (Lokahita, 2013). Besides the combustible and non-combustible material, the fine fractions from landfill have a properties of soil. This material could be used for top soil cover for new landfill or soil enhancer in city park.

Fig. 1 Piyungan Landfill. Thousands of cattle and scavengers worsening the landfill condition.

A strategy to solve landfill problem in Indonesia is needed. This research will investigate the potential of recovered material from landfill mining. Some researches on landfill waste utilization have been done in several years (Jones et al., 2013; Lokahita &

Takahashi, 2016). Composition analysis using SNI 19-3964-1994 will be done. On the other, the combustible waste were characterized using proximate analysis with moisture content test based on SNI (SNI 03-1971-1990, 1990), ash content based on ASTM (ASTM E830-87(1996), 1996), volatile content based on ASTM (ASTM E830-87(1996), 1996) and the fixed carbon was derived from residue. Heating value was examined using bomb calorimeter.

For the fine fraction, soil stability analysis was done based on compost maturity method by testing carbon dioxide level on the soil with a modification method of Verstraete, for every 3 to 4 days during 20 days of incubation.

MATERIAL AND METHODS

The waste sampling was done in inactive zone on the northern area of the landfill. That area was the oldest amongst the other part of the landfill. Four point in random location was chosen as drilling point. Spindel inti drilling machine (Fig. 1) was used to dig and retrieve the sample from the upper layer until the depth of 12 meters. The sample was taken in separated container for each meter (Fig. 2).

Extracted samples were separated to plastic, wood, paper, textile, organic, soil, rock and others. Manual sorting and sieving were used to separate the waste.

RDF model were assembled from average composition of combustible fraction (plastic, wood, paper, textile and organic). The model were used for proximate analysis and bomb calorimetry. The proximate analysis consist of moisture content, volatile content, fixed carbon content and ash content. Specific standard procedure were to analyze each parameter respectively.

Moisture content was analyzed according to SNI 03-1971-1990 standard method on aggregate moisture content testing. The sample was heated in the oven at 105ºC. Sample mass were measured every hour for 5 hours, followed by heating at 70ºC for 12 hours to ensure complete drying of the sample. The formula for moisture content calculation in as-determined percentage can be seen below.

$$\%moiture\ content = \frac{(wet\ weight\ - dry\ weight)}{dry\ weight} x100\%$$

Fig. 2. Spindel inti drilling machine

Fig. 3. Retrieved samples

The volatile content was determined using ASTM standard E 897-88. 1 g of sample was heated on the furnace with a temperature of 950ºC for 7 minutes. The formula for volatile content calculation in as-determined percentage can be seen below.

$$\%volatile\ content = \left(\frac{(wet\ weight\ - dry\ weight)}{wet\ weight} x100\%\right) - \%moisture\ content$$

ASTM E 830-87 standard method was used to determine the ash content. 1 g of sample was heated on the furnace with a temperature of 575ºC for 120 minutes. The formula for ash content calculation in as-determined percentage can be seen below.

$$\%ash\ content = \frac{(wet\ weight - dry\ weight)}{dry\ weight} x100\%$$

The fixed carbon percentage was calculated by subtracting volatile content and ash content from the total mass percentage of samples.

The calorific value was determined from direct measurement using Gallenkamp "Autobomb" adiabatic bomb calorimeter. The data will be displayed in kilo calorie per kilogram (kcal/kg).

High concentration of ammonia and volatile fatty acids in compostable organic fraction in the excavated waste could turn the materials into anaerobic, odorous, and develop toxic compounds. The stability of the soil like materials can be measured by respiration-based tests, such as carbon dioxide evolution or oxygen consumption tests. If the CO2 level decreases when incubated, the biological process were tend to be inactive.

Measurement of carbon dioxide soil was done by Verstraete method. Soil like material from excavated waste were weighed for 100gr then placed in a closed container and incubated at 70 C. Inside the sealed container was placed a bottle containing a solution of 5ml KOH 0.1N and 10ml pure water. It was incubated for 15 days and tested carbon dioxide levels every 3 days using back titration. CO2 concentration was calculated using following equation.

$$r = \frac{(a-b)x\ t\ x\ 120}{n}$$

For,

r = CO2 concentration (N)

a = ml HCL for soil samples

b = ml HCL for blank

t = normality of HCL

n = number of incubation days

RESULTS AND DISCUSSION

Figure 4 shows the characteristics of material composition in Piyungan Landfill. Each sampling shows significant difference in the composition percentage. Piyungan Landfill management do not have regular schedule for applying cover soils. It clearly shows on the varied amount of rocks and soils in the sample. Soils fraction also formed not only during cover soil application but also from the decomposition of organic materials. The composition of organic material, paper, textile, wood and plastic can be seen on figure 5.

In figure 5, the detail composition of combustible material is presented. It is necessary to understand deeper on the combustible material composition since energy recovery is one of strategy for processing landfill material. The organic fraction was more likely to be found on the top layers. As we dig deeper, the number of hard fiber materials such as wood and textile were found. The number of textile waste was mainly from leather home industries in the city. Since they are

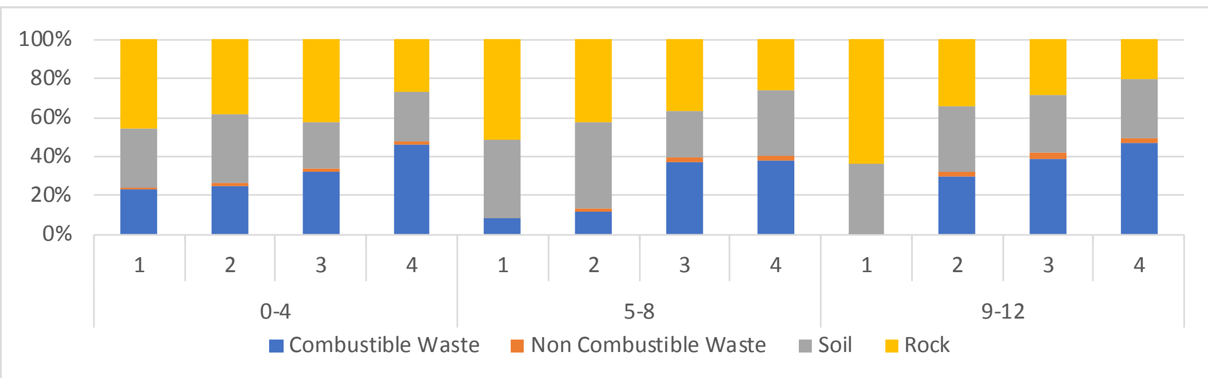

Fig. 4 Piyungan Landfill Excavated Material Characteristics

home industries, they don't have capability of industrial waste processing.

The changes of the moisture, volatile, ash and fixed carbon content in the different depth is shown in figure 6. Figure 6 present the average proximate analysis of excavated materials. Significant changes could be seen for volatile and fixed carbon content. The amount of volatile tend to decrease as we reach deeper. On the other hand, fixed carbon content was increasing in the deeper layer. Biological process in the landfill play bigger role in this phenomena. In the top layer of the landfill, aerobic process happened which breakdown higher chain carbon compounds into smaller one. In the middle layer, between the aerobic zone and anaerobic zone, hydrolysis and fermentation happened. It releases ammonia and acids which contribute to higher volatile content. Going deeper in the landfill, methanogenesis takes place and converts remaining carbon compound into fixed carbon and releasing methane. This explain the higher fixed carbon content in the deepest layer. In terms of fuel utilization, based on RDF quality standard in European country, the moisture content was still comply with the standard. However, the ash content has highly exceeds the standards (>40%) where the standard require RDF to have maximum ash content of 20%.

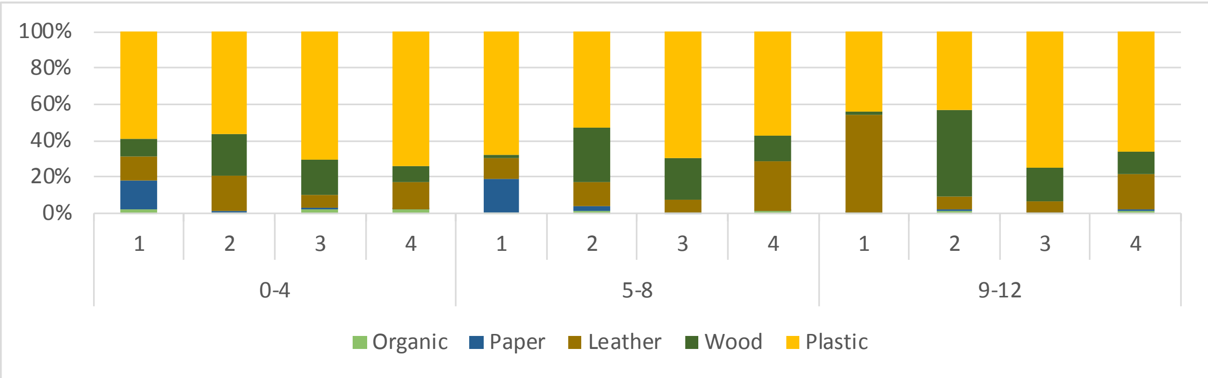

Fig. 5 Detail Composition of Combustible Materials

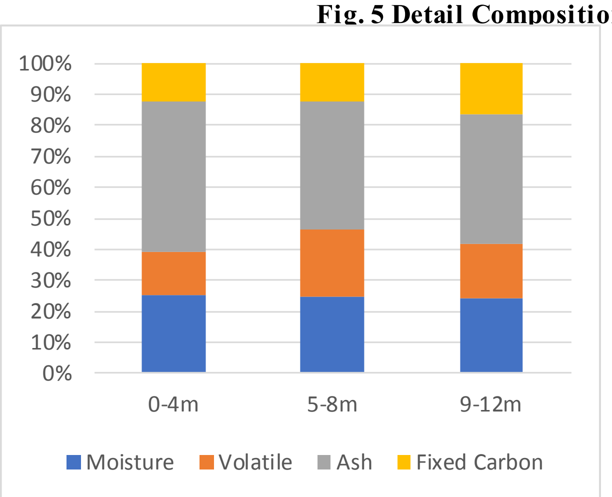

Fig. 6 Proximate Analysis of Excavated Waste

Table 1 Calorific Value of Combustible Fraction

Depth	Calorific Value (kcal/kg)
0-4 m	1595.34
5-8 m	1788.31
9-12 m	2361.66

Table 1 shows the results from bomb calorimeter.

The calorific value is increasing from 1595.34 kcal/kg to 2361.66 kcal/kg as we going deeper inside. It correspond to the proximate analysis results which have higher fixed carbon in the deepest layer. The fixed carbon plays the main role for increasing the calorific value. It also have 4 times bigger factor than volatile matter in the correlation formula of proximate analysis and high heating value (Parikh, Channiwala, & Ghosal, 2005).

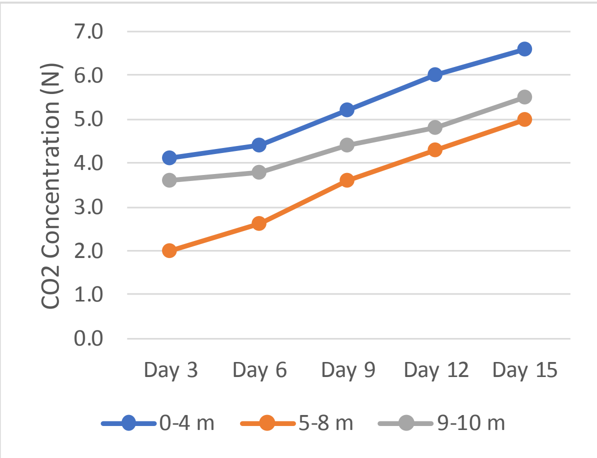

Fig. 7 Stability of Soil-like Material from Landfill

As seen on figure 7, after 15 days of incubating, the concentration of CO_2 is still increasing and did not shows any chance of stagnating or decreasing. This phenomena was caused by high microbial activity which is also mean that the soil was unstable. Raw material from landfill tend to have high microorganism activity because waste degradation process in the landfill was mainly the work of aerobic and anaerobic bacteria. The bacteria breakdown high carbon chain and releasing CH_4, CO_2, H_2S, ammonia, acids and also other smaller carbon chain compound.

CONCLUSIONS

As one of developing country with high GDP growth rate, Indonesia pose another great challenge in managing their environment, waste. High economic and consumption growth also lead to waste management problem. Jogjakarta as one of the big city in Indonesia only rely on Piyungan landfill until now. Landfill mining and re-utilize the excavated material may not only help to reduce the environment burden of the landfill area, but also bring profit to the locals. With heating value ranging from 1595-2361 kcal/kg, the combustible fraction could be co-combust with coal in the power plant. High ash content might become a problem during the operation, which is call for pre-treatment process before utilization. Hydrothermal treatment could be one of the feasible solution to reduce the ash content and homogenize the feedstocks. The plastic and biomass will agglomerate during hydrothermal process and the ash precursor fraction will be washed.

Although the soil-like material was still unstable, it could be use as enhancer for composting. Yogyakarta City produces high amount of organic waste from its traditional market. Mixing excavated soil with fresh organic waste to fasten the composting process produces higher quality compost and could be use in city gardens.

ACKNOWLEDGMENT

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SUSTAINABLE AND EFFECTIVE LANDFILL MONITORING BY UAV (UNMANNED AERIAL VEHICLE) IN MICRONESIAN REGION

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ABSTRACT

Micronesian countries face severe challenges such as limited resources, remoteness and vulnerability to natural disasters. These unique constraints include solid waste management as a major concern for Micronesia over recent decades. With regard to landfill sites, these countries have struggled with landfill monitoring, including lifetime estimation, which is essential for sustainable management, and conventional surveying can be burdensome in both time and cost, aside from the safety of the surveyors. To tackle these issues, this study applied photogrammetric techniques by using a UAV and conducted 3D mapping to estimate the remaining capacity of a landfill site on Majuro Atoll in the Marshall Islands. A portable UAV, a phantom 4 pro, was used to deliver a structured aerial mission, flown along a programmed route and shooting aerial photos at each waypoint from 50 m in height. After developing the 3D point cloud from the obtained images, the remaining capacity of the landfill site was estimated as 35,143m^3, if the waste is to be piled up to 30 m above sea level. This provides a lifetime of 2.8 years, based on the incoming waste amount survey. The result of this study shows that photogrammetric techniques using small UAV offer a highly workable solution to sustainable landfill monitoring for such a small island country.

Keywords: Photogrammetry, Unmanned aerial vehicle (UAV), 3D point clouds, Lifetime estimation, Landfill management

INTRODUCTION

Municipal Solid Waste (MSW), which includes all wastes generated within a municipality, are an inevitable by-product of human activity (Letcher and Vallero, 2011). Management of MSW is considered as a critical issue in most developing countries since waste contributes substantially to degraded environments and deteriorating human health (Adeel et al., 2012). Developing countries have faced a daunting challenge with effective waste management in recent decades due to the increase in waste associated with growing populations, urbanization and industrialization (Korai et al., 2017).

Micronesian island countries, a group of small island developing states, have had considerable difficulty with MSW, where unique constraints exist such as limited resources, remoteness and vulnerability to natural disasters. With regard to landfill siting, the shortage of, and traditional ownership of, land results in difficulties of land acquisition for landfills in this region. They have struggled with finding new sites for waste disposal before the quantity of MSW in existing landfills reaches maximum capacity, and so are required to prolong the life-span of existing landfills. For this reason, to accurately estimate the capacity of existing landfills is very important in order to implement sustainable management.

Conventional survey methods using total station or GPS devices have been applied for landfill monitoring at a practical level, but can be burdensome to landfill management in time, as well as costly and challenging for the safe operation of the surveyors. Some researchers have developed statistical models for life-span estimation to overcome the disadvantages of the classical way (Kalantarifard and Yang, 2012). Although the models produced in their studies are applicable for long-term planning, they are unsuitable for countries which lack temporal and historical data on MSW, and a clearly deliniated, engineered landfill.

In recent years, considerable attention has been paid to research methods using Unmanned Aerial Vehicles (UAV) in a variety of fields such as agriculture, forestry, disaster management and civil engineering (Siebert and Teizer, 2014), and even in studies of waste management (Gasperini et al., 2014). UAV systems have multiple advantages of low cost, speed, maneuverability and safety for collecting images, compared with satellites and manned vehicles, which may have low flexibility and high cost for aerial imagery (Siebert and Teizer, 2014). This research was aimed at estimating the remaining capacity of a current landfill site in the Marshall Islands, one of the Micronesian countries, applying photogrammetric techniques using a UAV.

METHODOLOGY

Study Area

The Republic of Marshall Islands (RMI) is located in the Central Pacific Ocean between 4º and 14º North and 160º and 173º East, and the total number of islands and islets in the RMI is about 1,225. The survey in this study was carried out on Majuro Atoll, which has the largest city and is the capital of the RMI, in May 2018. The only public disposal site is operated by Majuro Waste Atoll Company (MAWC), and is of approximately 1.6 ha on private land at the border between Batkan and Jable villages. Waste is discharged on to a concrete pad at ground level, then the waste is loaded with an excavator and piled up on to the top of the waste mountain. Wastes such as green waste, scrap iron and other fractions are diverted to other piles by the supervisor, but no compaction work is carried out on the main pile by any heavy equipment.

The largest waste pile in this landfill, being the general waste, is called “Mt. Batkan” as it is the highest point on Majuro Atoll. This mountain was targeted for lifetime estimation as it is the largest area of the landfill operation.

Flight Plannning

A small UAV, the Phantom 4 Pro (DJI, China), is equipped with a 1-inch CMOS sensor, four directions of obstacle avoidance, a 30-minute flight time and a 7 km transmission range. This light-weight quadcopter was used to achieve a structured aerial mission at the landfill site: all waypoints for the aerial shooting were pre-designed with Ground Station Pro, which is a free application distributed by DJI, working with an iPad (Apple, USA) used as a monitor for the UAV. The quadcopter flew automatically along the programmed route and shot images at each waypoint from a height of 50 m. The front overlap between two consecutive images captured along the main path was set to 80 %, and the side overlap on two parallel main paths was 70 %.

Image Processing

The Pix4D Mapper, an advanced photogrammetry software, can create 3D point clouds which is a set of data points in space, being orthomosaic, which is a geometrically corrected image. This professional mapping software was applied for developing an orthomosaic image with contour lines and generating 3D point clouds to acquire essential data for volume calculation, using aerial images taken by the mission.

Volume Calculation

After image processing, 2-dimentional polygons tracing the area of landfilled waste were built on the orthorectified image in the QGIS, a free and open source GIS software. Four different types of z-axis value, from 15 m to 30 m at five meter intervals, were attached to the generated polygons with Cloud Compare, a 3D point cloud and mesh processing software, in order to produce 3D models with a 1:1 slope simulating future shapes of the landfill at each level. The built-in function of the software calculated the difference between the future model in each height and the generated point clouds of existing landfilled waste.

The remaining lifetime of the current landfill was eventually estimated based on the following formula:

$$\frac{A}{B \times C \times D}$$

A: Calculated capacity at each level (m^3)

B: Incoming waste amount (ton/day)

C: Density of the landfilled waste (ton/m^3)

D: The number of days in a year (day/year)

The daily incoming waste amount disposed on to the waste pile (B) is identified as about 34 ton per day on average, based on the incoming waste amount survey conducted in July, 2017 (unpublished).

The density of the landfilled waste (C), stated above, is affected by various factors, including waste composition, compaction intensity, and duration of decomposition. It is defined as 1 ton/m^3 in this study, as a result of our experience in previous surveys in developing countries (unpublished) and in consideration of the current situation at the landfill site.

RESULTS AND DISUCUSSION

Image Acquisition

The aerial photography of this survey was conducted during three flight missions; the total allowable number of waypoints of any one mission is less than 100 points in the flight planning application. Table 1 shows the total number of waypoints programmed in the application, and the number of images acquired from each flight. As can be seen from this table, the UAV cannot capture images at all of the set waypoints during the mission.

Table 1. Comparison between the number of programmed waypoints and acquired images.

Flight No.	Programmed waypoints	Acquired images	Acquisition rate (%)
1	97	83	85.6
2	81	76	93.8
3	83	78	94.0

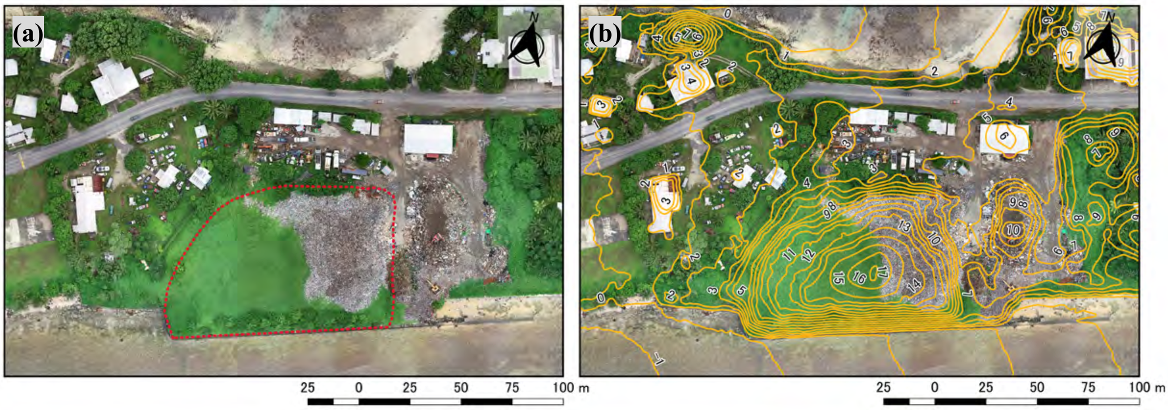

Figure 1. Orthomosaic map obtained from aerial images (a); and contour drawing from digital terrain model (b).

A previous study has noted that small UAVs are often easily affected by wind speed, aircraft posture, flying height and other factors, whilst they have good mobility, high efficiency and other advantages (Wei et al., 2017). Consideration of those features is important to achieve good image acquisition when aerial shooting using small UAVs.

Figure 1(a) shows the orthomosaic image of the landfill generated from a total of 237 aerial photos obtained by the UAV, where the area marked in red roughly illustrates the landfilled area of MSW. This image is high resolution, as the Ground Sampling Distance (GSD), the distance between two consecutive pixel centers measured on the ground, is 1.36 cm/pixel. Observing the contour lines drawn in Figure 1(b), the highest elevation of this landfill was found to reach about 17 m in height from sea level. Piling-up operation without compaction in a limited area results in this waste mountain being the highest point in both Majuro Atoll and the entire country.

Lifetime Estimation

The Pix4D Mapper generated 3D point clouds shown as Figure 2 which consist of 35,771,279 points in total, 1193.46 points per m^3. As a result of the volume calculation from the 3D point clouds, the total amount of landfilled waste above sea level is 73,410 m^3. In order to extend the lifetime of the landfill, the outline of the waste pile needs to be reshaped into a 1:1 slope using heavy equipment such as bulldozers, since the current operations are just piling incoming waste up to the top of the mountain using an excavator.

Using the generated 3D data, the capacity of the landfill was calculated at different height levels in the 1:1 slope condition, and then the lifetime of the landfill was estimated based on the formula mentioned in the methodology section above. The calculation result is shown in Figure 3. If waste is loaded up to 15, 20, 25 and 30 m high, the lifetime is determined as 1.2, 2.2, 2.7 and 2.8 years, respectively. As this figure shows, the

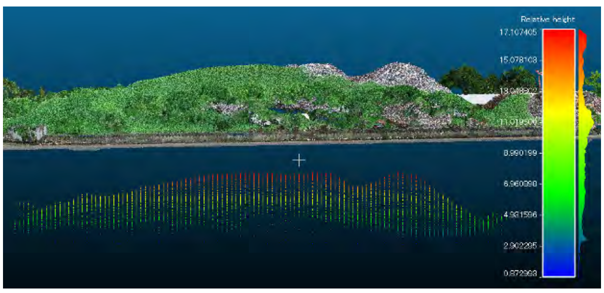

Figure 2. The generated 3D point clouds of the current waste mountain. The colored bar indicates relative height of this model.

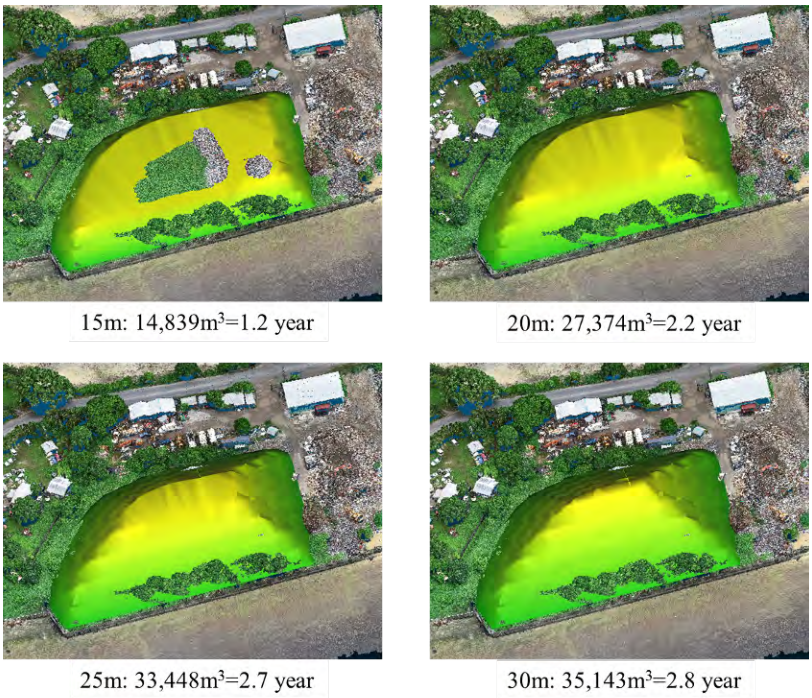

Figure 3. The results of volume calculation and lifetime estimation at each level (15, 20, 25 and 30 m high).

current landfill site can be used for only another 2.8 years even where waste is piled up to 30 m in height, along with a reshaping operation. It means that a new final disposal site will have to be found, and constructed, within about 2 years, or by the end of 2019.

CONCLUSIONS

The purpose of this study was to reveal the remaining capacity of the landfill in Majuro by means of photogrammetry techniques using a small UAV and 3D point cloud analysis by SfM software. The results obtained indicate that the method applied in this study is a highly workable solution to lifetime estimation compared with other conventional methods, since all processes required took less than a week, and the deliverables have a very high quality, for example 1.36 cm/pixel of ground sampling distance. What is notable is that the necessity for the future management of the landfill using 3D data is carried by a strong message to the relevant authorities because it is easily and visually understandable. This method greatly assists stakeholders to build a consensus on waste management, such as planning for safe closure of the current disposal site, and a decision on constructing a new disposal site. Future work may focus on periodical building of 3D point clouds at the same location to validate this lifetime estimation, and to monitor changes of landfill shape, through using these small UAVs for sustainable landfill management.

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STUDY OF VARIATION IN LANDFILL GAS EMISSION FROM A CLOSED SYSTEM DISPOSAL FACILITY USING A CHAMBER METHOD

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ABSTRACT

In this study new approach to measure aggregate landfill gas emission was validated. The Landfill site for this field investigation was a closed system disposal facility equipped with a roof which discharge natural rainfall and prevents the litter from scattering. The building of the facility is regarded as a big chamber in which gas concentrations will change depending on the gas emission from the surface of a landfill, and inflow and outflow of air through holes in it. Hence, the landfill gas emission rate was determined by fitting monitored data to the equation of gas volume and mass balance. In order to validate the measuring error of the chamber method using a roof of the facility, methane gas was artificially introduced at the set flow rate. The difference between set value (0.168 mol/min) and observation was around 0.01 mol/min. Despite small error of this chamber method, the variation of CO_2 gas emission at this site was up to 0.13 mol/min for 1 day. The relationship between the aggregate gas emission and the atmospheric pressure was not observed, although they ranged from 969 hPa to 989 hPa. it was considered that other factors affected the change of gas emission at this investigation.

Keywords: landfill gas emission, Closed System Disposal facilities, Chamber method, Atmospheric pressure, Temporal Variation

INTRODUCTION

Landfill gas generation indicates the degree of biodegradation of organic matter in a waste layer, thus landfill gas monitoring is conducted to determine the end of the aftercare. Gas emissions have been measured at the particular point of landfill, e.g. an outlet of gas venting pipe, cracks, and a surface by means of static chamber method. On the other hand, Aggregate gas emission from the whole of landfill surface has also been investigated, that is essential to recognize representative landfill gas emission from the spatial heterogeneous surface. In this study, a closed system final disposal facility was used as a big chamber for quantification of the aggregate gas emission from the whole surface of the landfill area. The objective of this study is to quantify the error of this method and the temporal variation of landfill gas emission.

Method of filed investigation

Landfill site

The landfill site for this filed investigation was a closed system disposal facility which has a roof to prevent natural rainfall from infiltrating into the waste layer and the litter from scattering. The height of roof from ground is approximately 5.2 m. The facility is equipped with fans and air inlets for ventilation, also windows and lights. To flash pollutions in landfill layer, water is supplied on the surface of landfill by using sprinklers. Landfill gas is released from the facility through the gas vent pipe and the ventilation system. Gas vents are out of the building.

Municipal solid waste incineration residues and shredded non-combustible wastes which include plastics and textile were disposed into this landfill site. These wastes are not covered with daily and intermediate soil cover. The maximum depth of the landfilled waste is approximately 5 m and the total area is approximately 900 m^2.

Methane gas almost has been not emitted from the surface in this site.

Measurement and quantification of the aggregate gas emission from the whole surface

The investigations were conducted on 31th October, 23th and 24th November, and 15th December. The big chamber method was applied to calculate the aggregate gas emission from the whole surface in the site. In this method, the building was regarded as a chamber, concentration of methane and carbon dioxide gas were measured at 1.0 and 5.2 meters above the surface of waste at 3 points (see Figure 1) by using a potable gas analyser (CGT-7000, SHIMADZU). It took 30 minutes on average for a round of measurement at the 3 locations. Before the measurements of gas in the building, it was ventilated and closed, and the gaps between shutters and ground and like that were sealed as much as possible.

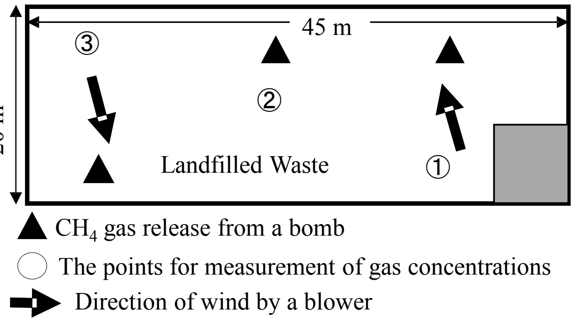


Figure 1 Schematic of landfill and points for measurements

For quantitation of aggregate gas emission, gaseous mass balance equation (1) for methane and (2) for carbon dioxide, and gaseous volume balance equation (3) were solved in assumption of steady gas emission and inlet and outlet flow through the holes in the building due to incompletion of sealing.

$$V\frac{dC_m}{dt} = C_{m\_in}Q_{in} - C_mQ_{out} + G_m \cdots (1)$$

$$V\frac{dC_c}{dt} = C_{c\_in}Q_{in} - C_cQ_{out} + G_c \cdots (2)$$

$$Q_{out} = Q_{in} + \frac{RT_gG_c}{P_g} + \frac{RT_gG_m}{P_g} \cdots (3)$$

Where, V is the volume of the space in the facility (6,184 m^3), Q_{in} is a gaseous inflow rate, Q_{out} is a gaseous outflow rate, C is landfill gas concentration, C_{c_in} and C_{m_in} are carbon dioxide and methane gas concentration in the inflowing-gas, G is landfill gas emission from whole surface of waste layer, R is 8.314 Pa m^3 mol^{-1} K^{-1}, T_g is the average of temperature in the facility during the measurement, P_g is the average of atmospheric pressure in the facility during the measurement, subscribe of c and m are carbon dioxide and methane, respectively.

Barometric pressure and temperature inside and outside the building were logged at the interval of 1 minuet during the investigation. Averaged wind velocity and the direction of wind were measured at 0.5 minuet interval.

Measuring error in the big chamber method

Methane gas was artificially released from the gas canister at three points (see figure 1), and the accumulated amount of released gas was measured with integrating flowmeter. Comparing the value of accumulated flow and that of the chamber method, the error of the method was calculated. The measurement for the concentration of gas inside the building is same manner above mentioned; in addition, two blowers (see figure 1) were used to accelerate mixing the gas.

RESULTS AND DISCUSTION

Meteorological conditions during the measurement by the method of the big chamber.

Figure 2 shows the temperature, barometric pressure and averaged wind velocity and the components of the wind in average during each measurement of aggregate landfill gas emissions by the big chamber method. The temperature inside the building tended to be higher than that outside although the difference between them might change by the weather. The temperature difference of inside and outside the building ranged

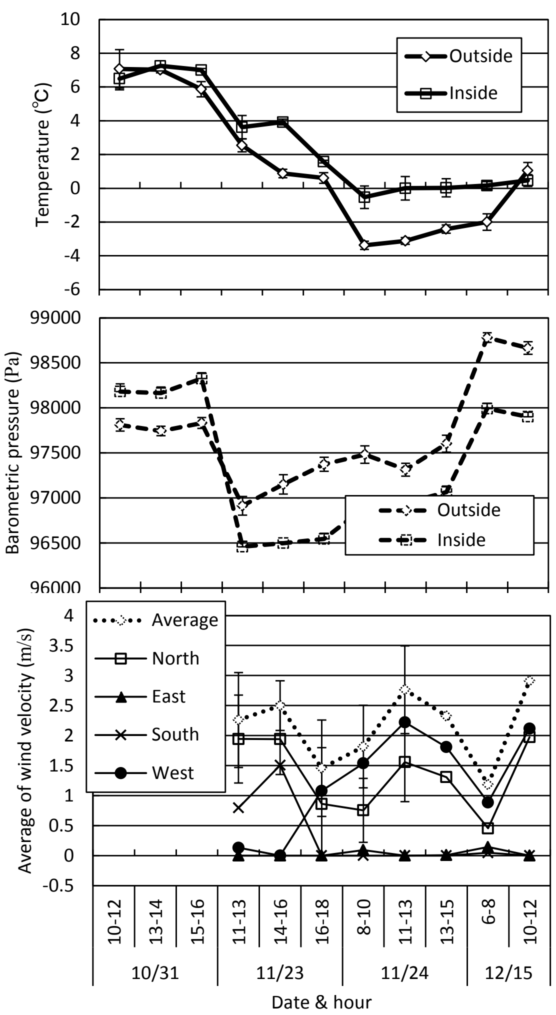
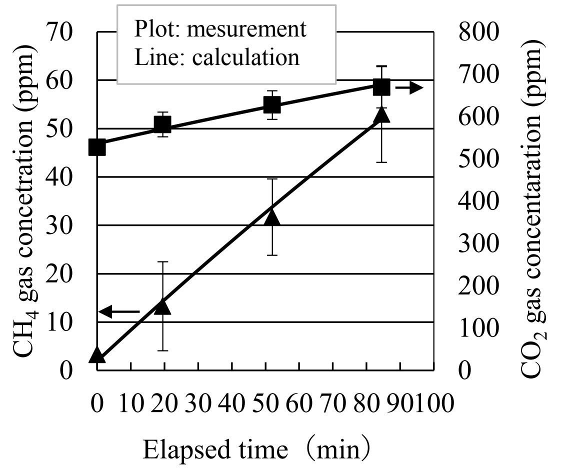


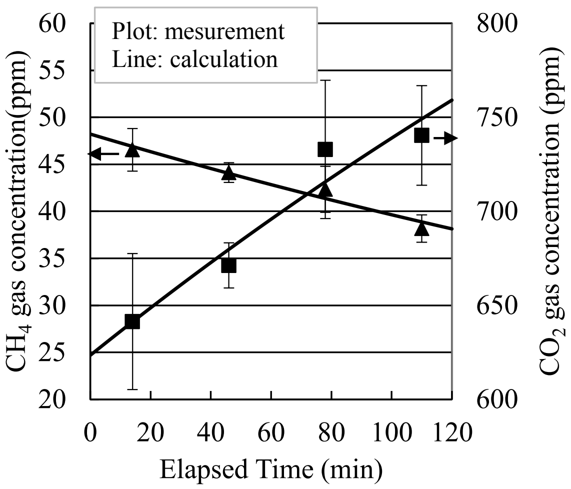
Figure 2 meteorological conditions during the measurement of aggregate gas emission by the method of the big chamber

from 0.6 to 3.1 Celsius degree, was particularly predominant when the temperature outside the building was low.

The barometric pressure inside and outside the building was the same changing in a day. These results show that the inside barometric pressures were mainly affected by atmospheric pressures. The standard deviation of the barometric pressure for 1-2 hours during the one measuring was several dozen. The difference of maximum and minimum barometric



a) During the artifical CH_4 gas release



b) After the stop of artificial CH_4 gas release

Figure 3 The change of the spatially and temporally averaged concentrations of methane and carbon dioxide gas during the big chamber method with or without artificial methane gas release.

pressure during all measurements of the aggregate gas emissions was approximate 18.7 hPa.

The averaged wind velocities were around 2 m/s during all investigations. North and south components of wind were remarkable at 2 times of measurements on 23rd November. At the other times, the remarkable components of wind changed to north and west.

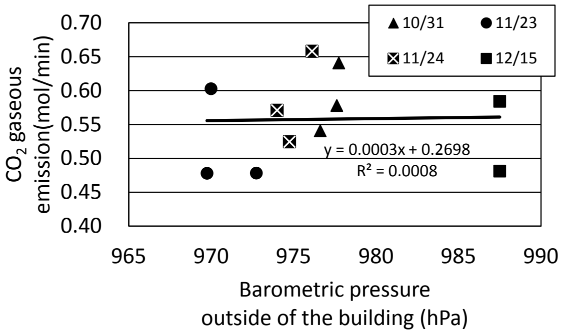


Figure 5 The relationship between the aggregate CO_2 gas emission and 10-minutes averaged barometric pressure before start of the big chamber method

Inflow rates and error of the big chamber method

Figure 3 shows the change of methane and carbon dioxide gas concentration at the averaged measuring time during the artificial release of methane gas and after the stop of it. The gas concentrations were averaged in the measuring points and the error bar in the figure indicated standard deviations. Spatially and temporally averaged concentrations of methane and carbon dioxide almost linearly increased, on the other hand, that of methane gas decreased after the stop of the methane gas release. These results and considering the small change of barometric pressure during the measuring indicated that the decrease of the methane gas concentration in the site was caused by the inflow and outflow of gas. As results of curve fitting for the concentration of both gases, the inflow of air from outside was estimated to be 13.1 and 14.5 m^3/min at two measurements on 15th December.

In the assumption of the steady inflow of gas into the building (above-mentioned values), the artificial emission rates were determined to be 0.180 and 0.155 by curve fitting for the increase of methane gas concentration (see figure 2). The difference of calculated rate and actual release rate was 0.013 and

0.007 mol/min.

Variation of the aggregate gas emission

Figure 5 shows the relationship the aggregate rate of carbon dioxide emission and the barometric pressure outside the building that was averaged for 10 minutes before starting the big chamber method. The negative correlation between barometric pressure and the emission rate of carbon dioxide gas was not observed. It was remarkable that the variation of carbon dioxide emission in a day was maximum, 0.13 mol/min, and was bigger than the error of the big chamber method. Czepiel (2003) reported the strong correlation between methane emissions and surface atmospheric pressure, however, Mcbain (2005) appeared that the barometric pressure was not most prominent factor affecting emissions of CH_4 on time-scales of weeks or months. In this investigation, other factors also influenced the daily and monthly variation of carbon dioxide emission from this site.

CONCLUSIONS

New approach of quantification of aggregate gas emission from the landfill was applied to a closed system final disposal site. The building in the site was used as a big chamber to measure the temporal change of gas concentration, then the fitting analysis was conducted to quantify the emission of carbon dioxide from the surface of landfill and inflow of air into the building. The error of this method was appeared to be around 0.01 mol/min by comparing known actual release rate with the quantified rate. In 13 times investigations for about 3 months, the correlation with the barometric pressure and carbon dioxide emission was weak. The daily variation was about 0.1 mol/min. the other factors influencing the emission of carbon dioxide should be clarified in the future.

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EVALUATION OF sUAS PHOTOGRAMMERTY ACCURACY FOR LANDFILL MAPPING

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ABSTRACT

2D and DSM (Digital Surface Model) maps are important information for the landfill maintenance and management tasks including landfill inspection, reporting, planning, and monitoring. The coordinates and height data are normally collected by traditional Global Navigation Satellite System (GNSS), triangulation, traverse, and levelling methods. However, in order to produce the high accurate results, these methods need more labor works and time. Recently, the Unmanned Aircraft Systems (UAS) photogrammetry is a disruptive technology for the mapping industry. In this study, the small UAS (sUAS) was used for landfill mapping. The objective of this study is to assess the photogrammetric mapping accuracy based on the variation of frontal overlap and side overlap. The frontal overlap and side overlap were varied between 80-90% and 75-90%, respectively. The Ground Sampling Distance (GSD) was set at 5 cm/pixel. Ground Control Points (GCPs) and Check Points (CPs) were established using GNSS technique. Ten points were used as GCP and twenty-five points were used as CPs with full 3D (XYZ) coordinates points. The collected photos and positions were processed in the Pix4Dmapper software for generating densified point cloud, digital surface model, digital terrain model, orthomosaic, and contour lines. The research output is evaluated for planimetry and vertical accuracy using root mean square error (RMSE). The results showed that flying with the 80% frontal and 75% side overlaps configuration gave the best planimetry and vertical accuracy. For the planimetry accuracy, the $RMSE_r$ of GCPs and CPs were 5.50 and 5.65 cm, respectively. In case of vertical accuracies, the $RMSE_Z$ of GCPs and CPs were 3.86 and 6.69 cm, respectively. Furthermore, summation of mean value accuracy, the $RMSE_T$ of GCPs and CPs were 1.34 and 1.75 cm, respectively. Finally, this study shows that sUAS is very useful platform for landfill mapping, if the high spatial resolution images are collected under the appropriate flight configuration.

Keywords: Landfill mapping, Drone, UAV photogrammetry, sUAS, Accuracy

observations (Messinger and Silman, 2016).

INTRODUCTION

Currently, solid waste disposal in most developing countries is still using open dumping and landfilling. Management and maintenance of solid waste disposal sites include various tasks such as landfill inspection, monitoring, reporting, and planning. In order to conduct the inspections and monitoring, the site inspectors have to spend a lot of their time for walking thought their sites by foot or they have to make the maps by using the traditional survey methods which the coordinates and height data are normally collected by traditional GNSS, triangulation, traverse, and levelling methods. These maps and spatial information can be used for tracking the landfill operation, estimating the remaining airspace, keeping sites close to the design, tracking and maximizing waste compaction density, evaluating the volume of daily cover in the stockpile, planning the stormwater and flood management, evaluating the gradient of disposal cells, as well as tracking the landfill operation over the timeline.

However, making the map with traditional methods is not safe for surveyors and no longer the most efficient methods because of sparse sampling and long times on site. Making the map by aerial survey using manned aircraft that has offered much better data and information, but at a very high cost. Currently, drone or UAS technology is used in many fields such as mapping, construction inspection, environmental monitoring, and precision agriculture. sUAS is becoming a valuable, cost effective tool for collecting high spatial resolution aerial images for photogrammetric analysis, particularly when compared to conventional airborne and space-borne sensor systems (Jurkofsky, 2015). Their rapid deployment and autonomous operation make them useful for routine observations (Messinger and Silman, 2016).

Nowadays, there are several Structure-from-Motion (SfM) software for carrying out 3D modelling of surfaces from taken photographs such as Pix4D Mapper, Agisoft Photoscan, and OpenDroneMap. SfM is a photogrammetric technique that automatically solves the geometry of the scene, the camera positions, and the orientation without requiring a priori specification of a network of targets that have known 3D positions. There are many factors that affect to the accuracy maps and 3D models obtained by UAS photogrammetry including flight altitude, terrain morphology, number of GCPs, frontal and side overlaps, and weather condition (Martínez-Carricondo et al., 2018).

If the number and distribution of the GCPs and weather condition are conducted appropriate, one of the factors with the greatest influence on the accuracy of the 3D model and orthophoto resulting from the photogrammetric process is the frontal and side overlaps. Therefore, the objective of this study is to assess the photogrammetric mapping accuracy of 3D models and orthophotos derived from sUAS photogrammetry based on the variation of frontal overlap and side overlap.

MATERIALS AND METHODS

Study site

The study area is located at Phatthalung landfill (7°35'09.7"N 100°08'54.1"E) in the South of Thailand (Fig. 1). The area of the study site was about 245 × 510 m, which covered 12.5 ha. Currently, there are about 30 tons of municipal solid waste that is landfilled each day. However, in the old landfilled waste part, the site is implementing the landfill mining process, which recovers the refuse-derived fuel for thermal utilization in cement plant.

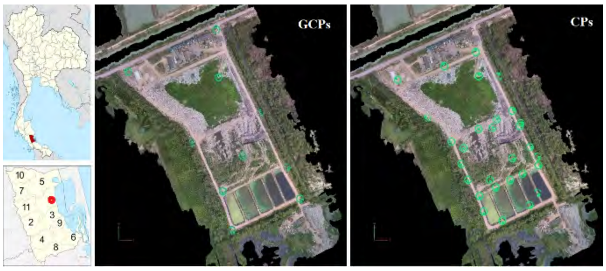

Fig.1. Location of the study area and the position of GCPs and CPs

Image acquisition

The images used in this work were taken from a very low-cost rotatory wing sUAS with four rotors (DJI Phantom 3 Professional). The sUAS was equipped with a motion compensated gimbal and a Sony EXMOR 1/2.3" CMOS camera with a lens with a fixed focal length of 20 mm. The resolution of the camera sensor was 12.0 megapixels (4000 × 3000).

The flight altitude was 114 m above ground level, which implies a surface of 200 × 150 m^2 covered by every photo and an equivalent GSD of 5.000 cm. The Pix4Dcapture application was used for creating the flight plans for all photogrammetric projects. This application was also used for flying and capturing image with the autonomous mode in all photogrammetric projects. In order to minimize the blurring effect, the hover and capture practice was used for each image acquisition.

Due to the main objective of this study that aims to assess the photogrammetric mapping accuracy based on variation of frontal overlap and side overlap under the fixed flight altitude and appropriate number and location of GCPs. The frontal overlap and side overlap were varied between 80-90% and 75-90%, respectively. There were 7 photogrammetric projects in this study as show in Table 1. According to the ASPRS standard, the number of static 3D check points in NVA is at least 20 points based on a project area with less than 500 m^2 (ASPRS, 2015).

Table 1 Flight configurations (FC)

Flight Configuration code	Frontal Overlap (%)	Side Overlap (%)	Number of captured	Number of GCPs	Number of CPs
FC1	80	75	180	10	29
FC2	80	90	359	10	27
FC3	85	75	184	10	29
FC4	85	90	462	10	29
FC5	90	90	647	9	25
FC6	85	85	282	9	22

Before the image acquisition, 10 targets for GCPs and 29 targets for Check Points (CPs) were scattered on the studied surface for the purpose of georeferencing (GCPs) and assessing the accuracy of the 3D model and orthophotos (CPs). The size of GCP which made from vinyl sheet was 1,200 × 1,200 mm) with black and white blocks inside. The green circle paper plates with the diameter 30 cm were used as the mark for all CPs. The locations of these targets are shown in Fig.1 and the GCP and CP are shown in Fig.2.

Fig.2. GCP and CP targets

Three dimensional coordinates of these GCP and CP points were measured with a GNSS receptor working in Real Time Kinematic (RTK) mode. Both rover and base GNSS receivers were CHC i80 systems. For RTK measurements, these dual-frequency geodetic instruments have a manufacturer's stated accuracy specification of ± 8 mm + 0.5 ppm horizontal RMS and

± 15 mm + 0.5 ppm vertical RSM.

Photogrammetric processing

The photogrammetric process was carried out using the Pix4D Mapper Pro - Educational, version 4.2.26. This Pix4Dmapper software automatically converts images taken by sUAS and delivers highly precise, georeferenced 3D models, maps, and mosaics. The Pix4Dmapper software is based on automatically finding thousands of common points between images. Each characteristic point in an image is called a key-point. When two key-points on two different images are found to be the same, they are matched and referred to as a "tie point." Each group of correct matched key-points will generate one 3D point (Wang et al., 2017).

Accuracy assessment

The typical RMSE formulation was used to evaluate the accuracy of all photogrammetric projects. The coordinates of CPs in orthoimages were compared to the surveyed GNSS coordinates, resulting in $RMSE_X$, $RMSE_Y$, $RMSE_r$, $RMSE_Z$, and $RMSE_T$, as defined in Eqs. (1)–(5), respectively:

$$RMSE_X = \sqrt{\frac{\sum_{i=1}^{n}(X_{Oi}-X_{GNSSi})^2}{n}} \quad (1)$$

$$RMSE_Y = \sqrt{\frac{\sum_{i=1}^{n}(Y_{Oi}-Y_{GNSSi})^2}{n}} \quad (2)$$

$$RMSE_r = \sqrt{\frac{\sum_{i=1}^{n}[(X_{Oi}-X_{GNSSi})^2+(Y_{Oi}-Y_{GNSSi})^2]}{n}} \quad (3)$$

$$RMSE_Z = \sqrt{\frac{\sum_{i=1}^{n}(Z_{Oi}-Z_{GNSSi})^2}{n}} \quad (4)$$

$$RMSE_T = \sqrt{(RMSE_{XY})^2+(RMSE_Z)^2} \quad (5)$$

Where:

-n is the number of CPs tested for each project.

- X_{Oi} and Y_{Oi} are the X and Y coordinates, respectively, measured in the orthophoto for the i^{th} CP.

- X_{GNSSi} and Y_{GNSSi} are the X and Y coordinates, respectively, measured with GNSS for the i^{th} CP.

- Z_{Oi} is the height in the i^{th} CP, derived from the DSM, taking into account its coordinates X and Y, measured on the orthophoto.

- Z_{GNSSi} is the Z coordinate of the i^{th} CP measured with GNSS.

RESULTS AND DISCUSSION

There are two parameters for accuracy investigation including GCPs and CPs. GCP is used for efficient georeferencing to check independent accuracy, and CP is used for project accuracy assessment (Eling, et al., 2015). Both parameters are shown in term of RMSEs of horizontal and vertical positions; RMSEs represents georeference reliability between tie points and ground distances. The $RMSE_x$ and $RMSE_y$ of both parameters in each flight configuration are shown in Fig.3. Most of GCPs were distributed at 10 positions, while some flight configurations, GCPs were located at 9 points. CPs were also distributed various positions and numbers as showed in the Table 1 and Fig.1.

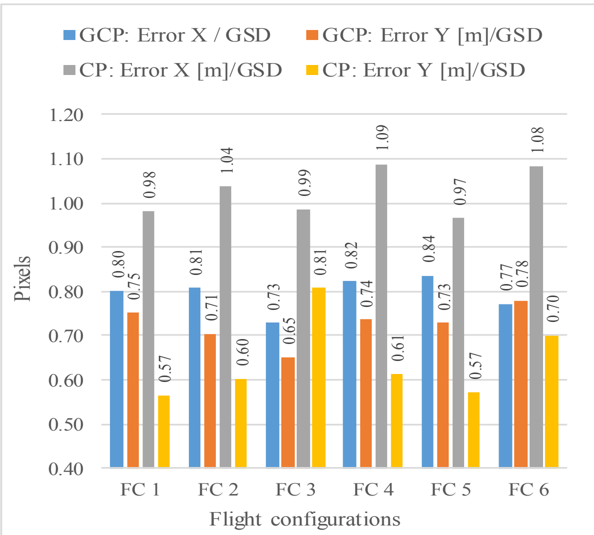

Fig.3. $RMSE_x$ and $RMSE_y$ of GCPs and CPs for each

flight configuration

According to the figure 3, $RMSE_x$ and $RMSE_y$ of GCPs were not more than 1 pixel in all flight configurations. Considering ASPRS Version 1.0-November 2014, those flight configurations were defined as a high accuracy work. However, there were three flight configurations with high accuracy based on CPs as the RMSEx and RMSEy were not exceed 1 pixel including FC1, FC3, and FC5, respectively. The others were defined as standard mapping.

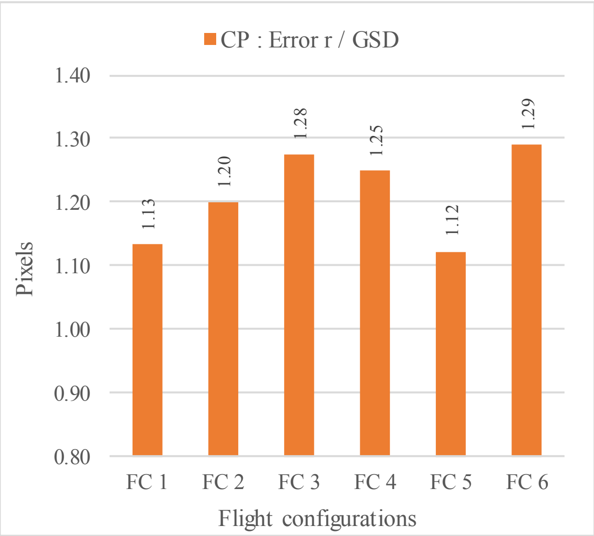

Fig. 4. RMSEr of CPs for each fight configuration

Fig.4 shows $RMSE_r$, which could refer to horizontal coordinate accuracy. The result was found that all flight configurations were less than 7.1 cm of $RMSE_r$, whereas three flight configurations were in the "5.0 cm - horizontal accuracy class" ($RMSE_r$ < 7.1 cm.) including FC1, FC3, and FC5, respectively. The others were in the "7.5 cm - horizontal accuracy class" ($RMSE_r$ < 10.6 cm.).

RMESz of GCPs in all flight configurations were less than 1 pixel, which implied a good georeferencing in all projects. Moreover, RMSEz could refer to vertical accuracy. From Fig.5, FC1-FC4 were in the "10 cm.- of vertical accuracy class", while FC5 and FC 6 were in the "15 cm. - vertical accuracy class". Hence, flying with the FC1-FC4 could generate OSMs with higher resolution.

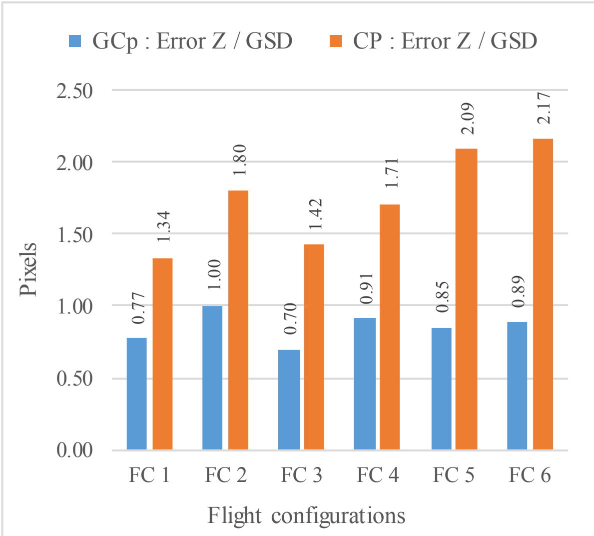

Fig.5. $RMSE_z$ of GCPs and CPs for each % of frontal over lap and side overlap

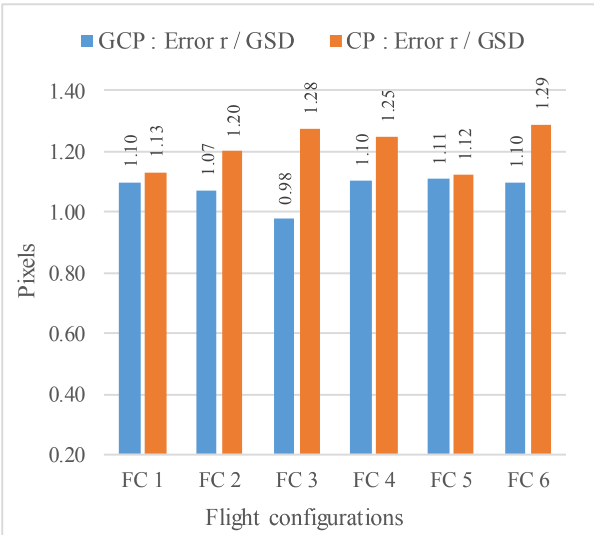

Fig. 6. Total $RMSE_T$ of GCPs and CPs for each % of frontal over lap and side overlap.

Table2. Summary of accuracy in all flight configurations

Flight configurations	Number of images	GSD (cm)	Digital orthoimagery accuracy (1)		Horizontal accuracy (2)						Vertical accuracy (3)					
			Higest accuracy work	Standard mapping and GIS work	Class $RMSE_x$ and $RMSE_y$ (cm)	$RMSE_r$ (cm)	Equvalent to map scale in ASPRS 1990				$RMSE_z$ NVA (cm)		Equvalentclass contour interval per ASPRS 1990 (cm)			
							Class 1		Class 2				Class 1		Class 2	
							1:200	1:300	1:200	1:150	10	15	30.0	45.0	15.0	22.5
FC 1	180	5	✓		5	7.1	✓		✓		✓		✓		✓	
FC 2	359			✓	7.5			✓		✓	✓		✓		✓	
FC 3	184		✓		5		✓		✓		✓		✓		✓	
FC 4	462			✓	7.5			✓		✓	✓		✓		✓	
FC 5	647		✓		5		✓		✓			✓		✓		✓
FC 6	282			✓	7.5			✓		✓		✓		✓		✓

[1] Digital orthoimagery accuracy is classified based on GSD

[2] Horizontal accuracy class is classified based on RMSEx, RMSEy and RMSEr of CPs

[3] Verticall accuracy class is classified based on RMSEz of CPs

According to Fig.6, RMSET was a factor measuring for the overall mean error of each project. The lower RMSET was gained, the higher precision was obtained, and the result showed that FC1 and FC3 are recommended to use as high accuracy mapping.

CONCLUSIONS

The results showed that the sUAS photogrammetry has high ability for making the 2D and DSM maps. Flight configuration accuracy can be determined by RMSE values. In order to identify the highest accuracy in each FC, the horizontal and vertical RMSEs including $RMSE_X$, $RMSE_Y$, $RMSE_{XY}$, $RMSE_Z$ and $RMSE_T$ of GCPs and CPs were interpreted.

Table 2 presented about digital orthoimagery accuracy, horizontal accuracy and vertical accuracy. The conclusions can summarize as following;

1. FC1, FC3 and FC5 were defined as highest accuracy work in digital orthoimagery

2. In a case of horizontal accuracy, FC1, FC3 and FC5 had more accuracy than the others, as reflected to the equivalent to map scale in ASPRS 1990.

3. The lower $RMSE_Z$ value in FC1-4 was found, the lower contour value was gained that lead to higher vertical accuracy.

4. FC1 and FC3 might recommend for sUAS photogrammetry in the landfills. Even, the FC5 has highest vertical accuracy than the others.

However, this FC cannot be recommended due to its longest processing times caused by the number of images (647 images). Considering RMSEs of CPs, the RMSE values in case of FC1 were completely lower than FC3. Therefore, the most suitable FC in this study was FC1.

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LCS SIMULATIVE CLOG OF MIXTURE OF DEWATERED SLUDGE WITH MSW LANDFILL

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Abstract

Dewatered sludge mixing with MSW to landfill is one of the main sludge disposal methods nowadays. Considering differences between sludge with MSW, Mixing process has influences on physical、chemical and biological properties of leachate which can accelerate the clogging of Leachate Collection System (LCS). Especially for quicklime dewatering process. Factors causing clog of LCS include particles sediment、biofilm growth、calcium compound precipitation. Considering the LCS clog mostly depends on properties of leachate. Research established a two-dimensional numerical model of LCS clog and take leachate properties of different scenarios as model parameters. Comparing the LCS clog in different scenarios, we find mixing MSW with quicklime dewatered sludge take the worst influence. LCS clogged time is significantly lower than other scenarios when mixture of MSW and quicklime dewatered sludge landfill. Based on "The Technical Specification for Sanitary Landfill Disposal GB 50689-2013", 1.0×10^{-7} cm/s is the permeability standard for judging the failure of LCS. Adding 8% sludge (20% quicklime addition) to MSW can shorten the LCS running time by 1/3. Adding 8% physical dewatering sludge to MSW can shorten the life by 1/5. We analyzed different clogged factors' proportion and find particles sediment is the main factor causing geotextile layer clogged, proportion is above 50%. Calcium carbonate Precipitation is the main factor causing gravel layer clogged, proportion is above 50%. Comparatively, influence of biofilm growth is not obvious.

Keywords：Sludge, Quicklime Dewatering, LCS, Porosity Clogging

INTRODUCTION

Sludge yield was rising sharply with the increase of the sewage treatment volume. According to statistics, the total designed sewage treatment capacity is 162 million m^3/d and 42 million 80% moisture content sludge was produced every year. The production of sludge is increasing and expected to break 60 million by 2020 (Zhang et al., 2007). As a derivative waste, sludge needs to be properly disposed. The main sludge disposal methods include composting、landfilling and incineration nowadays. Landfill will still be one of the major disposal mehods for a long time in the future considering both environmental and economic benefits (Singh et al., 2008). Because of the properties of high moisture content、strong water holding capacity、low permeability and high concentration of particles in sludge (Geenens et al., 2001). It will cause problems like hard to compact、forming a wetland after raining when landfilling which will furtherly cause instability of landfill site and landslide (Xie et al., 2010). Sludge must be pretreated before getting into landfill. The major methods for sludge pretreatment include physical and chemical dewaterin. Pressure filter is the mostly used physical dewatered method.(Mao et al., 2016). Adding quicklime、cement and coal ash to sludge is one of the most popular chemical methods (Yuan et al., 2003). Quicklime is undoubtly the most beneficial chemical from both technical and economic aspects (Wang et al., 2016). But whether the pretreated sludge is landfilled directly or mixed with MSW. Adding quicklime does have influences on the leachate. Firstly, quicklime will react with the water in sludge to form $Ca(OH)_2$ which will increase the calcium concentration in leachate. Secondly, high content of particles will increase the concentration of Total Suspended Solids (TSS) in leachate. Researches show that main factors causing the clog of LCS include: growth and attachment of biofilm (Rowe et al., 2015)、calcium and magnesium react with TIC in leachate to form the precipitated minerals (Rowe et al., 1998)、particles sediment (Maliva et al., 2000). Fleming et al. (2004) tested the components of clogged dry materials in a Germany landfill and Keel Valley Landfill which has been operating for 4 years in Canada and found that the proportion of calcium minerals exceeds 50%. Rowe et al. (2015) concluded that the physical clog caused by suspended particles reduced the porosity of the drainage system by nearly 24% by comparing the synthetic and raw leachate, this problem can not be ignored. Results of Bian et al. (2014) showed that particles were accounted for approximately 16-21% of the dry clogged materials. Brune et al. (1991) pointed out that the role of anaerobic microbial activities is crucial during the clogging process through both situ testing and waste column experiments. Zhang et al. (2018) found that for 70-86% moisture content sludge, when the adding proportion exceeds 50% to MSW, it can be only filled and not be piled up from the aspect of landfill stability. Valentina et al (2016) conducted a pilot study on the effects of degradation when sludge adding to MSW and found that sludge can accelerate the degradation process of organic materials and increase the gas production rate. But research on the LCS clogging when mixing sludge with MSW to landfill is insufficient nowadays.

We build a two-dimensional numerical model of LCS clogging and analyze the leachate properties of different pretreated sludge landfill scenarios directly and mixing with MSW to landfill. We take leachate properties as parameters and simulate differences of the clogged time and factors' proportion causing LCS clogged. From the aspects of slowing down the clogging of drainage system、prolonging the operating time, we give suggestions on sludge landfilling admission and sludge zoning landfill.

EXPERIMENT METHODS

Physical Model

When leachate passes through the LCS. The macromolecule organics in MSW will firstly decompose into small parts like VFAs. And microbial uses VFAs to grow and then form the biofilms which can be attached to geotextile and gravel layers. Besides Total Inorganic Carbon (TOC) including carbonate、carbonic acid、bicarbonate will be produced through microbial degradation. The proportion of different parts will change with the leachate pH. Calcium will react with carbonate to form insoluble materials and they will precipitate to surface of LCS. Meanwhile biofilm will connected with each other to form a net which can give a detention of particles. These three parts will cause the decrease of porosity and permeability of LCS which will cause the clog of LCS and then form a high water head in landfill body. This research builds a two-dimensional numerical model as showed in Fig 1 to simulate the LCS clogging process based on processes mentioned above (Masada et al., 1998).

According to the standards of "Urban Domestic Waste Sanitary Landfill Technical Specifications (GB 50869-2013)". The thickness of non-waven geotextile is 2 mm, the equivalent porosity is 0.9, the initial permeability is 10^{-3} m s^{-1}. The thickness of gravel layer is 300 mm, the diameter of gravel is 20 mm, the initial porosity and permeability is 0.36、0.037 m s^{-1} respectively. The slope the drainage pipe is set to be 2% and the length between two pipes is 25 m according to researches (Wan et al., 2008). The main drainage pipe is regarded as open border and the diameter of pipe is 10 cm. The upper border is in-flux and the remaining boundaries are regarded as no flux.

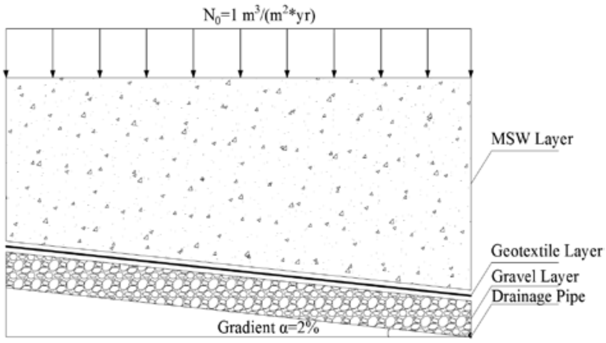

Fig 1 Schematic of two-dimensional numerical simulation model of LCS

Mathematic method

The establishment of the mathematical relationship is based on the clogging process and physical model of the LCS mentioned above. Relative formulas are as followings:

Equation of water flowing:

The clogging of LCS will accelerate the accumulation of upper leachate and cause the change of free head. In order to avoid the fluctuation caused by change of boundary, this research uses saturation and non-saturation seepage model to simulate the water flow in LCS (Richards et al., 2004). Pressure head h is regarded as dependent variable in Formula (2-1).

$$C(\theta)\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(K_{xx}(h)\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial z}\left(K_{zz}(h)\frac{\partial h}{\partial z}\right) + \frac{\partial\left(K_{zz}(h)\right)}{\partial z} + W \tag{2-1}$$

In the formula, h is pressure head (m). θ is moisture content, dimensionless, ranges(0,n). n is porosity, dimensionless. K(h) is tensor of hydraulic conductivity under non-saturation status (m s^{-1}). W is the source and sink items. C(θ) is the water content. Besides, t is the operating time. x、z represent horizontal and vertical direction respectively. Relationship between hydraulic conductivity and saturation can be described by Ven-Genuchen formula (Genuchten et al., 1980; Khire et al., 2007), they are as followings:

$$\theta = \theta_r + S_e \times (\theta_s - \theta_r) \tag{2-2}$$

$$S_e = \frac{1}{(1+|A\times H_p|^N)^M} \tag{2-3}$$

$$K_{(h)} = K_s \times S_e^{\frac{1}{2}} \times \left[1 - (1 - S_e^{\frac{1}{M}})^M\right]^2 \tag{2-4}$$

In the formula, θ_r is residual saturation and θ_s is the volumetric moisture content.

Contaminate migration and transformation Equation:

The mass change in process of pollutants migration and transformation are mainly from three parts: diffusion、convection、source and sink functions (Ahfir et al., 2007; Mobedi et al., 2010). We analyzed the pollutants mass change caused by effects mentioned above and combine the Fick-Law (Paradisi et al., 2001), the control equation including the source and sink items is as following:

$$\frac{\partial nC}{\partial t} = \frac{\partial}{\partial x}\left(nD_{xx}\frac{\partial C}{\partial x} + nD_{xz}\frac{\partial C}{\partial z}\right) + \frac{\partial}{\partial z}\left(nD_{zx}\frac{\partial C}{\partial x} + nD_{zz}\frac{\partial C}{\partial z}\right) - \frac{\partial nu_x C}{\partial x} - \frac{\partial nu_z C}{\partial z} + I \qquad (2\text{-}5)$$

Model of Particles Sediment:

Adsorption coefficients of gravel and geotextile layers are defined respectively as Katt_g、Katt_f, the formula are as followings：

$$K_{att,g} = \varphi_g \frac{3(1-\eta_g)}{2d_g} V_a \qquad (2\text{-}6)$$ $$K_{att,f} = \frac{-\ln(1-\eta_f)}{a} \times u$$

(2-7)In the formula, η_g is the capture efficiency of gravel layer; φ_g is spherical filter collection efficiency，range (0,1); d_g is the diameter of porous media; Va is Darcy velocity. Considering the speciality of geotextile, there is not enough research on capture efficiency η_f. Liu et al. (2018) has done leaching experiments by using fresh leachate from waste transfer station to rectify the different detention efficiency of leachate particles of different diameter range in geotextile, so the value η_g is from the research by Liu et al. (2018).

VFAs degradation and biofilm growth model:

There is high content of microbials in landfill and the biodegradation is also intense (Visnja et al., 2012). VFAs is regarded as the source of microbials degradation in the model which is described by first-order kinetic equation. Meanwhile we use Monod equation to describe the process of biodegradation (Qin et al., 2006; Merchuk et al., 2012), Formula is as following：

$$\frac{dC_{VFA}}{dt} = -Mh_u\left(\frac{C_{VFA}}{K_c + C_{VFA}}\right) \qquad (2\text{-}8)$$

In the formula, C_{VFA} is the VFAs concentration in the liquid phase. M is the active microorganisms concentration in the liquid phase. h_u is microbial degradation capacity constant which represents the maximum mass of VFAs that can be degraded per unit of active microorganisms mass per unit time. K_c is the half-saturation constant during the VFAs degradation. The values of parameters is referenced by related researches （Zhou et al., 2014; ）. Three representative acids including Acetic Acid、Propionic Acid、Butyric Acid are input as model parameters (Rowe et al., 2012).

Distribution of carbonate and Ca^{2+} precipitation model:

The proportion of H_2CO_3、HCO_3^-、CO_3^{2-} in the water phase is influenced by pH, and the relation formula of CO_3^{2-} in TIC (Huang et al., 2009) is as following:

$$r_2 = \left(1 + \frac{[H]}{K_1} + \frac{[H]}{K_2}\right)^{-1} \qquad (2\text{-}9)$$

In the formula, [H] is the mole concentration of hydrogen ion in the water, $[H]=10^{-pH}$. K_1，K_2 is ionization equilibrium constant of carbonate and bicarbonate respectively and the value is $K_1=4.2\times10^{-7}$ [mol/L]，$K_2=4.7\times10^{-11}$ [mol/L] (Patterson et al., 1982). Research by Yi et al. (2018) showed that VFAs is the main source of hydrogen ion which can be approximately regarded as: pH rises by 10% while VFAs concentration reduces by 30% (Liu et al., 2018).

$$I_{Ca} = \theta \times \frac{\partial C_{Ca}}{\partial t} = \theta \times \frac{r_2 \times C_{Ca} \times C_{TIC} - K_{Sp} \times (C^{\Theta})^2}{r_2 \times C_{TIC} \times \Delta t} \qquad (2\text{-}10)$$

Calcium can combine with carbonate to form the insoluble $CaCO_3$. Experiments verify the $K_{sp}=1.01\times10^{-6}$ [mol/L]. It is assumed that all precipitated $CaCO_3$ is on the surface of the gravel and stay inner of porous media and the already precipitated $CaCO_3$ can not be back to the liquid phase for the sake of calculation.

The coupling relationship of all multiphysics:

The factors causing the clog of LCS have been mentioned above. The formula of porosity of media is as following：

$n = n_0 - n_p - n_M - n_{Ca}$ (2-11)In the formula, n_0 is the initial porosity of porous media. n_p is the porosity clog caused by particle sediment. n_M is the porosity clog caused by biofilm growth and accumulation. n_{Ca} is the porosity clog caused by $CaCO_3$ precipitation. The formula of porosity clogging of every parts is as followings: Porosity occupied by particles ： $n_p = \frac{C_s}{X_p(1-\varepsilon_p)}$. Porosity occupied by biofilm growth and accumulation： $n_M = \frac{M}{X_M(1-\varepsilon_M)} + \frac{M_r}{X_{M.r}(1-\varepsilon_{M,r})}$. Porosity occupied by precipitation of $CaCO_3$：$n_{Ca} = \frac{C_{s,Ca}}{X_{Ca}(1-\varepsilon_{Ca})}$. The relationship between the permeability K and porosity n of porous media can be described by Kozeny-Carmen equation as for geotextile (Mitchell et al., 2005; Zhang et al., 2017), the formula is as following：

$$K_t = K_0 \frac{n^3}{(1-n)^2} \times \frac{(1-n_0)^2}{n_0^3} \qquad (2\text{-}12)$$

The relationship between saturated permeability and porosity can be described by exponential equation as for the gravel layer：

$K_{tg} = K_a \times e^{n \times K_b}$ (2-13)In the formula, K_{tg} is gravel layer permeability of t time, [LT^{-1}]. when porosity n > 0.21, K_a=9.8×10^{-6} (m s^{-1}), K_b=22.9. when porosity n < 0.21, K_a=2.4×10^{-8} (m s^{-1})，K_b=51.0 (Yu et al., 2012).

Solve method of model

The FEM is applied to slove the physics of migration of leachate. The Partial Differential Equations (PDE) is applied to solve the physics of the growth and accumulation of active/inert biofilm、precipitation of particles and calcium carbonate. Software Comsol Multiphysics 5.2a is applied to mesh (Li et al., 2009), and MUMPS is used to coupling multiphysics and calculated by time step. Time step is set to be 0.001d initially and 1d in the late period.

Results and discussion

Set of parameters

We conduct the leaching experiment of different scenarios, the leachate properties from all scenarios are tested and results are set to be the input parameters of the model. The monitoring indicators include： concentration of TSS、distribution of particle size、pH value concentration of TIC、VFAs and Ca^{2+}. Five scenarios are set (number #1、#2、#3、#4、#5 in graph), the specific landfill material and proportion is in Table 1..

Table 1 Landfill materials and proportion of all the scenarios

Number	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Landfill material	100% self-made MSW	92% self-made MSW+8% quicklime dewatered sludge	92% Self-made MSW+8% physical dewatered sludge	100% quicklime dewatered sludge	100% physical dewatered sludge

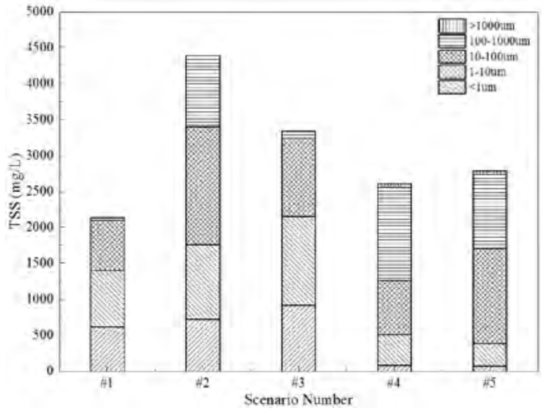

Fig 2 Distribution of particle size and TSS concentration

Diameter distribution of particles in leachate of all scenarios (Model Parameters) can be seen in Fig 2. pH value and concentration of VFAs、Ca^{2+}、TIC can be found in Table 2.

Table 2 Leachate properties of each scenario

Number	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
pH value	4.8	5.4	5.1	8.3	7.0
Acetic Acid	44.7	78.0	63.8	117.9	54.9
Propionic Acid	11.6	17.9	12.5	15.4	8.0
Butyric Acid	26.1	46.9	42.9	11.1	5.2
Ca^{2+}	3522	5179	4081	3936	2749
TIC	7206	3916	7719	7741	6244

Analyze of LCS clogging

Based on the process and mechanisms、physical model mentioned above, we use Comsol Multiphysics 5.2a to couple the different physics and analyze the simulated results of all scenarios, Results are as followings:

Porosity Filling：

The porosity of the gravel layer (initial porosity n_0=0.36) is simulated in different scenarios. Factors which can cause porosity filling of the LCS include: particles sediment、active and inert biofilm growth、calcium carbonate precipitation.

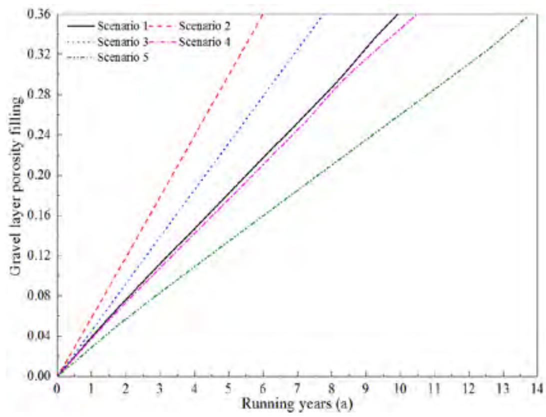

Fig 3 Porosity filling in gravel layer of each scenario

It can be seen from Fig 3 that porosity filling rate of scenario which sludge was added to the MSW is significantly faster than other scenarios. MSW with quicklime dewatered sludge (Scenario 2) is totally clogged within 6 years. Comparatively porosity is completely clogged at 10 years when the MSW is landfilled separately. Comparing scenario 2 and 3, it can be found that mixing MSW with quicklime dewatered sludge is more unfavorable than the physical dewatered sludge.

Meanwhile we simulated the porosity of the geotextile (initial porosity n_0=0.9). The results are shown in Fig 4.

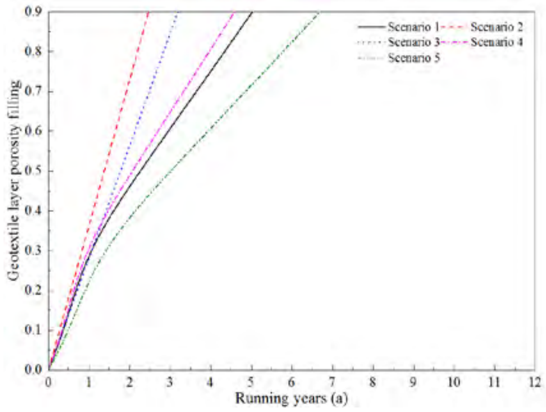

Fig 4 Porosity filling in geotextile layer of each scenario

It can be seen from Fig 4 that the clog rate of geotextile layer of mixing sludge and MSW is significantly faster than other scenarios. In the scenario which MSW is mixed with quicklime dewatered sludge, the geotextile layer is clogged within 2 years. Comparing the clogging of the gravel layer (Fig 3) it can be found the clogged time of geotextile layer is significantly lower than that of gravel layer. Researches from Wang et al. (2014) showed quicklime pretreat process can destroy the floc structure of sludge system, improve the proportion of particles of different particle size and adjust the particle structure, which is more conducive to particles leaching. According to the research results of Liu Yili et al. (2018), the particle proportion is as high as 66.7% among all factors causing the clog of geotextile layer.

<u>Variation of permeability coefficient in different scenario:</u>

We analyzed the equivalent permeability coefficient of both gravel and geotextile layer under different scenarios, Results are as followings:

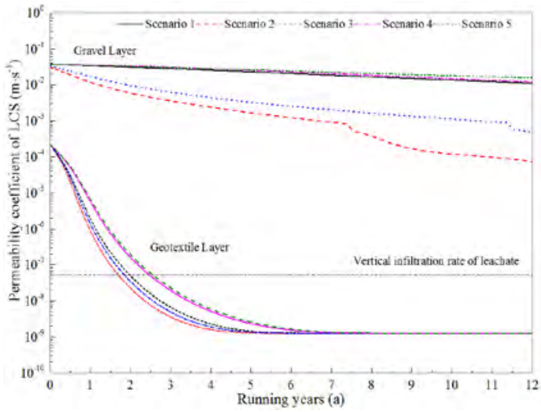

Fig 5 Equivalent permeability coefficient of gravel and geotextile layer

It can be seen from Fig 5 that for the entire geotextile layer, mixing MSW with sludge has a lower equivalent permeability decreasing rate than other scenarios. The discharge rate is lower than the vertical infiltration rate within 2 years. According to "Technical Specification for Domestic Waste Sanitary Landfill Treatment GB 50869-2013", the sub-film protective layer shall not exceed the requirement of clay permeability coefficient 1.0×10^{-7} cm/s. We use this as a standard to justify whether the LCS is failure or not. After running for 4 years, the equivalent K value is lower than 1.0×10^{-7} cm/s which means the drainage system has completely failed. For the gravel layer, the permeability coefficient of scenario that mixing of sludge with MSW is relatively decreasing faster of later stage. Besides adding 8% sludge (20% quicklime addition) to MSW can shorten the LCS running time by 1/3. Adding 8% physical dewatering sludge to MSW can shorten by about 1/5. Combining with the study of porosity filling mentioned above, the addition of sludge can accelerate the decrease of the permeability coefficient of drainage system. So the mixed landfill of MSW with quicklime dewatered sludge is the most unfavorable scenario from aspect of clog of the LCS.

<u>Factors proportion of porosity filling:</u>

We analyze the proportion of main factors causing the porosity of the drainage system (calcium carbonate precipitation、biofilm growth and particles sediment).

When porosity of gravel and geotextile layer is complete clog, we use the proportion of every factors in this time to reflect the effects of different factors causing the porosity filling, which is shown in Fig 6 and Fig 7.

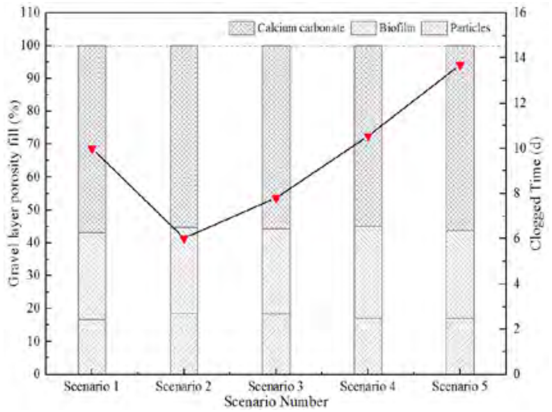

Fig 6 Clogged time and different factors proportion of gravel layer

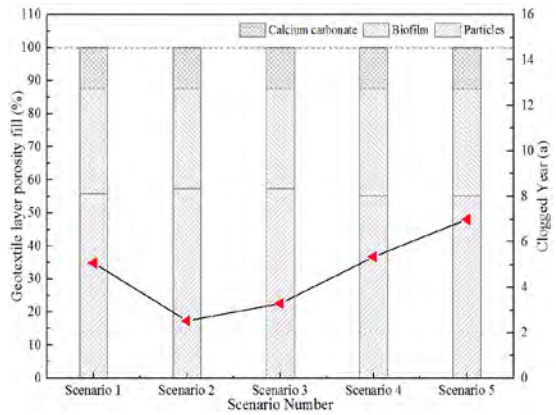

Fig 7 Clogged time and different factors proportion of geotextile layer

It can be seen from Fig 6 that for gravel layer, the proportion of calcium carbonate precipitation is above 50%. Fleming and Brune have done the determination of the dry basis composition of clogged materials from the KVL and landfill in Germany. Since the amount of added sludge is small, there is little difference of the effect on the final clogged factors proportion.

For the geotextile layer, the main clogging factor comes from the sediment of particles, which is consistent with the results of Liu Yili's research on the clog mechanisms based on the leachate from chinese MSW. Comparing various scenarios, the proportion difference of the clogging factors is not significant. But the proportion of particles sediment for the geotextile layer is slightly higher in the scenario which sludge was added than other scenarios.

Conclusion

Simulate and analyze the clogging of LCS of scenarios mentioned above, the conclusions are as followings:

1) Time of LCS clog when mixture of MSW and quicklime dewatered sludge landfill is significantly lower than other scenarios and based on "The Technical Specification for Sanitary Landfill Disposal GB 50689-2013", 1.0×10^{-7} cm/s is the permeability standard for deciding the failure of LCS. Adding 8% sludge (20% quicklime addition) to MSW can shorten LCS running time by 1/3. Adding 8% physical dewatered sludge to MSW can shorten by about 1/5.

2) Among factors causing the clog of LCS, particles sediment accounts more than 50% for geotextile clog and calcium carbonate precipitation accounts more than 50% for the gravel layer clog.

3) Effect of adding quicklime dewatered sludge to MSW is the most unfavorable way for LCS. From the perspective of slowing down clogging of drainage system and prolonging the running life of landfill, sludge should be zoning landfill, especially the quicklime dewatered sludge should not be mixed with MSW.

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STUDY ON PLANNING INFORMATION DATABASE FOR FACILITY IMPROVEMENT IN THE FIELD OF WASTE LANDFILLING AND RECYCLING

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ABSTRACT

It is important to collect and extract planning information and establish a basis that can be used to grasp the SWM trends. The author collected planning information on facility development for 81 organizations waste treatment facilities which will be newly built among those which were received the FY 2015 notification of Subsidies to Promote a Recycling-Based Society (Ministry of the Environment). As a result, the following points are raised: (1) a melting furnace more tend to be selected to avoid landfill; (2) there are some organizations which give up recycling a bottom ash while those who are planning to recycle bottom ash are becoming prominent, which raises issues that we need to consider recycling with sharing of experience; and (3) 45% of the organizations plan to replace the existing open-type landfill sites to the closed-type landfill site or have not determined which to select, indicating necessity of discussion making sure of stabilization of waste in the closed-type landfill site. The author will continue to examine development of a basis to collect and use planning information.

KEYWORDS : Using of planning information, The evidence based policy making, Developing waste treatment facilities

BACK GROUND

Developing waste treatment facilities faced with the situation which requiring due to low carbonize, reduction of quantity of waste generation, reduction of the management cost, and facing difficulty of securing landfilling capacity. On the other hand, government is promoting the concept of the evidence based policy making (Ministry of Internal Affairs and Communications Statistics Reform Promotion Conference, 2017). We have result data have already, it will be necessary for us to maintain trendy data for policy making.

OBJECTIVES

Therefore the authors collected planning information from materials such as "Regional Plans for the Recycling-Based Society"[#1] (hereinafter referred to as "regional plans") and "Basic Plans for Municipal Waste Management"[#2] created by local governments to understand the trends of future facility development related to waste treatment.

RESEARCH METHODS

Research objects

This research covers local governments which unofficially received the FY 2015 notification of subsidies to promote a recycling-based society (hereinafter referred to as "subsidiaries") from Ministry of Environment. This is because the regional plans made by the local governments publish on the website and allow the author to easily collect information.

Among the projects containing a "waste incineration facility" or "landfill site" in the "facility category" or "detailed facility category" in the list of local governments which have unofficially received notification of subsidies, the author extracted 81 local governments where the local government published on websites, existence of a regional plan to promote the recycling-based society or a basic plan for municipal waste disposal.

Research items

The author sorted out the title, FTP site, project planned year, formulated year, last revised year, local government information (project implementing body, area, population) of Regional Plans for the Recycling-Based Society and Basic Plans for Municipal Waste Treatment and collected information concerning the following to know the trends of facility development in every area. Table 1 shows research items and options

(1) Future trend of selecting intermediate treatment facilities
(2) Future trend of selecting methods to recycle bottom ash
(3) Future trend of selecting a landfill type
(4) Trend of background and related issues concerning building a new landfill site
(5) Trend of maintenance and management methods of the closed-system landfill site

RESULTS

Future trend of selecting intermediate treatment facilities

Figure 1 shows future trend of selecting intermediate treatment facilities. Figure 1 show the ratio of each intermediate treatment type and the trend of replacing the incinerator, respectively.

(i) Ratio of each intermediate treatment type

The current intermediate treatment facilities were classified into the incinerator 83%, (67 facilities), the melting furnace 14%, (11 facilities) and none facilities having no incinerator nor melting furnace: 4%, (3 facilities). In the future, 77% (62 facilities) will have an incinerator and 19% (15 facilities) will have a melting furnace.

(ii) Trend of replacing the incinerator

Among 67 facilities having an incinerator currently, 54% of the organizations (36 organizations) were planning to replace again it with a new incinerator, while 6% (4 organizations) will replace it with a melting furnace. Meanwhile, there are no facilities that will replace the melting furnace with an incinerator.

According to the regional plans, one of the reasons that the local governments determined to replace the incinerator with a melting furnace is high priority of securing landfill capacity by reducing bottom ash.

Future trend of selecting methods to recycle bottom ash

Figure 2 shows, future trend of selecting methods to recycle bottom ash. (i), (ii) and (iii) of Figure 2 show the ratio of how bottom ash is reused, the trend of landfilling incineration ash and the plans of recycling bottom ash.

(i) Ratio of how bottom ash is reused

72% (59 organizations) out of 81 organizations in total landfill bottom ash and 23% (19 organizations) recycle bottom ash.

Meanwhile, the landfill will account for 62% (50 organizations) in the future while the recycling will account for 30%, (24 organizations), showing that organizations recycling incineration ash tend to increase in the future.

Table 1 Research items and options

Scene	Large	Middle	Small	No.	Options				
Schedule and result	Intermediate treatment facilities	Type		(1)	incineration	Melting furnace	Ash melting furnace	others	—
		action			continuation	prolonging	renewal	—	—
	Recycling	type		(2)	Molten slag	cement	material of construction	others	—
	Landfilling	action		(3)	continuation	prolonging	renewal	—	—
		Landfill type			OP	CS	—	—	—
		Waste type		(4)	Crushed waste	Bottom ash	Crushed waste, bottom ash	Ash melting slag	Others
		Ultimate land use plan			Green belt	A playground	Photovoltaic power generation system	Un-decide	—
		Consensus building			Finish	During the adjustment	Having difficulty	Difficult	—
		Give up for			Securing of land	Selection of landfill type	Selection of landfill maintenance method	Others	—
Schedule		Basic policy for new establishment	Policy		Picked up about safety, landscape, fiduciary relationship				
			Landfill capacity		Showed	None	—	—	
			Expansion of collection area		Showed	None	—	—	
Schedule and result		CS	Waste stabilization method	(5)	Sprinkling and discharge	Sprinkling and non-discharge	Non-sprinkle and discharge	—	—

OP: Open type landfill, CS：Closed system landfill (landfill with covering facility)

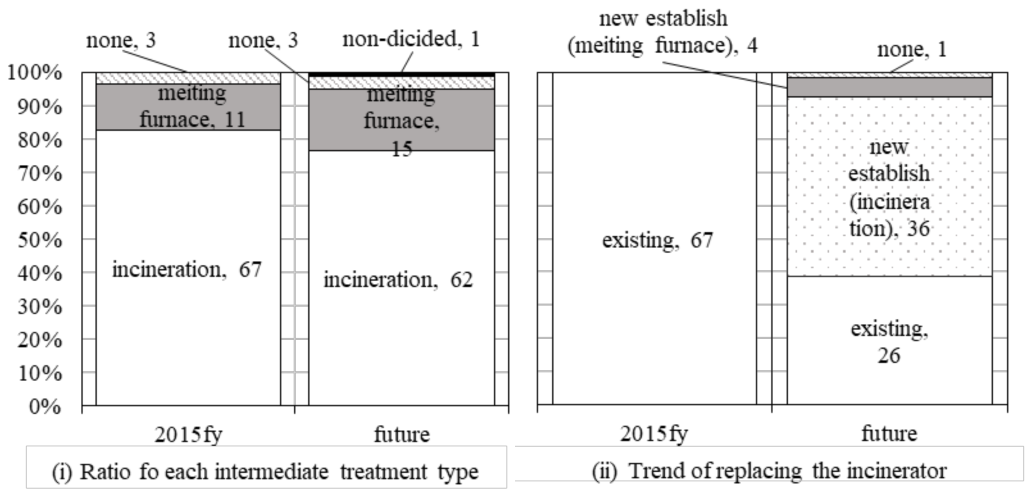

Figure 1 Future trend of selecting intermediate treatment facilities

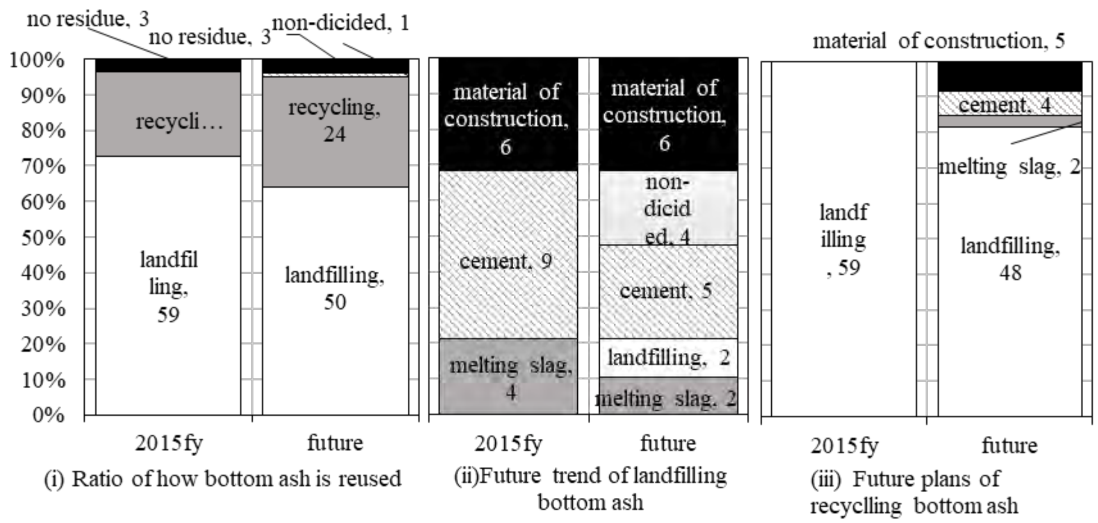

Figure 2 future trend of selecting methods to recycle incineration ash（Bottom ash）

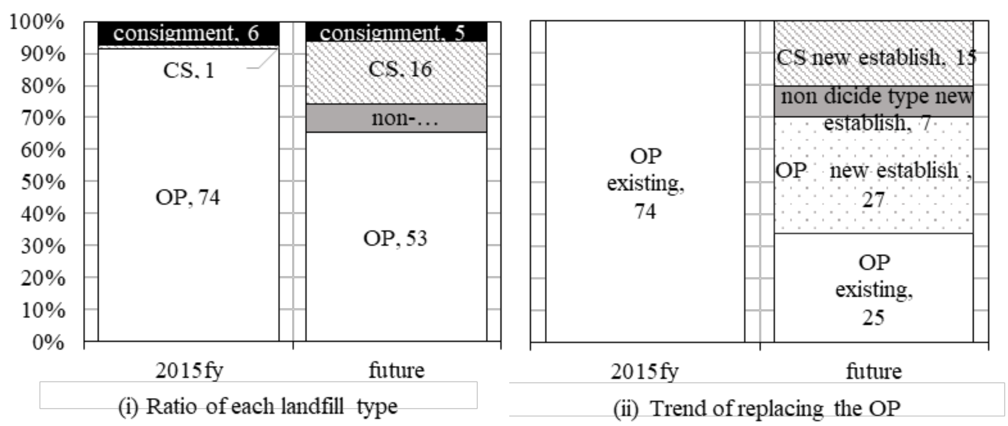

Figure 3 Future trend of selecting a landfill type

(ii) Future trend of landfilling bottom ash

Among 59 organizations landfilling bottom ash, 19% (11 organizations) are planning to recycle bottom ash instead of landfilling it in the future.

(iii) Future plans of recycling bottom ash

Among 19 facilities recycling bottom ash, 30% (6 organizations) will give up making it into cement or molten slag.

Circumstances and reasons that the organizations will give up recycling bottom ash are as follows:

- We are making it into cement, but we won't do it due to high costs.
- We examined effective use of bottom ash, but we put it off due to costs.
- We have a melting furnace, but actually we are not able to do it. We have determined to landfill slag instead of recycling it in the future as we landfill it in an open-type.

Future trend of selecting a landfill type

Figure 3 shows the research item (3), Future trend of selecting a type. (i) and (ii) of Figure 3 show the ratio of each landfill type and the trend of replacing the open-type.

(i) Ratio of each landfill type

Among 81 organizations, approximately 91% (74 organizations) will have an open-type (hereinafter referred to as "OP-type"), but the ratio will decrease to 65% (53 organizations). Currently, the closed-type landfill (hereinafter referred to as "CS-type") accounts for only 1% (1 organization), but it will increase to 20% (16 organizations) in the future.

Table 2 Basic direction of the background and reasons of building a new landfill

Landfill type (organization number)	Lack of the capacity	Rationalization of the management by the expansion of the collection area	Stable landfill management system for future tightening capacity	More acceptable to citizens and maintain a safe and secure facility.	Sustainable economy	consider the landscape	having difficulty with acquiring the site
OP-type (27)	18	12	12				
CS-type (15)	12	8	1	7	1	2	
Non-diced (7)	4	2					2

Table 3 Maintenance and management methods of CS-type landfill sites which will be newly built

Waste stabilization method	Sprinkling		Non-sprinkle and discharge	Non-decided	No data
	discharge	Non-discharge			
Total number 15	6	4	2	1	2

Table 4 Types of waste landfilled in the CS-type landfill which will be newly built.

Waste type	Crushed waste	Incineration residues	Crushed waste and incineration residues	Fly ash from Melting furnace	More than 3 kinds
Total number 15	6	3	4	1	1

(ii) Trend of replacing the OP type

Meanwhile, among the existing 74 organizations having an OP-type, which have approx. 34% (25 organizations) will continue to use that an OP-type, and approx. 66% (49 organizations) will newly build a landfill. Among the newly builds are approx.55% (52 organizations) will have an OP type, approx. 45% (22 organizations), which includes 15 CS-type and 7 unsettled sites.

Trend of the background and related issues concerning building a new landfill

Table 2 outlines the basic direction of the background and reasons of building a new landfill.

The features of the landfill types are as follows. Organizations which will newly build an OP-type describes that they will secure an appropriate and stable landfill management system for future tightening capacity, while those which will newly build a CS-type describes that they will strive to build a facility which would be more acceptable to citizens and maintain a safe and secure facility, or consider the landscape and environment as features of each new landfill type.

2 out of 5 organizations which have not determined the site type are having difficulty with acquiring the site.

Trend of maintenance and management methods of the closed-system landfill

Table 3 shows maintenance and management methods of CS-type which will be newly built.

Among 15 organizations in total, 10 organizations will have a water sprinkling system, 2 organizations do not have a water sprinkling system nor discharge and the remaining 3 organizations are unclear for maintenance and management. Among the 10 facilities which have a water sprinkling system, 6 facilities discharge treated water and 4 facilities do not do that. Table 4 shows types of waste landfilled in the CS-type which will be newly built.

In terms of waste landfilled, incombustible crushed residue (including residue to be recycled) is most seen and landfilled in 6 organizations, 4 organizations landfill incombustible crushed waste and incineration residue.

DISCUSSION

Based on the future trends learned from the regional plans, the author considers the direction of the future technical development as follows.

Future trend of intermediate treatment facilities

Following the former Ministry of Health and Welfare notification in January 1997, "Reduction Measures of Dioxins Related to Garbage Treatment" (No.21 of Hygiene and Environment) [#3], some local governments closed down melting furnace facilities.

It seemed that more organizations would select the incinerator rather than the melting furnace, when next renewal

However, according to the research results, 4 organizations will replace the incinerator with the melting furnace while no organizations replace the melting furnace to the incinerator. It is suggested that reducing the amount of waste landfilled is more prioritized even if maintenance and management of the melting furnace cost more.

The author considered that we need the scheme for selecting technology by technology mapping tool which are considered with intermediate treatment costs, demand and supply balance of resources for regional cyclical model, what kind options they would be selected after its prolonged service life.

Future trend of recycling technology of bottom ash and melted slag

According to the research results, there are some organizations already gave up recycling bottom ash while other organizations landfilling bottom ash make a policy to promote recycling bottom ash to reduce the amount of waste landfilled. It seems that we need to spread precedent experience to other organizations to examine validity of the recycling plan of bottom ash and develop technology necessary to smoothen the recycling.

In addition, some local governments which have selected a melting furnace for the intermediate treatment facility are not planning to recycle slag but landfill it at the beginning.

The author also considers that identifying issues and considering measures are necessary because landfilling slag is expected to raise different issues from landfilling bottom ash such as site development after using the facility or flowing out of slag into the leachate.

Future trend of stability/maintenance and management technology of the closed system landfill

Local governments which will build the CS type landfill mostly mentioned that understanding of local people and safety and security for the way of thinking for the new landfill. The increase of the CS-type indicates that they are more considered important as a scheme to reach a consensus by securing safety for local people. However, the CS-type may not be stabilized and abolished forever unless the timing of stabilization is considered in the technical conditions even if more CS-type are built. The author considered that it is necessary to infiltrate technical development matching the CS-type design concept and ideas of selecting landfill with a view of stabilization.

Possibility of using a planning information database as evidence to determine policy

This research was a small survey covering only 81 organizations among 1,741 local governments and 575 special district authorities, but attempted to identify the future trend at a certain level.

The author considers that it could be possible to propose a system to collect the planning information as a database by collecting information on more population parameters and adding research items effective for examining the direction of the technical development.

For examples of various information; the maintenance method in intermediate treatment facilities, quality of waste material (Sotaro Higuchi, 2016), Waste Data Sheet (WDS) (Ministry of the Environment, 2013), and Material Safety Data Sheet (SDS).

CONCLUSIONS

Consideration for needs

A certain level of tendency was found toward building a new landfill with the CS-type, recycling incineration ash and installing a melting furnace, which indicates necessity of technical development for reduction of the amount of waste landfilled, stabilization of the CS-type and reduction of maintenance and management costs for intermediate treatment facilities.

The author wants to continue to collect the following information to identify issues and consider measures.

(i) Stabilization methods of waste landfilled in a newly built CS-type

(ii) Issues and measures in landfilling slag

(iii) Issues and measures in promoting recycling incineration ash

Consideration for what the waste treatment facilities should be and their vision

We need to evaluate the development of waste treatment facilities comprehensively and propose what they should be while we understand and sort out the needs and the current trend. The author understands the development policy and needs of the burning furnace, but needs to connect it to analyses from the view point of policy implementation such as how we can make a way for consensus building and policy making to avoid the incinerator or how we can check budgets for the policy are allocated to make the waste treatment facilities close to what they should be.

To enable discussion to propose what the facilities should be upon analysing the current trend on an evidence basis, the author considers that it is useful if we can collect "plan-based" information created with unified items in a fixed form, understand and sort out information statistically all over Japan and use it as "public and private sector data[#4]".

In "Joint Council to Promote Waste Treatment and Recycling IoT introduction", a working group in the joint council begun to consider building a data platform (PF) for actual resource recycling using IoT technology (Makiko Doi et al., 2018). The author considers that adding information related to the trend of facility development to the above activity is useful.

NOTES

Note#1 Regional Plan for Recycling-Based Society: the regional plan outlines the basic direction of treatment systems in a region, a type and scale of facility development, complying with the basic policy of the Waste Management and Public Cleansing Act and showing the direction of waste treatment and a recycling system in the region for 5 years. Organizations which start the project using the subsidiaries are requested to submit the regional plan. The operation of this regional plan started in 2005. In formulating the regional plan, the local government must hold a joint council to have a scheme to exchange municipality's opinion mutually.

Note#2 Basic Plan for Municipal Waste Management: the plan is stipulated by Section 1, Article 6 of the Waste Management and Public Cleansing Act. The basic plan as a long-term plan for 10 to 15 years (Municipal Waste Management) and the implementation plan for each year (Implementation Plan for Municipal Waste Management) are formulated.

Note#3 A notification for exceptional measures: In December 2003 and another notification in March 2010 to allow close-down of waste treatment facilities even within the service life if certain requirements were met. These are issued due to existing problems with the maintenance and management costs and effective use of slag.

Note#4 Public and Private Sector Data: Information saved in electromagnetic record, and managed, used and provided by the government, local governments, independent administrative institutions or other enterprises for implementation of their affairs or projects (Article 2, Basic Act on the Advancement of Public and Private Sector Data Utilization).

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UNIVERSAL DESIGN OF BINS WITH PSYCHOMETRIC ANALYSES FOR PEOPLE WITH VISUAL IMPAIRMENT

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ABSTRACT

This study investigated the effectiveness of design attributes with eight bin prototypes. In addition, our surveys were conducted with the prototypes by following the concept of the Seven Principle of Universal Design introduced by Center for Universal Design at NC State University. Three different low vision settings, clear, blurred, and heavily blurred vision, were applied on each design for the surveys to uncover which design is the most preferred by people with low vision since ageing society and failing of eyesight is now, common issues in Japan as well as the other countries. The design attributes are basically shape, slot location, and information types for each bin. The aim of this study was to understand usage of these design attributes to introduce easy-to-recognise public bins for better waste management. We tested eight bins for PET bottle garbage collection. A Law of Comparative Judgement by L.L. Thurstone and Scheffé's Method were employed to determine uncertainties of people's preferences for each bin prototype with paper-based questionnaire. The results were shown to lead to determinations of the most preferred bin in each visual condition. This indicates that there is a possibility of using certain designs for public bins to help people find and differentiate several types of bins easily in the public places for their waste disposal even though their eyesight is not good enough.

Keywords: Psychological Preference, Universal Design, Visual Impairment, Bins, Pairwise Comparison

INTRODUCTION

<u>Bins in Our Daily Life</u>

Design works for rubbish bins are usually done as aesthetic factors by designers. People can easily buy attractive or beautiful bins as one of their home interior design and decoration. However, in terms of bins and their designs in the public, they are commonly ugly, bulky, too simple or complicated, and not well designed for improving waste collection and urban environment. They are just large containers in general.

We use rubbish bins many times in a day at different places such as our home, workplaces, public spaces, schools, and streets. In addition, huge volumes of wastes are collected from the bins which are located close to us and our daily life. Therefore, we could consider that bins are more important than we may think in our everyday life.

Design of Bins for Garbage Collection

Appropriate designs for rubbish bins can inspire people in our society for separate garbage collection in better ways. For example, if we have well designed bins in the public places for all types of people, regardless of their genders, ages, nationalities, languages, cultures, experience, and even physical abilities, we may have better garbage collection and improved garbage collection rate (e.g. PET bottles in PET bottle bins, not the other bins by human mistakes). This design concept is usually called as Universal Design (UD). Having that point of view, we have investigated different sort of bins in design-wise. There were only few dedicated research projects in the world, for understanding psychological preference on different kinds of rubbish bins in the public places with each waste type. The waste types are papers, magazines, and newspapers; combustible; incombustible; cans; and PET bottles. This is a common categorisation of waste for bins at public places in Japan.

As design studies, even if aesthetic factors would be the most integral attribute for pure design projects, engineering and usability should not be neglected. Consequently, in order to create good bin designs in the public places aiming for better garbage collection, we need to think about not only the bin designs themselves, but also potential users of the designs and their usability for the users.

Ageing Society: Bin Users with Visual Impairment

According to World Health Organization (2017), about 253 million people live with VI and 36 million people are blind who live without visual literacy. Thus, we are particularly interested in users who have visual impairments (VI). In detail, amongst of VI, we focused on low vision and less visual attentions. This is because Japan is one of well-known countries as ageing society.

According to the Centers for Disease Control and Prevention (CDC), National Center for Health Statistics and its National Health Interview Survey (NHIS) from the U.S. Department of Health & Human Services in the United States of America, basically, the ageing process is related to VI issues.

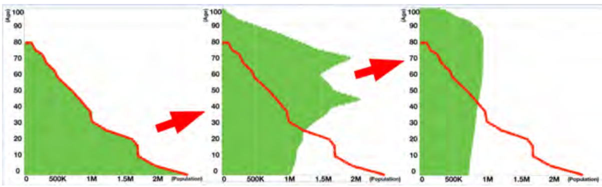


Figure 1. Demography changes in Japan: 1950, 2018, and 2100 (Expected)

A database for demography from Gapmidner (2018) clearly shows how the Japanese demography has been changed as figure 1 above. This shows arguably, we are going to have more elder people than younger people. Furthermore, according to the Center on an Ageing Society analysis of data from the 1998 at NHIS, their data defines four different groups by age range. The first group's age is from 0 to 17 years old; the second group's age is from 18 to 44 years old; the third group's age is 45 to 64 years old; and the last group's age is equal or more than 65 years old and the ratio of VI in each group within their population is about 3%, 6%, 11%, and 18%, respectively. That means just below 20% of people who are elder than 65 years old have eye problems.

As we shortly mentioned, Japan is well-known as one of the extreme cases of ageing society in the world, we can simply predict that we are going to encounter a number of people who have VI due to their ages. Thus, for the design studies, we should also consider about them, since user study is always important and required to create more efficient design for the actual users. Surprisingly, the average visual literacy has been decreasing due to ageing processes as people may believe having VI issues and being a disability were mostly because of eye diseases.

In addition, many people in the modern society started using visual display terminals (VDT) such as personal computers (PC) and smartphones, the average visual attention and eyesight of the people are enormously failing. Therefore, we designed eight potential rubbish bin prototypes for people who have low vision and possibly low visual attention.

The goals of these designs are keeping the same functionalities as a rubbish bin; following UD concepts as much as we can so that people, with various situation or difficulties especially for VI, could easily detect and recognise the bins and its usage; and investigates highly preferred design attributes (e.g. colours, shapes, and sizes) related to its appearance to understand people's psychological preference on certain designs to suggest better bin designs for commercial and industry level usage in the future, especially in cities of Japan.

In our past study, Prior work has documented the effectiveness or usefulness of existing bins by investigating commercial bins in the public. For example, Takahashi et al. (2017) researched seven common types of bins in the public. They conducted a web questionnaire for the seven bins and tried to confirm what type of bins is the most preferred and why. In terms of design elements, they worked on colour, slot shape, slot position, and inside visibility by having transparent window at front-side of bins. Their results suggested bins with multiple-colours, disposal slot on the front side, and no-transparent materials, were the most preferred. However, further study is necessary because these suggestions were not regarded as significant by statistical tests. In addition, the previous study only focused on existing bins. Jiang et al. (2017), Leeabai et al. (2018), and Dilixiati et al. (2018) started research on bin design research with different aspects such as colours, slot shapes, and waste segregation efficiency.

In this study, beyond working on design-side for creating successful commercial bins, we mainly focused on designing PET bottle bins in user aspects. As previously explained, product designs, in this case PET bottle bins, should be designed in good shapes, but that is not the only goal we consider. Because of the dramatical change on our demography, users in the 20th Century is definitely different than peoples in the 21st Century. Therefore, the objectives of this research are:

1) Investigating better designs for people with VI and without VI (any people with different eyesight should easily use the bins in the same efficient way)
2) Understanding effectiveness of Universal Design for better waste collection by people especially who have low vision
3) Gleaning the better design concepts and attributes to reinforce current PET bottle bins in the public
4) Being able to observe how people think, move, behave, interact with a bin when they are throwing their PET bottle way in the future study

METHODOLOGY

Universal Design with the Seven Principles

The candidate designs of bins are following the Seven Principles of Universal Design which has been introduced and developed since 1997 by a working group of researchers from architecture, product designers or engineers, and environmental design researchers, led by North Carolina State University. The principles basically have these rules as guidelines for designing new products, software, and objects: equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, size and space for approach and use. The prototypes of bins were designed based on the concepts and psychological preference of each design were analysed by Thurstone's Method and Scheffé's Method. Here below, the table 1 shows how we could relate each principle of UD into our bin design project.

Table 1. The Seven Principles of Universal Design and Potential Design Elements of Bins with Examples

Principles	Examples
#1: Equitable Use	* Equally usable by everyone: non-VI and VI users * People (non-VI and VI) should show the same performance for using a bin * Readability and usability should be same for the two user groups *(e.g. The rubbish bins should keep the conventional bin shapes, and they must give intuitive information to users so that people easily understand the objects are bins for PET bottles)*
#2: Flexibility in Use	* For various range of people with different eyesight levels should be able to use the bin in a same way
#3: Simple and Intuitive Use	* Easy for all people to understand the purpose of each bin's design, purpose, and how to use * Design must be intuitively clear and obvious (e.g. People can find bin for PET bottle easily without any hesitation)
#4: Perceptible Information	* The bin should provide all kind of necessary and essential information to the users as different format of information *(e.g. colours, logos, symbols, and shapes)* * Decent contrast to surrounding environment *(e.g. If bins are hard to find due to little contrast between the object and its environment, people might have difficulties to find the bins in the public places)*
#5: Tolerance for Error	* Make it simple: eliminate design features that might generate potential errors and unintended accidents * Durable to prevent people's abuse *(e.g. fragile bins are hard to maintain and broken bins can confuse people so that they would have difficulties to use the bins)* * The design should be able to predict accidental use and unintended behaviours by the users to minimise problems of the bin * No complicated design (trash bin lid and handle: fragile)
#6: Low Physical Efforts	* Design features that requires minimum or no unnecessary physical behaviours to use the bin. * Less behaviour required to use: must be easy to put PET bottle in to a bin * Lid and handle: hard to use finding the lid, find the handle, grab the handle, open it, throw waste in the bin, and close the lid
#7: Size and Space for Approach and Use	* Right size for everyone to use. *(e.g. not too small, too big, and too tall)* * Investigate people's height and proper bins' height * Secure adequate space that is appropriate to use for everyone

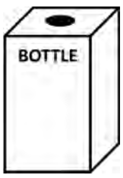
The Eight Prototypes

The eight prototypes were designed with three design attributes such as shape of bins, information type of labelling of bins, and slot location of bins. In case of shapes, we have square pillar, cylinder, and bottle shaped bins. In terms of the information types which means how we notify people about the bin categories, in this case, PET bottle bins, we use two simple methods: letter and symbol/image, to let people know about the prototype bins are made for PET bottle disposal.

We also make the slot location as two different styles which are top-side and front-side to understand any slot location preference of the PET bottle bins from the people. Rounded slot shapes were used in this research because of following two reasons. First, the circle slot shape for PET bottle bins are widely used in Japan. Our research was more focused on bin shapes, and information types. Therefore, we fixed the slot shape this time. The other reason is that if we have more options, then it makes us hard to conduct pairwise comparison since the number of all possible designs will be increased, therefore, the number of all pairs is also increased exponentially. Thus, the number of questions, at questionnaires for preference surveys, could be more than a hundred so that it would be hard to proceed the survey since it requires a lot of times to answer all questions.

Thus, in this research, we fixed the number of designs as eight with the small variations by having differences on shape, information type, and slot location. This means we can generate 28 possible pairs, therefore for conducting one questionnaire for evaluation all design by using pairwise comparison, we just need to ask people about their preferred design with only 28 questions. The questions is simple as we ask survey participants to answer their preference between two different designs. Answering each question may takes only few seconds. The detail will be explained at the data collection part with creating another questionnaire with low vision simulation on each bin prototype.

Table 2. The Eight Prototypes of Universal Design & Examples

	Prototypes							
Design	A	B	C	D	E	F	G	H
Image								
Shape	SP	SP	SP	CL	CL	CL	PB	PB
Info.	LT	LT	SB	LT	LT	SB	LT	LT
Slot	TS	FS	TS	TS	FS	TS	TS	FS
Terms	* Shape of the Boxes = {Square Pillar: SP, Cylinder: CL, PET Bottle Shape: PB} * Types of Information = {Letter: LT, Symbol: SB} * Slot Locations = {Top-side: TS, Front-side: FS}							

The Prototypes with Different Vision Levels

At the introduction in this paper, one of our objectives is "Investigating better designs for people with VI and without VI (any people with different eyesight should easily use the bins in the same efficient way)". In order to understand people's preference change on PET bottle bins, we did simple image processing by employing Adobe Photoshop and blurring option of the software. Each design was built in a fixed size: width 534px and height 756px to do fair comparison. To simulate low vison, we applied the blurring options for 0px (not applied), 10px (blurred, the letter, "BOTTLE", on the bin might be readable), and 14px (heavily blurred, hard to read the letter, "BOTTLE", on the bin). The differences of each image can be seen as figure 2 below:

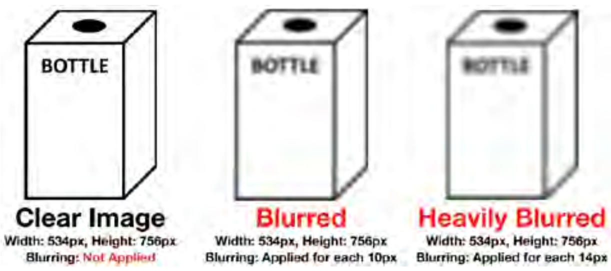


Figure 2. Three Low Vision Levels on a Bin

The Questionnaire

We made eight different PET bottle bin prototypes and we also explained about the three different low vision settings as clear image, blurred image, and heavily blurred image.

For the questionnaire part, we designed three stages according to the low vision level. We conducted three questionnaires for a same group of people with clear images, blurred images, and heavily blurred images. Since we have eight designs, a questionnaire has 28 questions to do pairwise comparison and it conducted three times for each visual level. Therefore, for the questionnaire, we technically get 84 questions (28 questions for clear images, 28 questions for blurred image, and 28 questions for heavily blurred images).

At first, we generate all possible pairs amongst the design A, B, C, D, E, F, G, and H (see the table 2 for the detail). One pair could be represented as AB, so we can get AB, AC, AD, AE, AF, AG, AH, BC, BD, BE, BF, BG, BH, CD, CE, CF, CG, CH, DE, DF, DG, DH, EF, EG, EH, FG, FH, GH. And then, we give random value for each pair by using an Microsoft Excel's random functions to sort all the questions for each pair randomly. For example, the figure 3 shows a question we were ask for the design pair, "AB".

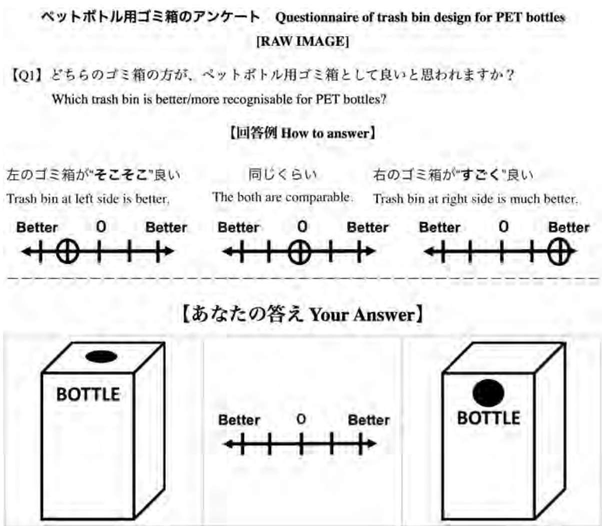


Figure 3. A Question for Clear Image

We also created the same questionnaire for images in blurred as well as heavily blurred image processing. The orders of all pairs for each visual setting were randomly sorted. This was done because we wanted to avoid possible bias by asking questions with a certain design continuously. Thus, all questions are randomly shuffled within their own visual clearness categories.

This means we did the random sorting within each image group.

Analysis Methods

In this research, we used paper-based questionnaires and gleaned data from papers with our participants' unique answers. And all the data were evaluated by employing binary pairwise comparison method that introduced by Thurstone (1927).

Since questions for the questionnaires are not actually in binary scale, whereas scaled questions basically numerical value in integer from -2 to 2 (-2, -1, 0, 1, 2), in order to run Thurstone's Methods, we need to convert the data into binary values which basically are "true", "false", and sometimes "neutral".

True stands for the design at the right-side of the question (see figure 3) is more preferred. Therefore, the integer values larger than 0 (1 and 2) were converted as 1. False means the design at the left-side is more preferred than right-side, (-2 and -1) so the values converted as 0. From the questionnaire few people marked both designs left and right side are the same and marked them as 0 value in the -2 to 2 scale-bar, in this case, we consider this data as "neutral" preference so that for the binary pairwise comparison, we converted 0 (in the five-integer-scale) into 0.5 for binary pairwise comparison analysis.

On other way, for the Scheffé's methods by Scheffé (1957), we are able to evaluate the design preference by having preference score as numerically scaled scores (in this research: -2, -1, 0, 1, 2). Therefore, we use the raw data without any treatment for using Scheffé's method.

RESULTS AND CONCLUSIONS

Results

Here are the results from the surveys with the eight prototypes and three different low vision treatments. We use the same data but applied two different data analysis method by using Thurstone's method and Scheffé's method. First of all, here are all values calculated as preference scores: z-value for Thurstone's method and preference degree for Scheffé's method. The table 3 shows the calculation results for each method with all prototype introduced in the three different low vision treatment:

Table 3. Z Value (Degree of Preference) by Thurstone's Method and Preference Degree by Scheffé's Method

		A	B	C	D	E	F	G	H
Thurstone's Method (Z Value)	*Clear*	-0.284	0.139	-0.058	-0.306	-0.179	0.122	0.219	0.316
	Blurred	0.065	0.053	0.098	-0.51	-0.2	-0.13	0.363	0.053
	Heavily Blurred	-0.09	-0.06	0.259	-0.41	-0.05	-0.09	-0.1	0.225
Scheffé's Method (Preference Degree)	*Clear*	-0.1658	0.1658	0.2117	0.0281	-0.051	0.0791	0.2398	0.3827
	Blurred	0.29337	0.15051	0.23469	0.03316	-0.0536	0.16837	0.07143	0.05102
	Heavily Blurred	-0.051	-0.0102	0.34439	-0.0612	-0.1199	0.2602	-0.227	0.23214

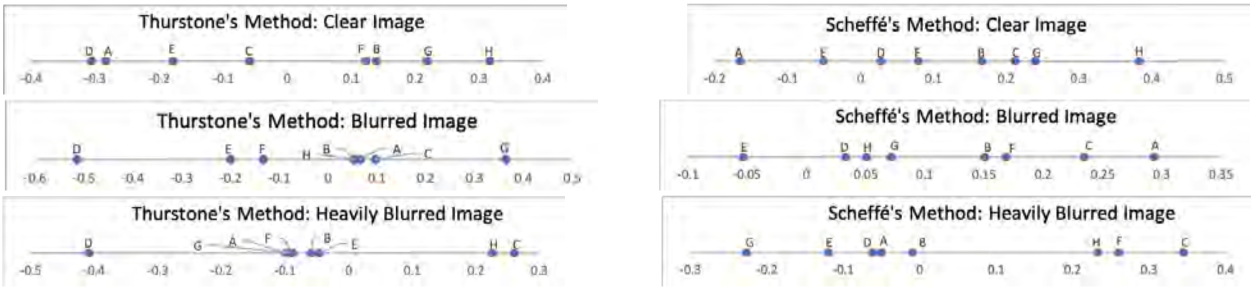


Figure 4. Results by Thurstone's Method and Scheffé's Method for Each Vison Level

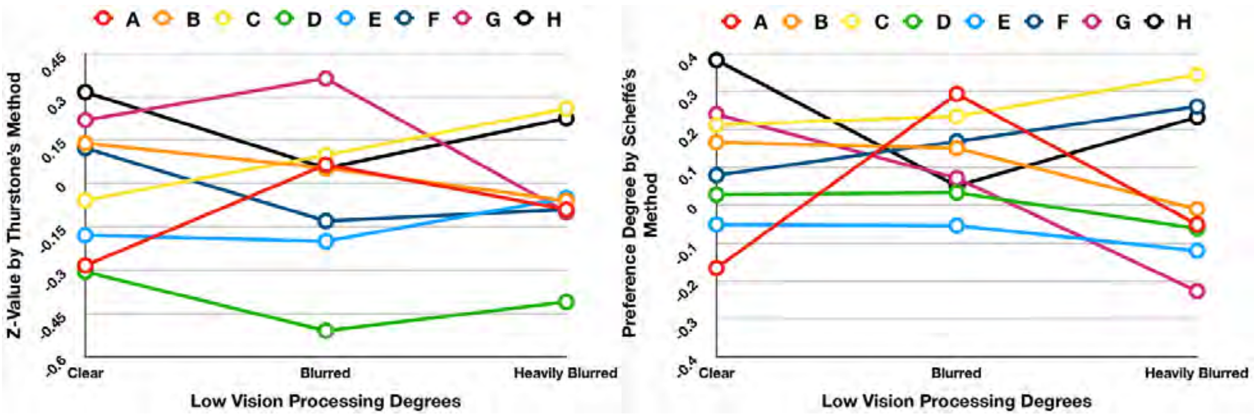


Figure 5. Preference Trends with Low Vision Levels: Thurstone's Method and Scheffé's Method

As we can see from the figure 4 and 5, the design preferences are different as the blur level of each image increased. Some designs are more preferred at the "heavily blurred" settings, so their preference values were increased when the vision level was decreased. For example, at the result by Thurstone's method, the design "C" was more preferred when the vision levels are lower). On the other hands, some designs were less preferred when the vision level was decreased. For instance, from the figure 4, the design "B" was the most preferred design at the clear vision level, but it was getting less preferred at blurred and its preference level get lower again, at the lowest vision settings.

Conclusions

In the previous research by Hahn (2018), transdisciplinary research is very important for deeper research on the waste management topics. In this research, we worked for mainly three topics: waste management by rubbish bins; ageing society and visual impairment; universal design for people with low vision.

The important findings from this research are simply summarised as below:

1) Different design preference in different visual levels
2) Some design preferred in low vision condition, vice versa
3) Preferred bins are usually in square pillar shape with PET bottle image and slot location at top-side

Future Works

In the future, we need to get large-scale quantitative data from people with various range of gender, age, and occupation. In addition, prototyping new bins is needed to improve the bin designs to create commercially usable bins in the public. Moreover, conducting workshops with actual bins is required to get qualitative data for understanding people's psychological preference deeply. Finally, finding meaningful attributes (colours, shapes, symbols, letters) is necessary for better designing of PET bottle bins both VI and non-VI people.

ACKNOWLEDGMENT

I would like to thank professor Takahashi, for his supports and guidance to conduct this research.

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PREFERENCE STRUCTURE ANALYSIS AND CATEGORIZATION OF TRASH BIN COLORS

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ABSTRACT

Nowadays, in order to implement the strategy of sustainable development, proper management of municipal solid waste (MSW) has become a global problem. A good designed trash bin might be able to have important roles on waste separation from the sources. In this context, authors have focused on psychological preferences of one of the most critical elements in trash bin design which is trash bin color, since it might give non-negligible impacts on human behaviors of waste separation. Therefore, this study investigated color preferences of different types of trash bins, in particular, targeted analysis of preference structure on special colony which shows higher preference degree in each type of trash bin.

In this study, web questionnaire data was used to scale the color preference by binary pairwise comparison method, it includes total 45 pairs of trash bins for each type, questionees requested to only answer the better color from each pair by imagination. The selection ratio dataset were analyzed to quantify the preference degree (Z value) using Thurston's law of comparative judgment, higher Z value means higher preference degree. Based on this, the authors have focused on gray, since it shows higher selection rate in each type of trash bin, gray selectors for each type were extracted, respectively. In order to reflect the similarity and categorization of their preferred colors, hierarchical cluster analysis was conducted.

Keywords: *Trash Bin, Waste Classification, Color Preference, Pairwise Comparison, Hierarchical Cluster Analysis*

INTRODUCTION

Along with the rapid expansion of urbanization, municipal solid waste (MSW) caused serious pollution problems. In Japan, MSW management system has been implemented over 40 years, as a result of these 4 decades of effort, Japan has a developed management system of MSW (Kojima, 2006). Waste separation also known as waste classification or waste segregation. In daily life, especially in the public places, generally MSW is requested to be separated into combustible waste, incombustible waste, and PET bottle and CAN (Qiuhui Jiang, 2016). However, it is not unusual that, in most cases waste are mixed even set the designated trash bins for different types of waste, it might be caused by some people have unwillingness and incomprehension to separation process or lack of psychological stimulate to correctly guide people to classify their waste.

Related social psychological studies show that the appearance characteristics of objects have decisive effects in people's psychological activities such as acceptation, rejection, and memorization. A good designed trash bins might be able to have important roles in waste collection by encouragement of waste separation from the sources. In this context, the authors have focused on psychological preferences of trash bin design since it might have non-negligible impacts on human behaviors including waste segregation, trash bin color might be one of the influencing factors, thus, this study investigated color preferences of trash bins, in particular focusing on gray, since it shows high selection rate in each type of trash bin, gray selectors for each type were extracted, respectively. In order to reflect the similarity and categorization of them, cluster analysis on their preference structures was conducted.

DESIGN OF TRASH BINS

Path studies about psychology of color had concluded the existence of a general order of preference for colors and the difference in color preferences between different genders and ages (Macmillan, 2014). For the sake of comprehensiveness of the survey, based on three-primary colors, mixed colors and white/black gradation, 10 common different colors for trash bin were decided, marked as blue-A, red-B, yellow-C, brown-D, purple-AB, green-AC, orange-BC, white-W1, gray-W2, and black-W3, respectively (Figure 1) . In

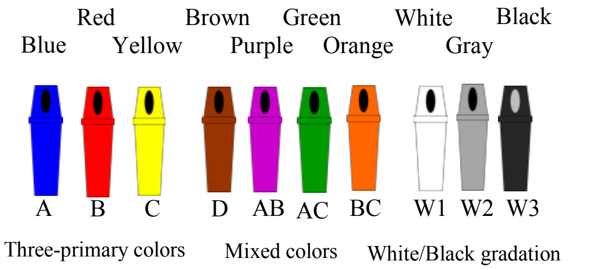

Figure 1. Designed trash bin colors

order to avoid the influence of trash bin shape on research results, the most common shape was chosen for whole process of color preference study, trash bin color was the single variable of this study.

WEB QUESTIONNAIRE SURVEY

<u>Design of WEB questionnaire</u>

Psychological researches show that, during a survey having a researcher present can lead to less honest and more social desirable answers. When using online or email questionnaires, because of there is no time limitation and no one waiting for an answer, respondents can take their time to complete the questionnaires and they will often answer more truthfully. Therefore in order to exclude other social psychological factors, in this study, WEB questionnaires data was used to scale the color preference by binary pairwise comparison method. This method shows two objects to questionees with the question, questionees were requested to only answer more preferred one, a piece of the WEB questionnaires shown as a sample (Figure 2) . If the number of tested objects are N, all of object pairs counted by $NC2=1/2*N*(N-1)$, In this case, it is include total 45

Figure 2. The sample of WEB questionnaires

pairs of trash bins for each type of trash bins. Questionees were from different part of Japan with balanced gender, equal age ranges of 20’s, 30’s, 40’s, 50’s and 60’s, different occupations and incomes. Collected valid answers were 730 in total.

Analysis of WEB questionnaire by Thurston’s law of comparative judgment

In this study, the authors used Z value to quantify the preferences of 10 common different colors. Binary pairwise comparison method was used to calculate the Z value as mentioned above.

Thurston’s law of comparative judgment assumes cumulative Gaussian normal distribution with the mean of 0 and the variation of 1 to describe the relation between selection ratio and the difference of preference of two objects presented to the questionees. (Thurston, 1927)

If questionees feel stronger preference for object A than the other (object B), for example, the chosen probability of object A will be higher. According to this analysis method, all data from the survey have been transformed to selection ratio .The selection ratio dataset were analyzed to quantify the preference degree (Z value) by inverse transformation of cumulative Gaussian normal distribution curve (Equation 1). Higher Z value means higher preference degree.

$$F(A)=\frac{1}{\sqrt{2\pi\sigma}}\int_{-\infty}^{Z_{AB}}\exp\left(-\frac{(Z_A-Z_B)^2}{2\sigma^2}\right)dZ_A \quad \text{(Eq.1)}$$

F (A) is selection ratio of object A

ZAB is the difference of color preference between object A and object B,

ZA and ZB are preference of object A and object B,

Obey the standard normal distribution：π=0 ， σ =1.

More detail of analysis method was shown in figure 3.

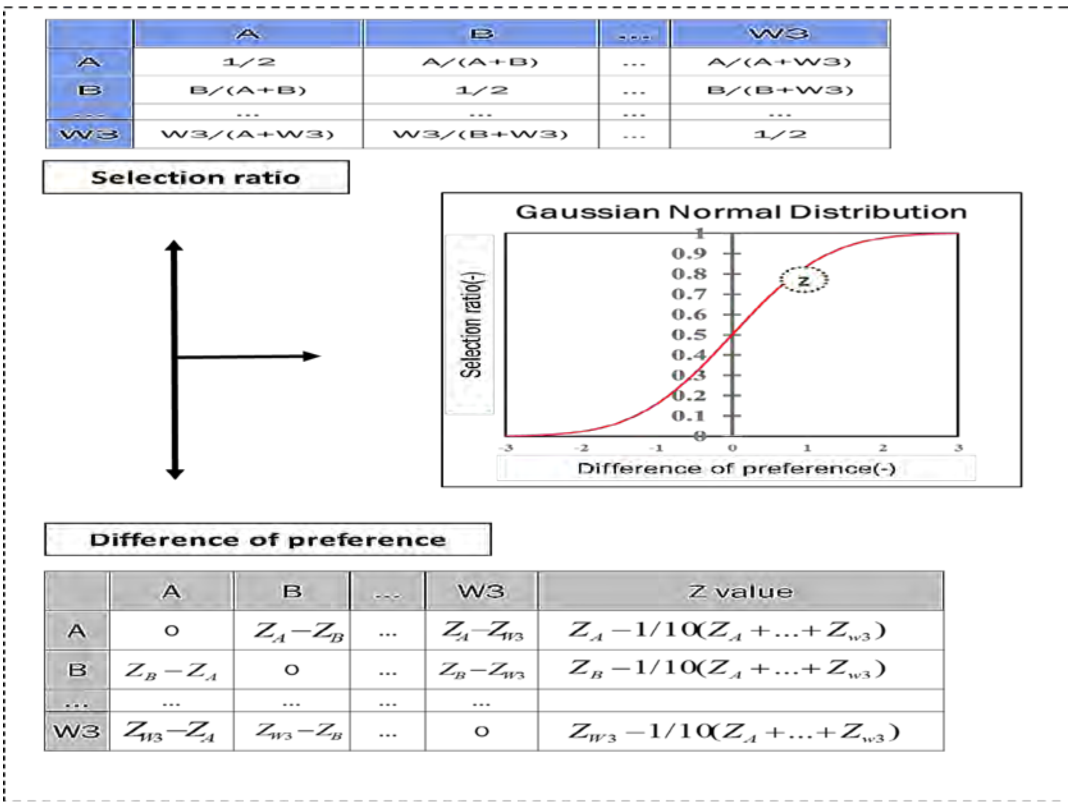

Figure 3. Concept of the Thurston’s law

TARGETED ANALYSIS

Preference structure analysis of gray selectors

According to the result of calculation, gray was not the best color in common but showed higher selection rate in each type of trash bin. Gray selectors for each type were extracted respectively as objects of targeted analysis, since there might be some regularities in their color preferences.

In this step, the authors have focused on extracted gray selectors for each type of trash bin, according to the Thurston's law of comparative judgment to calculated Z values of their answers for other types. For instance, if gray selectors for combustible waste were taken as research objectives (marked as C-gray-C), authors were calculated their color preference degree (Z value) of answers for other types of trash bin such as incombustible, PET bottle, CAN (marked as C-gray-INC, C-gray-PET, C-gray-CAN, respectively). Data calculations of gray selectors for the other three types (incombustible, PET bottle, CAN) were followed by this calculation method.

Hierarchical Cluster analysis

Hierarchical Cluster analysis (HCA) is a common technique of exploratory data analysis in social science. Based on the result of color preferences of gray selectors for each type of trash bin, in order to build a hierarchy of clusters (colors) to reflect the similarity and categorization of preferred colors, one of the HCA types which is divisive clustering was carried out and the result showed by the dendrogram.

RESULTS AND DISCUSSION

Color preference

Color preference degree (Z value) of each type of trash bin was shown in figure 4, higher z value means higher preference degree.

Z value of combustible waste trash bin was shown in figure 4 [a], preferred colors from the best to the worst were red, orange, gray, brown, white, yellow, green, black, blue and purple. Red and orange were preferred for combustible waste trash bin, it might because of these colors are colors of fire as mental suggestion in properly disposal of combustible waste (Hanes,R.M, 1959). Purple and blue were less preferred colors, may be due to they are cold colors in color theory (Adam,G.K, 1923).

Z value of incombustible waste trash bin was shown in figure 4 [b], preferred colors from the best to the worst were gray, black, blue, brown, orange, green, white, purple, yellow and red. Gray and black were preferred colors for incombustible waste trash bin, probably compare with others, trash bins in gray or black were easier to identified as incombustible waste trash bins. Z value of red shows much lower than others, this result was completely opposed to combustible waste.

Z value of PET bottle trash bin was shown in figure 4 [c], preferred colors from the best to the worst were white, gray, green, orange, yellow, blue, red, black, brown and purple. White was shows the highest selection rate it might because in traditional Japanese society white represents purity and cleanliness that, can be related to the washing which is one of the general steps of PET bottle disposal. Green was also shows higher selection rate might due to green is a more Eco-friendly color or the PET bottles of green tea covered by green label are very common in Japanese daily life which can easily reminded questionees of the green trash bin.

Z value of CAN trash bin was shown in figure 4 [d], preferred colors from the best to the worst were gray, orange, blue, yellow, black, green, brown, white, red and purple. Gray was selected as the most preferable color might because it is the color of most of the common metals, orange and blue were also preferable since those colors are common colors of appearance of canned drinks.

The most significant similarity is gray was relatively preferable for all types while purple was relatively less preferred.

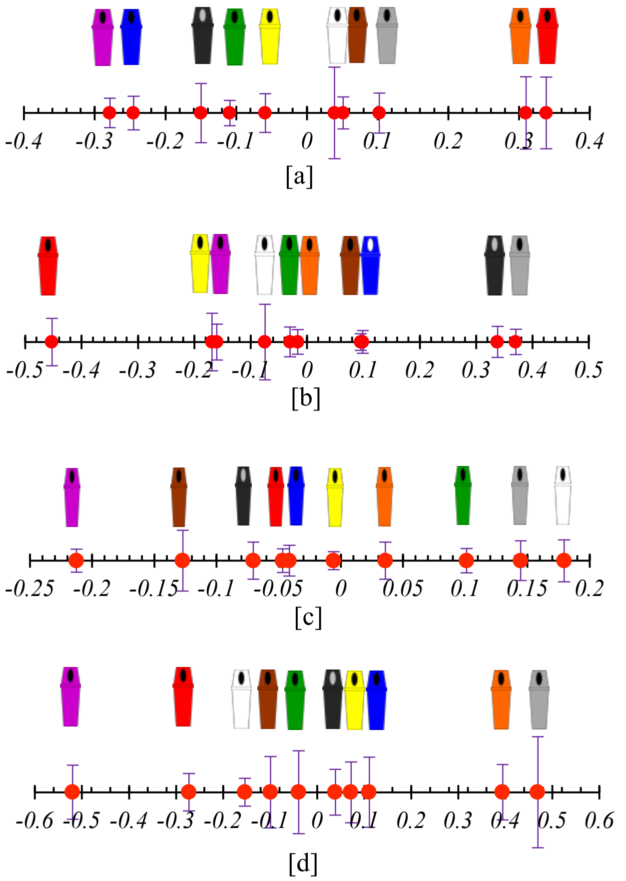

Figure 4. Z values of trash bin colors

[a] Combustible waste [b] Incombustible waste

[c] PET bottle [d] CAN

Color preference structures of gray selectors

Color preference structures of gray selectors shown by figure 6, descending order from left to right. Some color selection regularities were founded after observation. It is not difficult to see that for gray selectors, colors from white/black gradation were more preferable, except combustible waste, the most preferred color is gray, in addition, orange was showed higher selection rate. Purple as the less preferred color for each type, it was also showed lowest selection rate in these selectors. Brighter and easier detectable colors such as yellow and red have lower preference degree while green, blue and brown were in the middle position relatively but for combustible waste blue was also one of the less preferred colors.

According to this result, authors were preliminary assumed that, generally, trash bins in white/black gradation might be more favorable to gray selectors, some brighter colors such as red and yellow were not included in the scope they can be easily accept. It might be caused by people's understanding and definition of experimental object which is trash bin or personality traits, favorite color and cultural backgrounds.

Categorization of preferred colors of gray selectors

Based on the color preferences structure of gray selectors, hierarchy of colors was shown in figure 5. According to the dendrogram, experimental trash bin colors can be divided into three main categories which are gray, brown-black-orange-white, blue-green-yellow-red-purple and five sub-categories which are gray, orange-white, brown-black, red-purple, blue-green-yellow.

Colors which were divided to the same category showed similar selection rate. In another word, they showed similar performances to trash bin type being

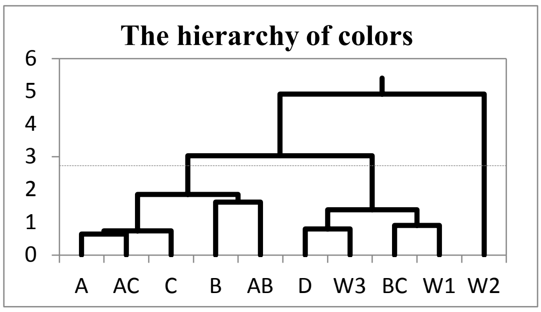

Figure 5. The hierarchy of colors

investigated in imaginations of questionees.

Order	1	2	3	4	5	6	7	8	9	10
C-gray-C	W2	W1	W3	BC	D	AC	C	B	A	AB
C-gray-INC	W2	W3	BC	W1	D	A	AC	C	AB	B
C-gray-PET	W2	W1	BC	AC	W3	C	B	D	A	AB
C-gray-CAN	W2	BC	W3	A	W1	B	AC	D	C	AB
INC-gray-C	B	W2	BC	D	W1	W3	C	AC	A	AB
INC-gray-INC	W2	W3	W1	D	BC	AC	A	C	AB	B
INC-gray-PET	W2	W1	AC	BC	A	B	C	W3	D	AB
INC-gray-CAN	W2	BC	W3	W1	A	AC	D	C	B	AB
PET-gray-C	BC	W2	B	W1	W3	D	AC	C	A	AB
PET-gray-INC	W2	W3	D	BC	A	W1	AC	AB	C	B
PET-gray-PET	W2	W1	BC	W3	AC	D	C	A	B	AB
PET-gray-CAN	W2	BC	AC	A	W3	W1	D	C	B	AB
CAN-gray-C	B	BC	W2	W1	D	W3	AC	C	AB	A
CAN-gray-INC	W2	W3	W1	D	A	BC	AC	AB	C	B
CAN-gray-PET	W2	W1	BC	AC	C	W3	A	B	D	AB
CAN-gray-CAN	W2	W3	W1	BC	D	AC	A	C	B	AB

Figure 6. Color preference structure of gray selectors

CONCLUSION

This study investigated in structural analyzed preference structures of trash bin colors for combustible waste, incombustible waste, PET bottle and CAN. Gray was relatively showed higher selection rate for all types, therefor gray selectors were extracted and targeted analysis were conducted. The result shows that gray selectors prefer white/black gradation colors more than others and orange was also one of the preferable colors. In contrary, some brighter colors showed lower selection rate even they are easy to detect and distinguish. Moreover, hierarchical cluster analysis was conducted, experimental colors were being categorized by similarity of selection rates. Interesting results have been obtained, for instance white and orange as well as red and purple were in the same color categories, further investigations on several influencing factors such as age distribution, gender balance, cultural background and other psychological factors are needed in future works.

ACKNOWLEDGMENT

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BASIC RESEARCH IN DETERMINING ORGANICS CONTENT OF SOILS FROM DISASTER DEBRIS BY LOSS ON IGNITION

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ABSTRACT

Organic matter in the soil is disadvantageous for use of soil as a soil resource. Therefore, it is important to know the organic matter content more accurately and easily at the site. Therefore, a method to improve ignition loss was proposed and evaluated. Also, if ignition loss can be corrected by improving procedures and conditions, ignition loss is practically useful as a means for determining the organic matter content. In this study, we focused on the combustion behavior of woody biomass. Samples are wood, cellulose and lignin. Comparing the cellulose lignin mixture to wood, the weight loss of the wood was almost 100%, but the weight loss of the mixture depends on the composition of the cellulose. Experimental results revealed that the influence of the flame retardant of biomass typified by lignin does not depend on its content but depends on its structure. In the same container, the larger the initial mass, the narrower and longer the container of the same mass, the longer the time required for weight reduction. Regardless of the cover of the crucible, it took quite a while to burn the sample using the cover. As a result of measuring the oxygen concentration, the supply of oxygen was greatly hindered even if there was a gap.

Keywords: Ignition loss, organic matter, disaster waste, tsunami deposit

INTRODUCTION

The damage caused by large-scale natural disasters such as earthquakes and torrential downpours extends not only to human lives and architectural constructions but also to topographies. As the result, a huge amount of disaster waste including rubble, dirt, driftwood and so on will be generated. Disposing these wastes quickly is essential for protecting public hygiene and rebuilding the affected area (Shimaoka, 2009). In the Pacific coast of Tohoku Earthquake in 2011, a disaster waste of 31 million tons occurred. (Ministry of the Environment Government of Japan, 2015). The largest percentage of the waste was 11 million tons of tsunami deposits. Most of them were used to construct parks and green spaces as a redundancy zone against tsunamis and to fill the areas where ground subsidence occurred significantly. However, wood chips in the disposal soil impair the physical and material properties of the soil. (Katsumi, 2015). It is important to know organic matter content in recovered soils in order to use as resources effectively.

There are several ways to estimate the organic content. The most typical one is the Total Organic Carbon (TOC) analyzer. In this method, the sample is completely burned in a high-temperature oxygen atmosphere, and another sample is burned in an acidic atmosphere. Finally, machine compare the amount of carbon dioxide produced. In other words, the amount of organic carbon is measured by subtracting inorganic carbon from total carbon. It features very accurate analysis results. However, the equipment is very expensive and the facilities that can be implemented are limited. In the event of a disaster, The TOC analyzer was not used and Loss on Ignition (LOI) was recommended. In LOI, the sample is placed in a hot air atmosphere and the weight difference before and after heating is measured. The weight difference ratio indicates the ratio of the volatile components in the sample (The Soil Testing Law revision editorial committee, 1970, JIS A1226:2009). This analysis method was originally used for analysis of incineration residue and sludge. However, because it is easy to conduct, it is being used instead. For example, the criteria for the Pacific coast of Tohoku Earthquake is that the LOI for 3 hours at 600 ℃ is 5% or less. (Ministry of the Environment Government of Japan, 2011).

As mentioned above, LOI is different from organic content. This is because it is affected by release of structured water from clay and decarbonation of carbonate. This tendency is remarkable especially in high temperature tests and samples with low organic matter content. Therefore, currently used standards and methods may overestimate organic matter. The ultimate goal of this research is to improve LOI and to promote effective use of waste from disaster. Specifically, we optimize the test method including temperature, time, container and weight. First, the behavior of organic matter is clarified. National Institute for Environmental Studies, Japan (NIES) and Kogakuin University confirmed the temperature using known samples mixed with soil and wood chips. As a result, when the temperature was lower than 350 ℃, the wood chip remained burned, and the error rapidly expanded. The error was minimal at 375 ℃ and showed a tendency to rise gradually as the temperature increased. Also, the discharge of structural water from clay increases when it exceeds 450 ℃. Based on the above, it is estimated that it is the optimal temperature condition at 400 ℃.

In this study, the influence of the several kind of containers and organic components on examination conditions was investigated. The shape of the crucible and the presence or absence of a cover may affect the heating of the sample and the supply of oxygen. Tested with multiple crucibles of different shapes and find correlation conditions. Next, confirm that the cover affects decomposition of organic matter. Also, it is considered that the mixed organic matter differs depending on the affected part. This time we will focus on biomass and verify the difference in degradation behavior.

EXPERIMENTAL

The general process of the experiments follows the Ignition loss. The experimental temperature is 400 ℃, but this is temperature of the furnace. Other conditions vary by experiment. The experiments are roughly divided into two kinds. The weight measurement and the oxygen measurement. Each summary is described below.

Evaluation of ignition loss

Changes over time in sample weight were recorded during heating at constant temperature. Can observe the pyrolysis and combustion behavior by following the changes in the sample weight. The outline of equipment is shown in Figure 1. The heating of the sample uses a PID control electric maffle furnace. Use a gas port on the ceiling of the furnace, connect the hanged scale inside the furnace and the balance on the furnace. A balance and a PC are connected by wire and record the weight automatically every 5 seconds.

The samples used Japanese red pine, Japanese cypress, Eucalyptus, Cellulose, Lignin. These biomasses were ground with a blender. Then, it passed through a 2.0 mm of sieve, and remained on 0.5 mm sieve. Cellulose and Lignin used powder products. For crucible, several different shapes of alumina container are used. Mainly used 3 kinds of inner diameter and depth of 92×20, 62×52, 45×65 mm. The thicknesses are about 3 mm. Also, as an auxiliary to the oxygen measurement experiment, 75×76 mm, thickness is about 5 mm was used.

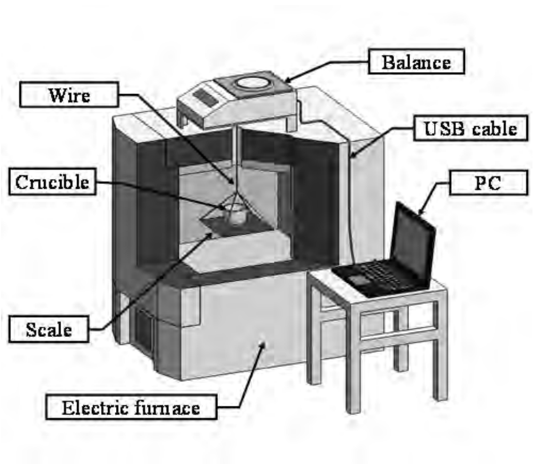

Figure 1 Experimental equipment for weight measurement

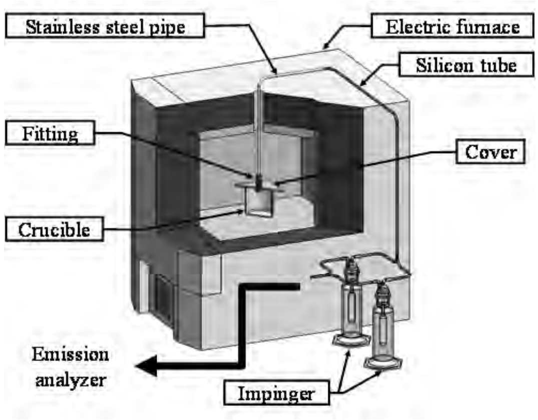

Figure 2 Experimental equipment for O˜ concentration measurement

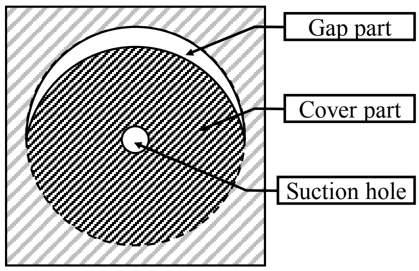

Figure 3 Cover plate for covering and gas collection

Effect of diffusion and convection in a furnace

The time course of the oxygen concentration in the crucible was recorded during heating. The outline of this equipment is shown in Figure 2 and 3. This experiment is done by putting a cover plate on the crucible. Cutting a part of the plate makes the space open. This is to reproduce the situation when the cover is placed diagonally on the crucible. The gas generated in the crucible is carried out of the furnace through the gas port just like the weight measurement experiment. The gas passing through the impinger is inhaled by emission analyzer (testo327-2). Then, read and record value indicated by emission analyzer. Actually, recorded it as a video.

The sample is chips of Japanese red pine. The crucible kind is 75×76 mm that used in the weight measurement experiment.

RESULTS AND DISCUSSION

Evaluation of ignition loss

Changes over time in weight ratio of Japanese red pine are shown in Figure 4. And, experimental conditions and results are shown in Table 1. All curves are divided into two at about 30% of the weight ratio. The first half of the reaction is mainly Pyrolysis, and the latter half burns slowly char. Pyrolysis proceeds very fast, so it will be completed in a few minutes. In the meantime, most of the mass is lost as gas and tar (Kawamoto, 2015). Most of the time to lose weight is char combustion.

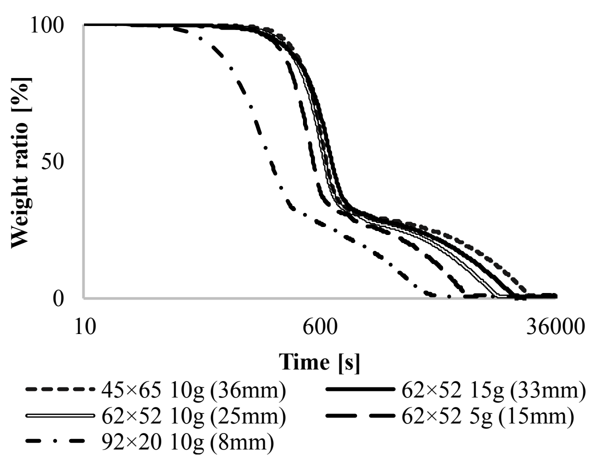

Figure 4 Change with time of weight ratio of Japanese red pine (excerpt)

Legends: Size of crucible (Inner diameter × Depth), Sample weight, Height of stacked samples

Table 1 Conditions and result (Japanese red pine)

Crucible diameter	Crucible depth	Sample weight (wet)	Sample weight (dry)	Height of stacked samples	99%weight loss time
92mm	20mm	2.5g	2.3485g	3mm	3760s
92mm	20mm	5.0g	4.4961g	6mm	4265s
92mm	20mm	10.0g	8.9130g	8mm	4410s
62mm	52mm	5.0g	4.4792g	15mm	8980s
62mm	52mm	7.5g	6.7190g	20mm	11150s
62mm	52mm	10.0g	8.9512g	25mm	13030s
62mm	52mm	12.5g	11.6898g	30mm	16816s
62mm	52mm	15.0g	13.3912g	33mm	17826s
45mm	65mm	5.0g	3.9968g	24mm	13825s
45mm	65mm	7.5g	6.7058g	29mm	18730s
45mm	65mm	10.0g	8.9301g	36mm	23081s
45mm	65mm	12.5g	11.1421g	45mm	26325s
45mm	65mm	15.0g	13.4034g	57mm	29841s

Table 2 Result of regression analysis

	Crucible diameter	Crucible depth	Sample weight (dry)	Height of stacked samples	Intercept	R^2
Coefficient	-526.70	-470.13	89.17	439.45	59045.92	0.9860
P value	1.056E-01	1.193E-01	7.340E-01	1.689E-03	9.810E-02	
Coefficient	-457.12	-412.22		469.70	51782.38	0.9857
P value	4.804E-02	7.272E-02		6.388E-07	4.817E-02	
Coefficient	-56.13			477.91	6105.72	0.9792
P value	1.556E-01			6.857E-07	9.217E-02	
Coefficient		45.74		490.29	19.25	0.9775
P value		2.636E-01		6.355E-07	9.880E-01	
Coefficient				533.21	1195.77	0.9743
P value				4.280E-10	1.493E-01	

When effect of initial sample weight was investigated, the larger initial weight was, the longer time taken to burn out became. Using crucibles with different shapes, on the other hand, different weight loss behavior was indicated even though initial weight was equal. In particular, it was found that the time taken to burn out became long with increased height/width ratio of crucibles. The cause of this result is that char combustion is very slow. Ignoring the thermal conduction bias in the crucible, the Pyrolysis will appear in the whole area of sample. However, combustion of char is expended oxygen, so it exists only at the top of sample.

In order to show this quantitatively, a multiple regression analysis was performed. The time at which the sample decreased by 99% was taken as the dependent variable, and other relevant conditions was taken as the independent variable. The results are shown in Table 2. The weight of the sample seems to affect the time at which pyrolysis ends. However, P value is very large, weight may not be a direct factor. Alternatively, pyrolysis itself may be too small as a factor. Calculations using three variables have high determination coefficient, but the signs of the coefficients are contradictory. If container deep, it is difficult for air to reach the sample.

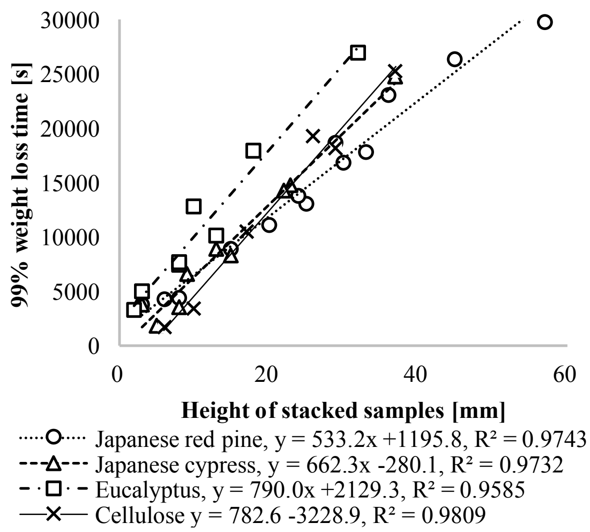

Figure 5 Time at which weight reduction with respect to stacked height of sample and its linear approximation

All the results show that the height of stacked samples is the most linear. Similar results were obtained for the other two biomass and cellulose. Linear regression was performed for each sample and the results are shown in Figure 5 as a linear function graph. In the comparison of the coefficients, the coefficients are large in the order of cellulose and Eucalyptus, Japanese cypress, Japanese red pine. Cellulose, hemicellulose and lignin are the main components of biomass. Lignin is difficult to volatilize, and it has the property of easily producing char. Component analysis of the sample used this time is not completed yet, but it is generally said that hardwoods are less lignin. From the lignin content of the literature, it seems to be more in order of Japanese cypress, Japanese red pine, Eucalyptus (Asano, 1982, Okano, 2013, Kamei, 1979). This seems to conflict with experiment results.

A comparison of various samples of the same mass is shown in Figure 6. A large amount of residue is produced in a mixed sample of lignin simple substance, cellulose and lignin. Cellulose alone and biomass decrease by 99% or more, but eucalyptus is slower than the other three species. From the above results, it is considered that the influence of flame retardant in biomass typified by lignin depends on the structure of the tissue regardless of its content. Lignin in biomass exists as an adhesive for cellulose fibers, but simply mixed lignin promotes carbide formation without burning with cellulose. Therefore, it did not burn completely. Differences in biomass samples were born mainly due to differences in the structure of conifers and hardwoods. As conifers have a uniform structure consisting entirely of tracheid, lignin and cellulose also exist dispersedly. Hardwoods are inhomogeneous structures of cellulose fibers and vessels, whose cross-section structure is unique for each tree species (Asano, 1982, Okano, 2013).

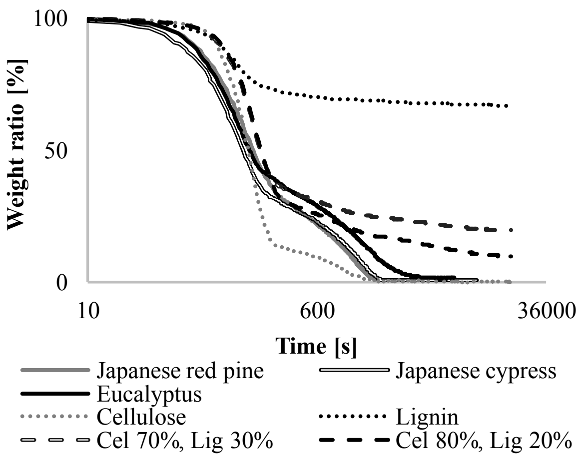

Figure 6 Change with time of weight ratio of various samples of the same mass

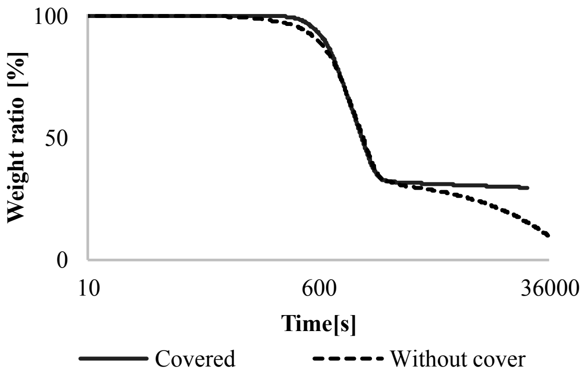

Figure 7 Change with time of weight ratio with and without cover

<u>Effect of diffusion and convection in a furnace</u>

Figure 7 shows a comparison of the weight ratio variations of covered and uncovered heating. To emphasize the difference, the amount of sample is excessive. In the first half of the reaction, the reaction is started slightly later by the cover, but the main reaction proceeds in the same way. The time and weight ratio of the reaction transferred in the second half are also the same. Symmetrically, the latter half of the reaction has definite differences over time. This is because the reaction in the latter half is mainly burnt char. Since the first half of the reaction is the order of pyrolysis and combustion gas, its effect is small even in the cover. However, since combustion of char is mainly based on pure oxidation reaction, oxygen is indispensable for the progress of weight loss.

The results of oxygen measurement experiments are shown in Figure 8. The curve of sample weight ratio without cover is for comparison with the degree of progress of the reaction. A part of the cover is cut off and the gap shows its area ratio. On all covers, oxygen starts to sharply decrease with sample weight ratio.

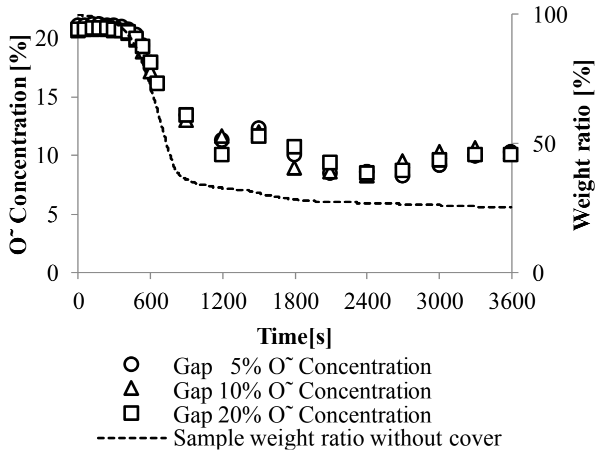

Figure 8 Change with time of oxygen concentration

As mentioned above, it appears to have ignited volatile components. When gently reacting, the decrease in oxygen converges but the decrease in oxygen concentration does not recover and continues to rise and fall at about 10%. From the above, if there is no cover, it slightly affects the initial stage of heating. However, it seems that there is very little whether there is no effect such as accelerating the progress of major reactions. Conversely, if there is a cover, even if the crucible is not completely covered, there is a high possibility that oxygen deficiency is induced. This can adversely affect the combustion of char occupying most of the weight loss time.

CONCLUSIONS

As a result of weight measurement, the time required for weight reduction of organic matter will depend on the shape of the crucible and the type of biomass mixed in. The shape of the crucible is flat, and when it is widely opened, weight reduction is completed in a short time. Leading to suppression of errors due to non-organic matter which expands with time. The influence of the type of biomass may not be that large for small samples. However, depending on the specific tree species and preparation method of the sample, it may be considered.

Oxygen measurement experiments showed that the test method covering the crucible has the potential to extend the test time.

ACKNOWLEDGMENT

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RECYCLING OF BY- PRODUCT SALT BY MATSUYAMA METHOD

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ABSTRACT

Matsuyama city has produced a disinfectant (hereinafter referred to as "Eco sodium hypochlorite") from the by-product salt generated in the leachate treatment process of final disposal sites of municipal solid waste ahead of other cities in the world, constructed a salt recycling system to be used as a substitute for sodium hypochlorite (hereinafter referred to as "commercial hypochlorite") which is a conventional commercial disinfectant at the sewage treatment.

In the final disposal sites of municipal solid waste, by-product salt is generated in the reclamation of ash which incinerated residue during the leachate treatment process, however, an effective recycling method for this by-product salt has not been established. With regards to the recycling of by-product salt, the efficient use of Eco sodium hypochlorite has been reported in various kinds of research results, including Salt Recycle System Association. However, the comparison with commercial hypochlorite from aspects of composition, effective chlorine concentration has not been put into practical use.

Matsuyama city developed the generating system and injection treating device for Eco-sodium hypochlorite through nearly one year demonstration test, examined the stability, safety of Eco-sodium hypochlorite and the disinfection effect on sewage treatment water, then put into practical use

Keywords: Eco sodium hypochlorite, Matsuyama method, salt recycling system

1 BACKGROUND

The Yokoya Landfill Center (hereinafter referred to as "Landfill Center") is an MSW landfill site in the city of Matsuyama. The capacity of this landfill center is 550,000 cubic meters, and the use of it was started in April 2003, mainly for noncombustible matter from households and incineration residues from incineration plants. The leachate which was oozing through the landfill sites is collected in a reservoir and a given quantity is treated in leachate treatment plant then detoxicating discharged into the river. However, as a feature of the plant, since it is used as agricultural water in the downstream of the river, desalination is carried out by membrane treatment. In the leachate treatment plant before improvement, the salts in leachate by incineration ash is concentrated by the membrane and solidify in fuel oil boiler. Then, it is disposed in the private treatment plant outskirts of the city.

Although the remaining capacity of final disposal sites nationwide is not enough, the construction of a new one is so difficult that the extending life of the existing plants becomes an important issue. Under such circumstances, the duration of landfill in Matsuyama city was greatly extended by doing various kinds of efforts to reduce landfills for the purpose of the extending life of the landfill center. However, due to the promotion of recycling of landfills except for the incineration ash, the ratio of incineration ash among all landfills was increased. Moreover, the chlorine contents in incineration ash were increased by means of the exhaust gas in the incineration plant, it caused the chloride ion in leachate becomes a high concentration. As a result, the decline of the efficiency of membrane treatment in the leachate treatment plant is remarkable, the throughput of all leachate plants had fallen to about 30% of the design capacity. As the water level of the leachate reservoir increased, a danger of overflow of untreated water during the periods of heavy rainfall such as the rainy season and typhoon. Therefore, it is necessary to take drastic measures to stabilize the leachate treatment in the future.

In the Matsuyama city, as temporary measures for the rise in water level of leachate reservoir, some correspondence is made. For instance, leaching the leachate which has a relatively lower chloride ion concentration from the reservoir or external treating the high concentration salt water at the bottom of the reservoir. However, these measures did not lead to a drastic improvement in the amount of treated water. Furthermore, facing the problem of the amount of treated water being reduced, when the capacity increase was done as it was as dry salt, a new membrane treatment plant or extension for dryers become necessary. Additionally, a large amount of construction cost and maintenance cost such as membrane maintenance costs and by-product salt treatment costs are expected to increase. Therefore, these correspondences were difficult to carry out. With the aim of improving the processing capacity economically and rationally and promoting the recycling of by-product salt, we try to change the processing flow of leachate treatment plant and introduce eco sodium hypochlorite generating apparatus so that eco sodium hypochlorite generate from by-product salt and it can be effectively used as a disinfectant for sewage treatment plant.

2 THE INTRODUCTION OF ECO SODIUM HYPOCHLORITE GENERATING APPARATUS

The improvement work on leachate treatment plant began in February 2014 and completed in March 2016. (Pic.1 and Pic. 2)

After the introduction of eco sodium hypochlorite generating apparatus, the leachate treatment flow is shown in Fig. 1. In the equipment for flocculation sedimentation treatment, a flocculant is added to the leachate which containing suspended matter and calcium content. After removal by flocculation sedimentation treatment, BOD is decomposed, chromaticity and COD are absorbed and removed in an air diffuser type filter tank or an activated carbon filter. Then, suspended matter and SS dioxins are removed in the precision filtration device to prevent the membrane from clogging in the latter part. The processing flow up to this point is as same as the flow before improvement. Then, in the case of before improvement, the concentrated water which containing salts is concentrated to 5% by the reverse osmosis membrane apparatus, and further converted by the ion exchange membrane of electrodialyzer, then make it into dry salt which moisture content is below 10% by a vacuum type dryer and the external treatment is carried out. However, in the case of after improvement, utilizing the property that the electrodialysis concentrating apparatus is superior to the reverse osmosis membrane apparatus in concentration efficiency towards high concentration salt water, changing the order of the electrodialysis concentrating apparatus and the reverse osmosis membrane apparatus, enhancing the electrodialysis concentrating apparatus. The generated concentrated salt water is electrolyzed by a diaphragm free in an eco sodium hypochlorite generating apparatus. Then, the produced eco sodium hypochlorite is effectively used as a disinfectant. Besides, a new chelating adsorption tower is installed in the front of eco sodium hypochlorite generating apparatus, as it can prevent the occurrence of the adhesion of calcium scale of the electrode, eco sodium hypochlorite generating apparatus becomes possible to operate for a long time.

In addition, the vacuum type dryer which was used in the drying step of concentrated salt so far is being inactive.

Pic.1 The foreground of eco sodium hypochlorite generating apparatus

Pic.2 Eco sodium hypochlorite generating apparatus

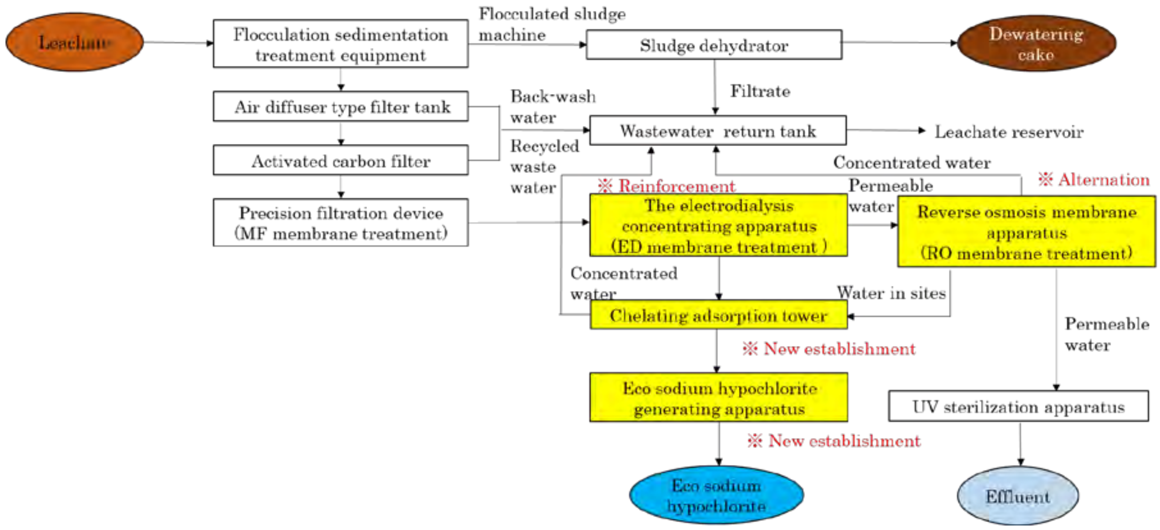

Fig.1 The flow of leachate treatment

3 THE DEMONSTRATION TESTS

Since there is no other example of generating eco sodium hypochlorite from by-product salt in MSW landfill sites and using it as a disinfectant for sewage treatment plants, three demonstration tests are gradually carried out in order to make sure the disinfecting effect and safety of eco sodium hypochlorite. Since there is no prescribed method for these tests, we believe that it is necessary to verify the test method and results. Mr. Sotaro Higuchi, a professor from Fukuoka University who is the leading scholar of eco sodium hypochlorite and Mr. Tetsuya Kusuda, an emeritus professor from Kyushu University with a distinguished insight for sewerage technology, has inaugurated the investigation commission members of the demonstration test for eco sodium hypochlorite in the city of Matsuyama.

The demonstration test for eco sodium hypochlorite is carried out as the first demonstration test. It confirms that it is possible to produce eco sodium hypochlorite by an available chlorine concentration which was arbitrarily set and the generated eco sodium hypochlorite satisfies the standard concerning the characteristics (28 items of health items, 15 items of living environment items, dioxins). As a result, it suggests that eco sodium hypochlorite can be stability produced by an available chlorine concentration (1,000～3,000mg/L) which was arbitrarily set, and the generated eco sodium hypochlorite satisfies the standard concerning the characteristics.

A pre-test is carried out at the second stage. In this test, a scale device, a tenth part of the actual disinfection tank, is installed in the sewage treatment plant, and the treated sewage effluent, eco sodium hypochlorite and commercial hypochlorite are reacted in this device. Then, the disinfecting effect, the water quality and the implantation condition in actual operation can be confirmed. Besides, since the destination of the treated water after eco sodium hypochlorite injection is a sea region, considering the influence on marine organisms, we also conducted a test on biological effect by using *Tigriopus*. As a result, the treated water after eco sodium hypochlorite injection satisfies the effluent standard in the Sewerage Law, and there is almost no effect on water quality by eco sodium hypochlorite injection. It is also confirmed that there is almost no pH increase of treated water among the range of injection ratio of eco sodium hypochlorite. Besides, the difference between eco sodium hypochlorite injection and commercial hypochlorite injection is not recognized. In addition, the acute toxicity of eco sodium hypochlorite to marine organisms is lower than that of commercial hypochlorite. It is also verified that the dilution of range in this test has not influenced on the breeding of marine organisms. The treated sewage effluent which has already added eco sodium hypochlorite is temporarily stored in the initial precipitation basin, analyzed by the measurement certification business operator, confirmed within the effluent standard in the Sewerage Law and then discharged.

As a demonstration test at the final stage, it is carried out by an actual machine. This test is assuming actual operation, using eco sodium hypochlorite injection plant constructed in the sewage treatment plant for about 1 year and an existing disinfection tank. Eco sodium hypochlorite and commercial hypochlorite are injected and disinfection effect and controlling conditions are confirmed. The treated sewage effluent which has already added eco sodium hypochlorite and commercial hypochlorite are discharged as usual. As a result of this test, the quantity of discharge in eco sodium hypochlorite, commercial hypochlorite and treated sewage effluent can be properly injected, the number of coliform bacilli in discharge water cannot be count and the sufficient disinfection effect can be confirmed. It also confirmed that all the discharge water quality standards can be satisfied. Besides, in the case of the concentration of residual chlorine, we obtained that only the result of commercial hypochlorite is as same as the disinfection result in the following year. The results which the investigation commission members of the demonstration test for eco sodium hypochlorite have shown are as follows. It is possible to produce eco sodium hypochlorite with an available chlorine concentration which was arbitrarily set and the generated eco sodium hypochlorite satisfies all the standard concerning the characteristics. Therefore, there is no problem with its quality. It has the same disinfection effect as commercial hypochlorite, so it can be used as an alternative without difficulties and problems. Besides, it is evaluated that both eco sodium hypochlorite and commercial hypochlorite is able to properly injected and there is no problem with residual chlorine concentration.

At the leachate treatment plant in landfill center, the chloride ion concentration of leachate is 13,000mg/L. If it can be treated 115m^3 per day at the maximum operable time, the discharge water with a chloride ion concentration of 200mg/L is 95.7m^3. When the chloride ion concentration is 108,000 mg/L, 17.8m^3 of eco sodium hypochlorite can be generated with an available chlorine concentration of 2,000mg/L. After transporting to sewage treatment plant by lorry tank, eco sodium hypochlorite will be stored in a storage tank and combined use with the existing commercial hypochlorite. In the case of the method for combined use, a certain amount of eco sodium hypochlorite is injecting while the injected amount of the existing commercial hypochlorite is controlling against the fluctuation of a purge flow rate of sewage treated water. The available chlorine concentration of generated eco sodium hypochlorite can be arbitrarily adjusted within the range of 1,000 to 3,000mg/L by setting the current value. (Fig.2) (Pic.3, Pic.4)

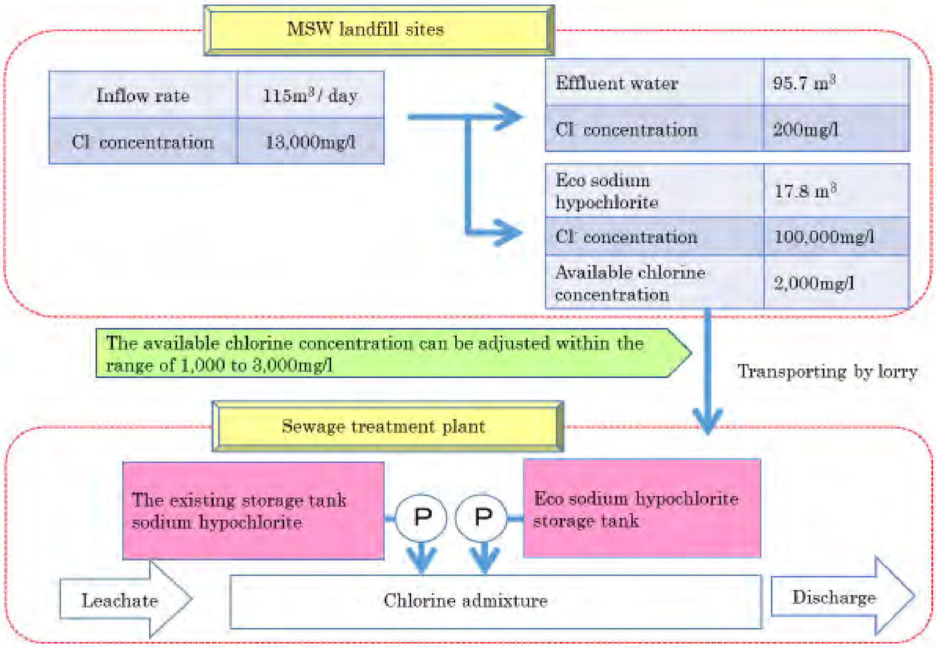

Figure 2　The using flow of eco sodium hypochlorite

Pic.3 Eco sodium hypochlorite injection equipment in sewage treatment plant

Pic.4 Eco sodium hypochlorite injection pump

4　INTRODUCTION EFFECTS

With the introduction of eco sodium hypochlorite generating apparatus, the water level of leachate reserving pond has decreased because the restoration of the leachate treatment amount was depressed in the landfill center, a stable leachate treatment become possible. Comparing with increasing the conventional method for dried salt, in addition to drastically decrease of maintenance costs, maintenance and management costs such as flue costs which used in the drying process and processing cost of dried salt are reduced. Moreover, CO_2 emissions are also reduced by not using heavy oil during the drying process. (Table 1)

In addition, in the sewage treatment plant, with the using of eco sodium hypochlorite, the purchase quantity of commercial hypochlorite is reduced.

Table 1　The comparison between the introduction of eco sodium hypochlorite generating apparatus and the expansion by conventional method(Landfill center)

	The introduction of eco sodium hypochlorite generating apparatus	The expansion by conventional method	Reduction
Maintenance cost	Nearly 900 million yen	Nearly 4 billion yen	Nearly 3.1 billion yen
Maintenance cost per throughput	Nearly 4,600 yen/m^3	Nearly 8,700 yen/m^3	Nearly 4,100 yen/m^3
CO_2 emissions per throughput	Nearly 21kg- CO_2/m^3	Nearly 65kg- CO_2/m^3	Nearly 44kg- CO_2/m^3

5 CONCLUSIONS

As a countermeasure towards high concentration of salts at the landfill center in the Matsuyama city, eco sodium hypochlorite generating apparatus was introduced and the generated eco sodium hypochlorite was used as a disinfectant for sewage treatment plant became fully operational from April. 2017. This work is a global recycling system that uses the unnecessary salt produced by waste treatment as a useful disinfectant for sewage treatment, therefore, careful handling is required to this project, the environment department and sewerage department cooperated with each other and completed the demonstration test for nearly a year. From now on, we will transmit this recycling system to the world as "Matsuyama method", and work on this project so that it will become a means for local governments who are struggling with the treatment of by-product salt generation from the MSW landfill sites.

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POST-CONSUMER PLASTIC WASTE MATERIAL FLOW ANALYSIS: A CASE STUDY IN KANDY MUNICIPAL COUNCIL OF SRI LANKA

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ABSTRACT

Though recycling and recovering are the most appropriate and productive solutions to avoid the piling up of Post-consumer Plastic Waste (PCPW) in dumpsites, it is often hindered by lack of quantitative and qualitative assessment. Thereby two related studies were carried out in the Kandy Municipal Council (KMC) studying the dynamic behavior of PCPW flow. The quantitative data was numerically analyzed by software STAN® to explain PCPW flow as a network of flows, stocks and processes. All five major processes of a material flow analysis; consumption, collection, processing, manufacturing and dumpsite disposal were identified within KMC. The PCPW generation and its composition were analyzed based on the Resin Identification Code. It was showed that the major portion of PCPW is Low Density Polyethylene (37% w/w) followed by Polyethylene Terephthalate (20% w/w), Polypropylene (14% w/w), and High Density Polyethylene (8% w/w). It was estimated that the PCPW average generation in KMC for year 2014-18 was 12.0 MT/day (117 g/ person/day) that consisted of 87% soft and 13% rigid plastics. The overall PCPW recycling rate in KMC was 30% (3.6 MT/day) in which 17% is processed to crushed pieces, 15% to manufacture goods and 68% transport to other cities. It also revealed that restaurants and hotels are less willing to cooperate in source-segregation rather than other sources, which is accounted for heavy contamination of PCPW in waste stream.

Keywords: post-consumer plastic waste, material flow analysis, recycling, resin identification code

INTRODUCTION

Increasing demand for quality municipal solid waste (MSW) collection, processing and disposal services is an emerging environmental and socio–economic issues faced by many local authorities and municipalities, specially in developing countries.

Most severe part of the solid waste accretion is inclusion of considerable amounts of non–degradable solid wastes that have to be disposed at dumpsites. Minimizing energy and natural resource use, minimizing waste and gas emissions to the environment and enhancing 3R concept are most feasible options to handle the issues (Binder, et al., 2009). Among those options, recycling and recovering are considered the most applicable and successful solutions for the management of post-consumer plastic waste - PCPW (Howard, 2002). A better understanding of qualitative and quantitative characteristics of PCPW is needed. (Al-Salem, et al., 2009).

Most of the time, the readily available waste composition data is not satisfactorily reflect the "dynamic flow" of solid waste within an entity. Material Flow Analysis (MFA) is an important tool in analyzing the material flows and it can be defined as the analysis of the throughput of process chains comprising extraction or harvest, chemical transformation, manufacturing, consumption, recycling and disposal of material (Ayres and Ayres, 2002). It has been shown that MFA will help to fill the gaps and to obtain a complete image about any "material flow" within a geographical or imaginary boundary.

The quantitative assessment of PCPW can be effectively used to improve the collection and overall management of waste in a city. However, knowledge on the quality and composition of PCPW are needed to develop appropriate recycling programs. Most of the mechanical recycling systems prefer to sort plastics based on Resin Identification Code that is often used during the plastic good manufacturing process.

Therefore, first aspect of this study is set to identify and quantify the flow of post-consumer plastic waste in MSW stream of the Kandy Municipal Council (KMC) of Sri Lanka which is the second largest urban area of the country. Secondly, to study the composition of post-consumer plastic waste, particularly based on Resin Identification Code (RIC) System.

METHODOLOGY

<u>Study Area</u>

Kandy Municipal Council (KMC) is the second largest city in Sri Lanka and urban center of Central Province. As shown in Figure 1, the KMC administrate a city area of 28.53 km^2 with a residential population of 102,500 and a large daily migration population up to 400,000 (Dissanayake, 2013). The city is densely populated with households, commercial and institutes. It has been estimated that the daily waste generation is 176 metric tons/day (MTD) and the present collection is about 130 - 150 MTD (Dissanayake, 2013). The collected waste is delivered and dumped at Gohagoda dumpsite, approximately 8 km away from city center.

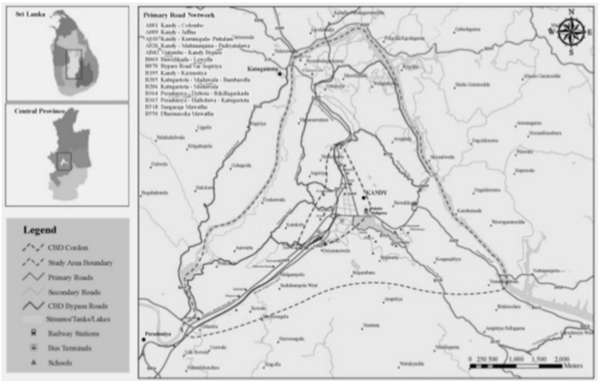

Figure 1. City map of Kandy Municipal Council (KMC) area, Sri Lanka

Material Flow Analysis

The basic methodological principle use in this analysis is the principle of mass balance (Cencic and Rechberger, 2008). As illustrated in Eq. 1, The net change of a particular material stock is given by the total inflows minus the total outflows from the stock, using the principle of conservation of mass (Kuczenski and Geyer, 2010).

$$\Sigma \text{ Inputs} = \Sigma \text{ Outputs} + \Delta \text{ Stock} \qquad [1]$$

The masses of material generate, flow in, store and destroy and flow out within an arbitrary or geographical boundary over a predefined period of time is defined as system components. The quantification need extensive amount of data handling; thus the data processing was done using software STAN® (short name for subSTance flow ANalysis). The STAN® was developed for the purpose of MFA by Cencic and Rechberger (2008). In this software, results of the mass flows are presented in the form of Sankey diagrams. In Sankey diagrams, mass flows of goods and substances are displayed as Sankey arrows and width of a Sankey arrow is proportionate to the mass flow value (Schmidt, 2008).

The amount of PCPW generation was estimated using two approaches with several sub-activities.

1) data collection from stakeholders

i. Identify sources and quantities of PCPW for a year (2015) from secondary data sources (records, bills and inventories) related to waste generators, collectors, processors and disposal sites.
ii. Collect primary and missing data from key stakeholders through questionnaire survey

2) Development of database and execution of Material Flow analysis using STAN®

i. Review collected secondary data
ii. Design initial MFA diagram
iii. Calculate material flow dynamics within the KMC boundary

The questionnaire survey filled through direct interviews and verifying the responses with available data. There were 42 surveys in total including large waste generators (Markets, institutes, religious places etc.), recycling venders, recycling factories and plastic good manufactures in and around KMC limits.

PCPW composition analysis

The waste generators in KMC area were categorized into four major groups; Households, Hotels, Businesses and Other sources. Thereafter, the sample size was determined to represent 0.2% of the total waste generators that comes to 69 establishments. The sample was consisted of 16 households, 28 businesses (traders), 19 hotels and 6 other institutions (hospitals, government institutions, religious places). First, waste generated were instructed to separately dispose daily generation of all plastic waste into provided garbage bag. The garbage bags containing the PCPW from each establishment was daily collected in the evening from each establishment by the surveyors and transported to laboratory for analysis. The sampling was continued for 7 consecutive days in January, 2018.

Each bag sample was weighted and sorted into nine pre-defined categories Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), Polypropylene (PP), Polystyrene (PS), other plastics, laminated and aseptic plastics. The weight of plastic waste in each category of a sample was also recorded (Figure 2).

Figure 2. Sampling and analysis of plastic waste collected from waste generators in KMC area

RESULTS AND DISCUSSION

The preliminary estimates based on secondary data and questionnaire survey on plastic waste generation quantities showed that the percentage of PCPW in waste stream of KMC is 6.82 % of the total MWS generation.

Table 1 Summary of the collected PCPW flow data for each process in MFA

Source	Nos.	MSW (TPA)	PCPW (TPA)	PCPW (% of MSW)
Households	170,915	12,663	805	1.25
Traders	5,089	16,410	2,199	3.42
Private institutes	342	3,723	124	0.19
Government institutes	269	2,916	99	0.15
Schools	80	701	102	0.16
Religious places	209	2,123	149	0.23
Hospitals	12	2,259	249	0.39
Hotels	436	17,795	864	1.34
Other (markets etc.)	560	5,760	230	0.36
Total	*177,445*	*64,350*	*4,391*	*6.82*

As summarized in Table 1, the largest contributor is the commercials (traders and vendors) that is responsible for generating 2,199 MT of waste per year (TPA) which is equal to 3.42% of total MSW generation (64,350 TPA). The second largest plastic waste generator was hotels followed by households.

The MFA analysis identified that all processes in plastic waste management such as plastic consumption, plastic waste collection, dumpsite disposal, plastic recycling, export/import out of the boundary and plastic good manufacturing are presence within the PCPW management cycle.

The Figure 3. shows the Sankey diagram of PCPW flow in KMC area for the year 2015. The MFA showed that major portion of plastic waste directly flows to the dumpsite (2540 TPA) whereas a small portion of plastic waste are collected by scavengers (255.67 TPA). The total plastic waste recycling was only about 33 % from the total plastic generation. Approximately 5.5% of mechanically recycled plastics are used for manufacturing goods within the KMC limit but the major portion (153.4 TPA) export to other cities as pellets and flakes. However, it should be noted that PCPW flows into KMC area as recyclable plastics through collectors (182.6 TPA), as raw material for recycling centers for processing (14.6 TPA), and as raw materials for plastic good manufactures (20 TPA).

The main outflow channel is the transport and sale of raw PCPW to recyclers and venders outside the KMC boundary which is high 964.2 TPA. The total outflow of PCPW in the form of raw recyclable plastic is as much as 82% of total plastic outflow from the city. Four major sources of PCPW contribute to the accumulation of PCPW at Gohagoda final disposal site. The annual stock increment of PCPW at Gohagoda dumpsite is about

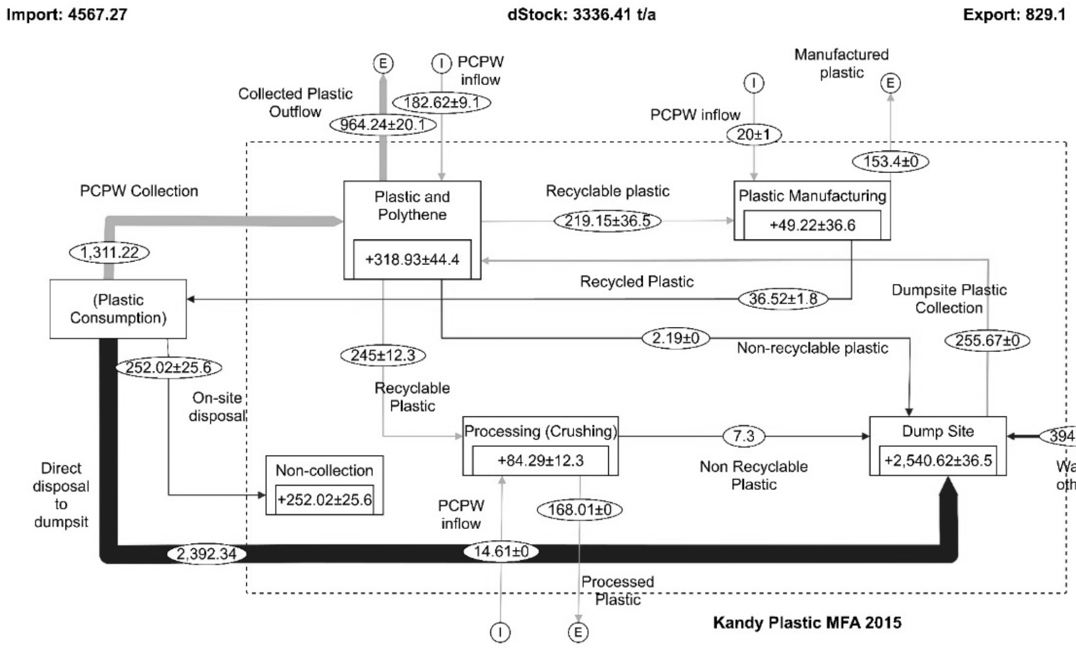

Figure 3. Sankey diagram of PCPW flow in KMC area for year 2015

2540.6 MT that include 394.46 MTA of waste disposed by the other local authorities. The total PCPW outflow from the dumpsite remains very low which is limited only to scavenging.

Plastic waste classification based on RIC

The PCPW characterization and composition analysis showed that 54% of plastic is in the form of film/sheet plastic mainly from packages, 33% of rigid/solid plastics mainly found in appliances and household goods, 7% aseptic packages and 6% laminated plastics in packages. The major issue with the soft plastic was the high percentage of contamination which make it difficult to proceed with plastic recycling. It was also found that PCPW sample comprised with 61% of cleaned plastics and 39% of contaminated plastics. The contaminated plastics were mainly cooked food packages (lunch sheets and food wrapping) and snack wrappings.

A summary of PCPW composition in term of plastic resin type is shown in Figure 4, where it shows, the major portion of the PCPW consists of LDPE (37%) followed by PET (20%) and PP (14%) on average. The PET in form of bottles was mainly originates from hotels and restaurants.

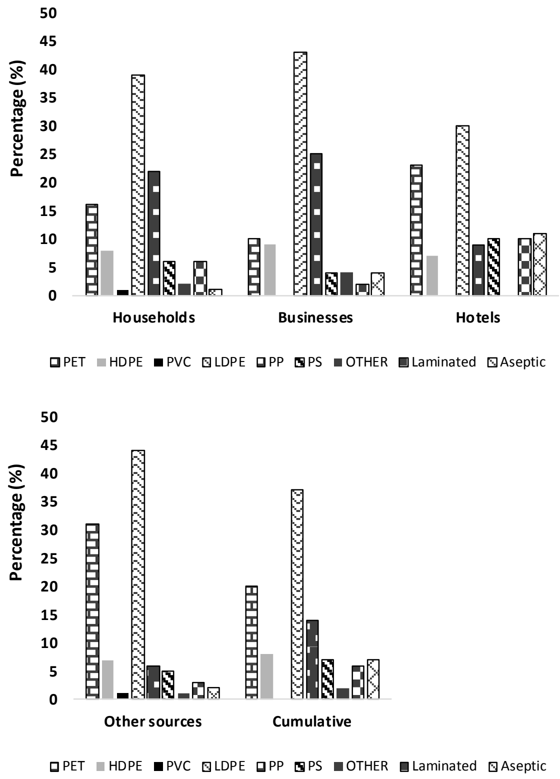

Figure 4. Composition of PCPW in KMC area

The MFA and PCPW composition analysis showed several possible ways in managing PCPW in KMC. The clean film and rigid plastics amount if approximately 61% that can be directly used for the recycling process. In Sri Lankan plastic recycling industry HDPE, LDPE and PP are having higher demand and 59% of PCPW in KMC is high demanding recyclable plastics. The other possible major PCPW management alternative is the PCPW incineration for energy recovery which has not yet fully implemented in Sri Lanka.

CONCLUSION

A detailed situational analysis of plastic waste management in Kandy Municipal Council (KMC) area reveals that there are improvements to be done which needs to be considered in designing a sound waste management system. The major portion of plastic waste ended up at the dumpsite and the overall post-consumer plastic waste recycling rate in KMC remains at 30% (3.6 MT/day) in which 17% is processed to crushed pieces, 15% to manufacture goods and 68% transport to other cities. Among many types of resin types in plastic wastes, LDPE (37%), PET (20%), PP (14%), and HDPE (8%) are the major types. The amount of clean and uncontaminated plastic waste in PCPW stream is about 61%. Though there is currently an improvement in source segregated disposal within KMC, still there is a need to promote source segregated disposal, especially among hotels and traders.

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Surface properties of municipal solid waste incineration fly ash composites by geocasting and calcination treatment

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ABSTRACT

Fly Ash is one of the byproduct from municipal solid waste incineration treatment and it's required extra treatment with toxic heavy metal elements. For the extra treatment in Japan, chelate treatment is used to hold heavy metal from leaching condition. But chelate treatment has possibility of chemical/biological decomposition and cause long-term high concentration of organic hydrocarbons in landfill site as well as leaching of heavy metals to the environment. In this study, for finding alternative fly ash treatment, authors focus to replace fly ash to fluidized bed combustor sand. But fluidized bed sand requires bigger size than fly ash. Therefore, geocasting was used in this research to aggregate to bigger particles with physical requirements of heat carrier. Geopolymer were prepared by stirring municipal solid waste incineration fly ash with a mixture of potassium hydroxide and potassium silicate. After geocasting, sample calcinated in several condition for simulating similar situation in fluidized bed combustor. Lastly, SEM-EDX, toxicity characteristic leaching procedure and Brunauer–Emmett–Teller (BET) analysis were used to check characteristic of samples. The characteristics of the geopolymer foams shows that porosity and irregular shape. And when experimental condition of geocasting was changed, it gave non-negligible impact on specific surface area of geocasted samples.

Keywords: Fly ash, Geopolymer, Morphology, Heavy metal immobilization, Surface area

INTRODUCTION

With growing industry, Municipal solid waste (MSW) generation is also increasing rapidly since 20th century. For reducing MSW volume and weight, many variety of treatments were announced. Incineration is one of the major treatments by which has potential to reduce the volume of solid waste up to 10-20%. In Japan, as much as 80% of MSW was treated by the incineration method in 2017 [1]. However, the main problem emerge from this treatment method is disposal of byproduct generated from this process.

In Japan, MSW incineration (MSWI) bottom ash and fly ash are generated by two major type incinerators which are stoker type and fluidized bed type. Bottom ash is produced by stoker type and contains less toxic heavy metal than fly ash. In this research, the authors were aiming on fluidized bed fly ash.

MSW contains several substances has hazard potential to the environment such as Pb and Zn. After incineration, those substances might stay in the residues and leach to the environment in certain occurrence such as soil pollution. Potential contaminants release from MSWI residues is most frequently evaluated based on leaching tests. In worldwide, several leaching tests are used for the characterization of MSWI residues, such as the USEPA's Toxicity Characteristic Leaching Procedure (TCLP), European standard test, and the Japanese standard leaching test (JLT). The key point of disposal of MSWI residues should be considered stabilization from those leaching test [2].

In order to immobilize hazardous heavy metals in fly ash, treatment techniques may be grouped in four categories: (a) extraction and separation, (b) chemical stabilization, (c) solidification, and, (d) thermal treatment [3]. Because of efficiency, in Japan, chelate treatment is one of the well-known chemical stabilization method. However, chelate treatment has possibility of chemical/biological decomposition and it may cause long-term high concentration of organic hydrocarbons in landfill site as well as leaching of heavy metals to the environment. From those reasons, this focused on the alternative treatment for chemical stabilization of fly ash.

In fluidized bed type combustor, sand is used for combustion material as heat carrier and fly ash has similar physical and chemical characteristic. This characteristic can be used as fluidized bed sand and it might provide thermal treatment like calcination during combustion operations. To replace fluidized bed sand by fly ash, however, fly ash characteristic is too fine particle. Therefore, it should be aggregated to bigger particles in order to comply with physical requirements of heat carrier in fluidized bed combustors.

For application for fluidized bed sand aggregation, geopolymerization was proposed in this study. Geopolymer, also referred to as Aluminosilicate Inorganic Polymers (AIP) and Alkali Activated Cement (AAC) are based on alkali soluble aluminum and silicon precursors [4]. Its characteristics are high phosphorous and impressive fire-resistant properties. Moreover, Geopolymer materials not only have comparable or superior properties to traditional cementitious binders, but also have low greenhouse emissions. Therefore, fly ash based geopolymer is expected to solve physical requirements of heat carrier.

The purpose of this research is finding alternative treatment of the fly ash produced by a MSW incinerator in Japan planning to its stabilization with geopolymerization with replacing fluidized bed sand. Therefore, geocasting and calcination treatment with morphology observation, leaching test and elemental analysis was used in this study.

Materials and methods

Fly Ash (FA)

By incinerations, some gas residue will be converted to fly ash by exhaust gas treatment equipment. In landfill case, fly ash has problems which contains various hazardous elements such as lead, chromium, cadmium, arsenic, antimony, etc. Fly ash has more soluble forms than those in bottom ashes. In this research, the fly ash used was provided by a fluidized bed type MSWI plant in Japan. Sample of fly ash prepared 5kg, and it were taken from incineration silo. The fly ash sample was stored in air-tight plastic containers. The collected ash was dried at 80°C in an oven for moisture removal. After this procedure, each fly ash sample was used to produce geopolymer.

Geocasting and calcination treatment

For making geopolymer, fly ash is one of good candidate for source materials because it contains complex microstructure comprising of silicon and aluminum. Geopolymerization is required high alkali solution such as potassium hydroxide or Sodium hydroxide [5]. In this research, potassium hydroxide was used as alkali solution. Geopolymer slurry was produced using 15M KOH solution, which should be used 24 hours after the solution curing. Then KOH solution was mixed with potassium silicate and distilled water in a mixer (200rpm, 20 min) according to the following weight ratio: KOH solution (15 M): potassium silicate: H2O = 1:2:0.5. In this study, the authors added 30 g of KOH solution, 60 g of potassium silicate and 15 g of distilled water.

Fly ash was added to this solution with equal amount to 15 M KOH solution. They were stirred at 200 rpm for 30 min at room temperature. For Accelerating geopolymerization, geopolymer slurry was placed into an oven at 80 °C for 2 hours. After casting geopolymer foam, some samples were calcined with several temperature condition which are 300, 400, 500, 600 °C for 4 hours for simulating similar situation in a fluidized bed combustor.

Morphology observation

After preparing samples, samples were analyzed by scanning electron microscopy with energy dispersive X-ray spectrometry (SEM-EDX) for checking its morphology characteristic.

Surface Area

To compare significance between leachabilities and morphology, surface area was also analyzed by QuadraSorb SI (NIES, Japan). In this observation, samples are used raw fly ash, geopolymer and 600°C calcined geopolymer. To Analyze data, Authors used Brunauer, Emmett and Teller (BET) and Density Functional Theory (DFT) Method.

Leaching test

Although geopolymer can be replaced to fluidized bed sand with its physical requirements, stabilization is also required option for alternative treatment of fly ash. In order to investigate the leaching properties of fly ash and geopolymer, Japanese leaching test 46 (JLT-46) and toxicity characteristic leaching procedure (TCLP, US EPA Method 1311) were used. In TCLP test, extracting solvent is acetic acid solution and liquid to solid weight ratio (L/S) is 20. After mixing samples with acid solution, bottles were shaken at 30rpm for 18 hours, residual materials were collected by the filtration using a 0.6-0.8μm glass fiber filter. In JLT-46 test, extracting solvent is distilled water and liquid to solid weight ratio (L/S) is 10. Bottles were shaken at 200 rpm for 6 hours, residual materials were collected by the filtration using membrane filter with a hole diameter of 0.45μm.

Elemental analysis

After leaching test, residual materials were separated by two leaching condition and elemental analysis of the leachates was made by inductively coupled plasma atomic emission spectroscopy (ICP-AES). In this study, Pb, Zn and Cu concentration in the leachate of fly ash were investigated for checking heavy metal immobilization. Standard solutions of the elements of interest (Pb, Zn and Cu), were prepared from single element standard solutions for ICP by dilution.

RESULTS AND DISCUSSION

Morphology of raw and treated fly ash

According to SEM-EDX observations results, raw fly ash mainly consisted of Al, Na, Ca and Cl. As shown in Figure 1, SEM picture showed sphere particles with smooth surface. On the other hand, geocasted fly ash consisted of more Si and K than raw fly ash. Because geocasted fly ash was produced by high alkali solution such. According to W. D. A. Rickard, one of characteristic of geopolymer is porosity [6]. Surface of geocasted fly ash showed porous characteristic and crystallization. After calcination treatment, although porosity was decreased, crystallization was remained. After leaching test, however, structural integrity of calcined geopolymer has been compromised.

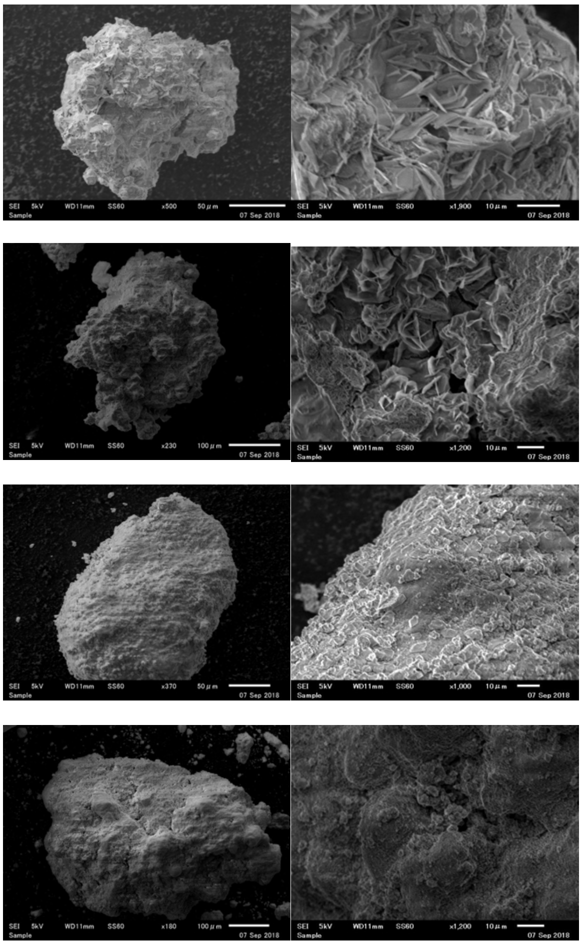


Figure 1. From the above, SEM images of particles of MSWI

fly ash, geopolymer, calcined geopolymer, geopolymer after leaching test and calcined geopolymer after leaching test.

Surface Area (BET, DFT Method)

As shown as Figure 2, surface area of ray fly ash was lower than geopolymer. However, after calcination treatment, surface area of calcined geopolymer was decreased again. Results showed high temperature affected porosity, therefore, imply to decrease surface area.

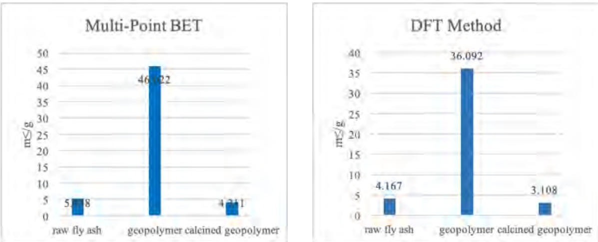
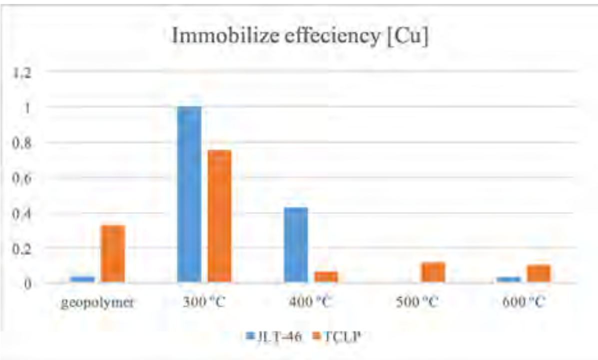
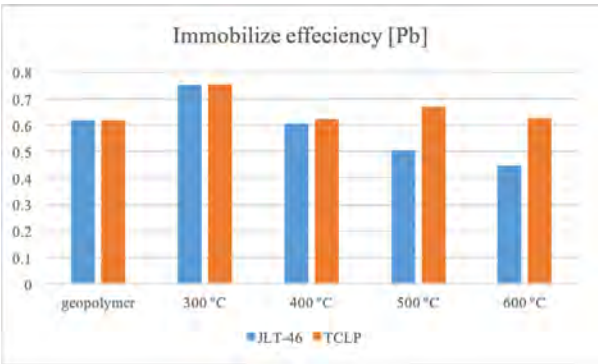


Figure 2. Surface area of raw fly ash, geopolymer and 600°C calcined geopolymer

The impacts of geopolymerization and calcination treatment on metal leachabilities

In order to heavy metal immobilization, ICP analysis checked three heavy metal leachabilities such as Pb, Zn and Cu. Figure 3 shows immobilize efficiency of each geopolymer and calcined geopolymer from raw fly ash. The graph showed high heavy metal leachabilities in various research condition. However, with only aqueous leaching condition, immobilize efficiency of Zn was high immobilization. In addition, most of immobilize efficiency of Cu and Zn are not significant result between calcination temperature. From those results, we could know calcined geopolymer at 300 °C showed improved heavy metal immobilization properties.





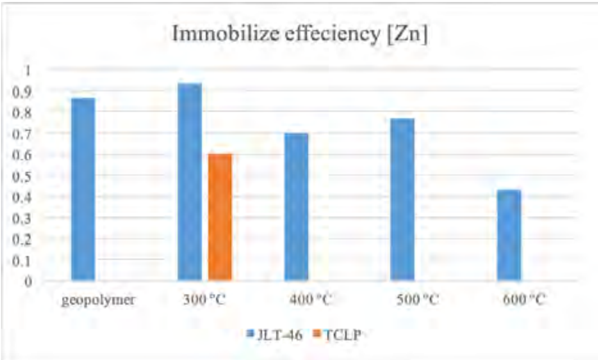


Figure 3. immobilize efficiency between raw fly ash, geopolymer and calcined geopolymer.

CONCLUSION

This study shows that geopolymerization with fly ash imply to be chemically bonded with some heavy metals. Although SEM images couldn't define significance with heavy metal leachabilities, some geopolymer by calcined condition showed improved heavy metal immobilization value with specially in Pb elements. In order to high temperature, however, SEM pictures and results of leachabilities showed calcination treatment can change geopolymerization. Therefore, porous characteristic and heavy metal immobilization were decreased in other condition. Further research will check durability of each samples to compare with fluidized bed sand.

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FACILE SYNTHESIS OF FLY ASH-BASED POROUS GEOPOLYMER AND METHYLENE BLUE ADSORPTION EFFICIENCY

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ABSTRACT

Large amounts of coal fly ash are generated after thermal energy production and mainly disposed by landfilling. The management of this waste material becomes an environmental concern. In order to reduce environmental problems and achieve economic benefits, recycling of fly ash waste is necessary. Chemically, coal fly ash contains significant alumino-silicate component that can be used to form geopolymer by react with an alkali activator. Geopolymerization reaction induces to form repeating units of aluminosilicate at elevated temperature range and creates solid structure of fly ash. The geopolymer has been used as cement or concrete replacement. Moreover, geopolymer production also emits less carbon dioxide and consumes lower energy compare to ordinary Portland cement production. However, ordinary geopolymer products present closed cell structure, has low porosity, and low water permeability which limit the adsorption capability. In term of environmental cleanup application, high porosity and large active site of adsorbent material is important. This study, an alkali activator, stabilizing agent, and blowing agent were used in the preparation of fly ash-based porous geopolymer. The synthesized porous geopolymer exhibited microstructural fly ash framework and highly sponge-like porous structure. Furthermore, the porous geopolymer indicated a great removal efficiency for methylene blue dye at about 95%. The results were confirmed by significant decrease in the intensity of the absorption band at 664 nm with increasing incubation time. This work demonstrates the fly ash-based geopolymer as a potentiality adsorbent in dye removal and can be further used for other organic compounds and heavy metals removal.

Keywords: Fly ash, Geopolymer, Adsorption, Methylene blue

INTRODUCTION

Million tons of coal fly ash each year are produced after electricity generation worldwide. The management of by-product fly ash after coal burning is mainly disposed by landfilling (Wang & Wu, 2006). An improper fly ash disposal is considering as an environmental issue (Ahmaruzzaman, 2010; Yao et al., 2015). To eliminate environmental problems and achieve economic benefits, utilization of fly ash waste as much as possible is significant. Nevertheless, only a small percentage of the fly ash waste has been used to recycle (Bhattacharjee & Kandpal, 2002; Zhuang et al., 2016).

Understanding the physical and chemical properties of coal fly ash is important. In fly ash, alumino-silicate is a primary component which could be employed as a source to form geopolymer (Zhuang et al., 2016). Geopolymer is a semi-crystalline three-dimensional silico-aluminate material (Bai, Ni, Wang, Li, & Colombo, 2018). Geopolymer can be simply synthesized through geopolymerization reaction by reacting alumino-silicate with an alkali activator (Zhuang et al., 2016). Geopolymers have been used in many applications such as cement replacements, and also used as effective adsorbents for various heavy metals and organic compounds (Ahmaruzzaman, 2010; Zhuang et al., 2016).

However, the conventional geopolymer products have closed cell solid structure, low water permeability, and low porosity (Lassinantti Gualtieri, Romagnoli, & Gualtieri, 2015; Prud'homme et al., 2010; Zhang, Provis, Reid, & Wang, 2014). The authors intend to develop the fly ash geopolymer for toxic heavy metals removal applications, high porosity and large surface area of adsorbent material is very significant. In this study, fly ash-based porous geopolymer was produced using alkali activator and pore forming agents. The synthesized porous geopolymer was characterized and tested the performance for methylene blue (MB) removal.

MATERIALS AND METHODS

Materials and method

Coal fly ash powder was used as raw material. Analytical grade potassium hydroxide, oleic acid, potassium silicate solution (30%), and methylene blue trihydrate were supplied by Wako Pure Chemical Industries, Ltd.. Analytical grade hydrogen peroxide solution (30%) was obtained from Kanto Chemical Co., Inc.. Potassium hydroxide and potassium silicate were used as an alkali activator in the preparation of geopolymer. Firstly, potassium hydroxide and potassium silicate solution were mixed using a laboratory mixer for 10 min at 300 rpm. Fly ash powder was then added. After stirred for 10 min, the geopolymer slurry was kept in an oven at 80 ° C for 10 min in order to encourage the geopolymerization reaction. Then the oleic acid was added into the slurry follow by the hydrogen peroxide solution to create porous structure. Finally, the geopolymer paste was casted into a silicone mold and sealed in plastic bag. The geopolymer was obtained after cured at 80 ° C for three days. After geopolymer was demolded, the additional calcination treatment was given to remove the remaining surfactants on the geopolymer surface.

Characterization

For characterization, a S2 Ranger energy dispersive X-ray fluorescence (XRF) spectrometer was used to determine the elemental analysis of the raw fly ash (Bruker AXS, Germany). The morphologies of raw fly ash and geopolymer samples were analyzed using a scanning electron microscopy (JSM-6610, JEOL Japan). The FTIR spectra were obtained using a fourier transform infrared spectroscopy (FT/IR-6100FV, JASCO Japan) on samples mixed with KBr pellets.

Sorption experiment

To investigate the methylene blue (MB) adsorption efficiency, 0.5 g of geopolymer samples were immersed in 25 mL of methylene blue solution at concentration of 5 ppm. The sample vials were kept in dark room at room temperature and using a rotary shaker under an agitation speed of 120 rpm. For reference, MB stock solutions without geopolymer sample were prepared under the same conditions and run in parallel. The geopolymer were separated from the solution and the solution were collected at design time. The concentration of MB in solutions were evaluated by determining the absorbance using a UV-Vis spectrophotometer (UV-2550, SHIMADZU Japan) at $\lambda = 664$ nm.

The removal efficiency (E) of MB was determined using equation (1):

$$E\,(\%)= \frac{C_0 - C_e}{C_0} \times 100$$

where C_0 is the initial concentration of MB (mg/L), C_e is the remaining equilibrium MB concentration (mg/L).

RESULTS AND DISCUSSION

Characterization of fly ash and geopolymer samples

The elemental components of raw fly ash are silica, alumina, iron, calcium, and titanium oxides measured by XRF analysis as shown in **Table 1**. The fly ash is defined as class F (SiO_2 + Al_2O_3 + Fe_2O_3 > 70 wt% and low in lime content) according to ASTM C618 (Ahmaruzzaman, 2010; Zhuang et al., 2016).

Table 1

Chemical composition (%) of raw fly ash sample by XRF analysis

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	TiO_2	K_2O	MgO	Na_2O	P_2O_5	SO_3	SrO
Fly ash	56.45	21.94	9.82	3.09	2.50	2.30	0.87	0.76	0.71	0.98	0.24

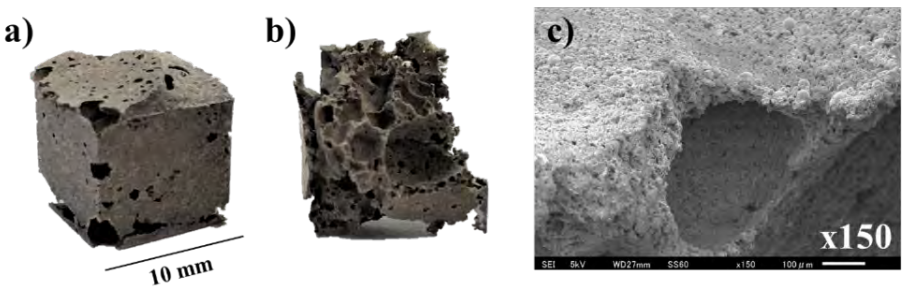

Fig. 1 Macro images of the synthesized geopolymer: a) the appearance of the geopolymer; b) the internal of the geopolymer; and c) SEM image of the geopolymer surface

The morphologies of synthesized fly ash-based geopolymer are presented in **Fig. 1.** The obtained geopolymer exhibits highly pore structure with various pore sizes (see **Fig. 1a** and **1b**). The morphologies of geopolymers were analyzed using a scanning electron microscopy as shown in **Fig. 1c**.

Obviously, it shows that fly ash particles are successful interconnected and exhibits a sponge-like solid framework with highly porous microstructure.

The IR spectra of fly ash and synthesized materials, were investigated using KBr pellet technique, are presented in **Fig. 2**. The FTIR spectra of both fly ash and geopolymer clearly show dominant bands at 1420, 1070, and 795 cm^{-1}. The synthesized geopolymer present the characteristic IR bands similar to the raw fly ash. A small broad band at around 1640 cm^{-1} is corresponding to the bending vibration of the OH bond (Mucsi, Molnár, & Kumar, 2014). The stretching vibrations of carboxylate (O-C-O) can assign to the presence of a broad peak at around 1420 cm^{-1} (Liu et al., 2016). The bands at around 1070 and 795 cm^{-1} are assigned to Si-O-Si asymmetric stretching vibration and Si-O symmetric, respectively. These bands can confirm the presence of quartz in the structure (Alehyen S., 2017).

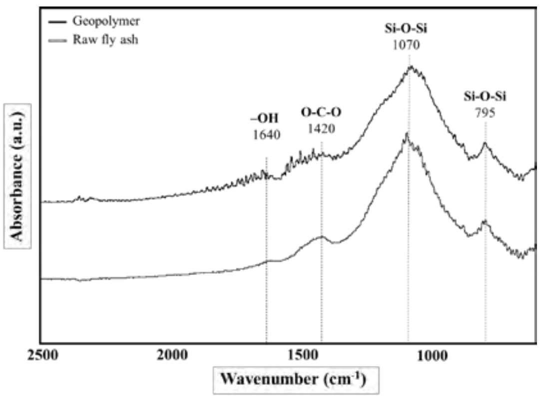

Fig.2 IR spectra of fly ash and the geopolymer

Methylene blue adsorption ability

The removal performance of geopolymer onto methylene blue as the effect of incubation times is shown in **Fig. 3**. The incubation periods varied from 1 to 48 hours. The removal result indicated that the geopolymer can adsorb methylene blue rapidly in the first hour with a percent removal about 61.7%. Furthermore, the geopolymer can reach equilibrium adsorption after about 24 hours of contact time. After 48 hours, the maximum removal efficiency of methylene blue adsorbed onto the geopolymer is about 94.7%.

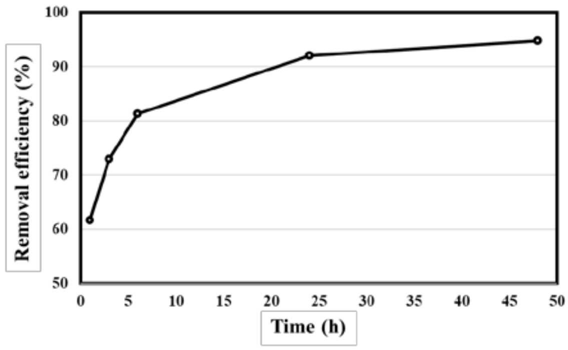

Fig. 3 Methylene blue removal efficiency of the geopolymer

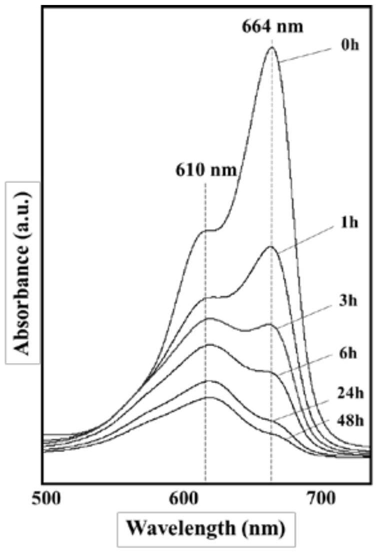

Fig. 4 UV-vis spectra of methylene blue degradation recorded as a function of contact time

The degradation of the MB solution adsorbed on geopolymer can determine by the absorption band profile at 664 nm and a shoulder at 610 nm using the UV-vis spectrophotometer. **Fig. 4** shows that the peak intensity of MB significant decrease with increasing of contact time. Therefore, the notable decrease in peak intensity might because the MB uptake by the geopolymer. These results suggest that the porous geopolymer has an excellent performance for MB removal.

CONCLUSION

The fly ash-based porous geopolymer has been demonstrated in this study to be very effective in MB removal. The removal efficiency is at about 95%, confirm by the decrease in absorbance intensity of MB when the contact time increase. Moreover, FTIR and SEM results indicate that the synthesized fly ash geopolymer can be successful interconnected by creating fly ash framework and exhibited highly sponge-like porous structure.

ACKNOWLEDGEMENTS

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THE EFFECTS OF THE WORKBENCH HEIGHT ON SORTING RATE IN HAND-SORTING

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ABSTRACT

Hand-sorting is known as basic technique for picking useful material up from mixed items. However, there has been little study that tried to evaluate the appropriate height of workbench quantitatively. The purpose of this study is to demonstrate the relation between workbench height and sorting-rate. Experimental condition was as follows. There were 196 pieces of cube samples (30mm x 30mm x 30mm) on the workbench (900mm x 900mm). The condition of the workbench height as "high", "middle" and "low" were 122cm, 96cm and 70cm from ground, respectively. The examinee stood in front of workbench and the collection box was set beside of examinee. The cube sample was gripped and collected into collection box one by one. The operational state was taken as moving image. The sorting-rate was measured from moving image data after experiment. The results of experiment were as follows. The sorting-rate was faster along with distance from collection box (start position) to cube sample. However, the sorting-rate was decrease on the far range than arm of examinee (60cm). The sorting-rate of "middle" and "low" height of workbench was same, approximately. The sorting-rate of "high" condition of workbench was 20 % lower than other condition in all the range. These results are useful for to establish the hand-sorting operating condition and to design the mechanical conveyer and so on.

Keywords: Hand-sorting, Workbench height, Ergonomics, , Flushing

INTRODUCTION

Separation is the most basic technique for appropriate waste treatment. Mechanical separation, mechanical sieving, air classifier, magnetic separation and so on, has been developed. There is the technique to collect the items using artificial intelligence (AI). On the other hand, these is no hoard of scientific knowledge about hand-sorting which is the most basic technique of waste treatment. the standard of hand-sorting conditions have not been established yet. The first action of waste treatment is hand-sorting in disaster site. The quality and quantity of collected recyclable materials are dependent on this first separation against generated waste ensuing disaster. The condition of hand-sorting is also important for high quality and efficiency sorting. It was demonstrated that the effects the condition of hand-sorting, condition of working environment and category of waste, on sorting efficiency by using practical disaster waste (*Ochiai* et al., 2016). The relationship the hand-sorting efficiency and worker position in conveyor was demonstrated (*Yamada* et al., 2015). The purpose of this study is to clarify the effects of the height of workbench on motion rate of hand-sorting.

MATERIALS AND METHODS

One examinee was selected. The physical description of the examinee is as follows. 44 age, height 167cm, eye height 158cm, acrominon height 139cm, olecranon height 106cm, the length of acrominon and olecranon 34cm, the length of olecranon and grip 32cm, length of back to grip 61cm. Figure 1 shows the schematic of experiment. The examinee stood in front of the workbench. The permitted moving area for examinee is 30 cm x 60 cm. All of target items were picked up and carried into collection box (22 cm x 30 cm x 22cm) by only right hand with grab. The collection box was set right of examinee.

The collection motion was recording by video camera. The collected sample was cube (3 cm x 3 cm x 3 cm, 1.4 gram/piece). 196 pieces (14 lines x 14 columns) samples was put on workbench in a reticular pattern.

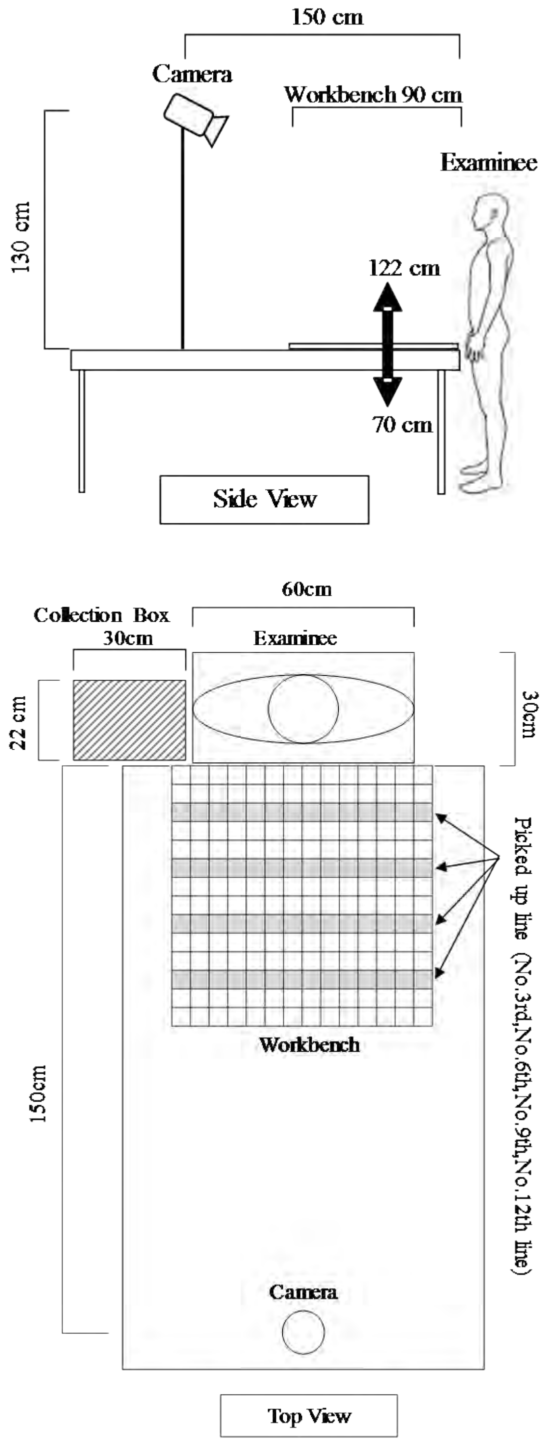

Figure 1 Schematic of experiment

The interstice was 2 cm each cube sample. The target sample cubes were 3rd, 6th, 9th and 12th line from examinee (Figure 1). Three conditions of the workbench height were "low", "middle" and "high" which is 70 cm, 95cm and 122 cm from ground, respectively. The moving rate of right hand was calculated from motion data. The moving time and the distance was T1 and L1, respectively, when the hand moved from collection box to target sample. The moving time and the distance was T2 and L2, respectively, when the hand moved from target sample to collection box.

RESULTS AND DISCUSSION

Figure 2 shows the relationship between collection time (T1+T2) and distance of the hand motion (L1+L2). It takes far from collection box to target sample more time regardless of the height of workbench. The shortest time for collection was "middle" of workbench height. The time for collection was almost the same in "middle" and "low". It takes time 1.3 times in "high" condition compare to "middle" and "low". It thought that the physical burden, especially shoulder and/or arm, was imposed in "high" workbench condition.

Figure 3 shows the results of the distance of L1 and the moving rate (L1/T1). The moving rate is faster in long distance regardless of height of workbench. The trend and level was same in "middle" and "low" workbench height. The moving rate was slow in "high" workbench height compare to "middle" and "low".

Figure 4 shows the results of the distance of L2 and the moving rate (L2/T2). The moving rate is faster in longer distance regardless of workbench height. The fastest of motion was in condition "middle". The motion rate of L2/L2 was faster than L1/T1 compare to Figure 3 and Figure 4.

It was considered that one of the reasons for the difference of the motion rate that the grip action of the cube sample is more difficult than put it into collection box.

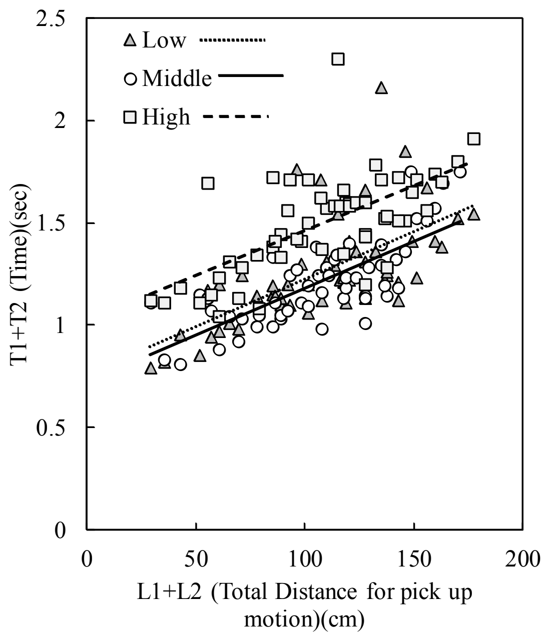

Figure 2 Collection time and distance of hand motion

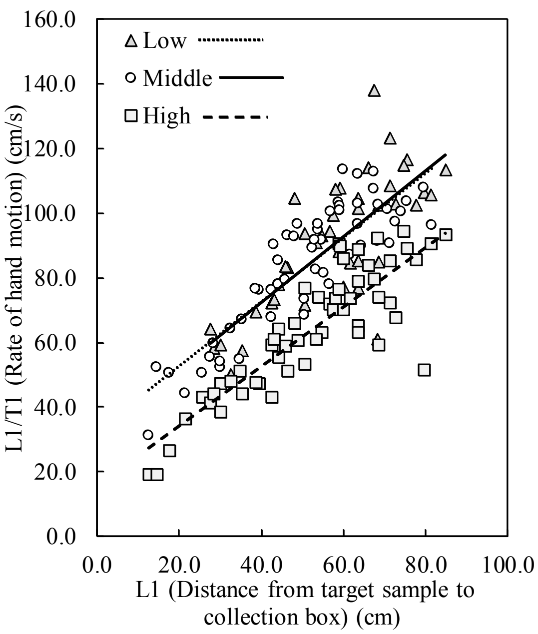

Figure 3 Distance (L1) and hand motion rate

Moving from collection box to target cube sample

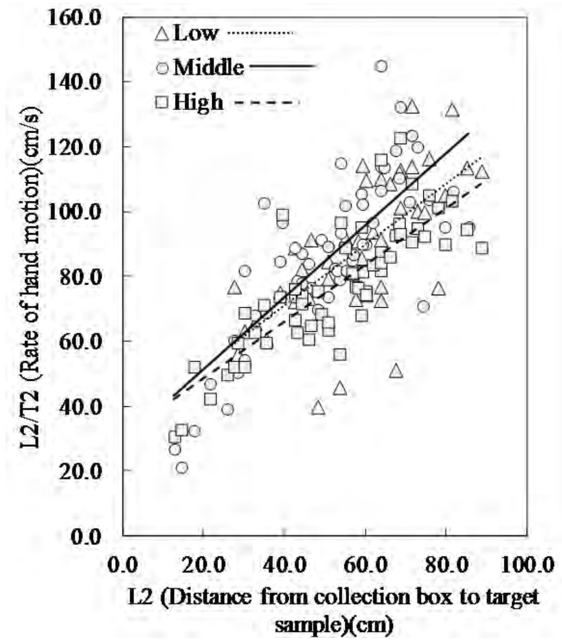

Figure 4 Distance (L2) and hand motion rate
Moving from target cube sample to collection box

As a result, it found that the most efficient workbench height is “middle”, which is olecranon height of examinee in this experiment.

It is important to make the most suitable distance from worker to waste in order to design the workbench and equipment. The rate of hand motion was increase linearly under 60 cm of distance from examinee to target cube sample. The rate of hand motion was constant or decrease (dispersion of data) over 60 cm of distance from examinee to target cube sample. The length of back to grip of examinee was 61 cm. It is inferred from the physical description that the whole body of examinee must be stretched as well as arm in order to reach the cube sample in over 60 cm. That is, the physical burden was imposed to pick up over 60 cm far sample. The stretch motion was observed in experiment. It was guessed that the physical constraint condition resulted in limits of hand motion rate in picking up far position items. Therefore, it seems reasonable to conclude that the suitable distance from worker to waste is length of back to grip of worker (60 cm approximately in this experiment).

CONCLUSIONS

The effects of the workbench height on hand-sorting motion rate was demonstrated in this study. Three conditions of the workbench height were “low”, “middle” and “high” which is 70 cm, 95cm and 122 cm from ground, respectively. As a result, “middle” workbench height condition is most efficient for hand-sorting motion. The “middle” height was olecranon height of examinee in this experiment. The suitable distance from worker to waste was length of back to grip of worker. It is 60 cm approximately in this experiment. The suitable workbench height (vertical condition) and distance from worker (horizontal condition) was suggested in this study. This information is useful to design the workbench and equipment (conveyor and so on) for hand-sorting.

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NUMERICAL SIMULATION OF PORE-FLUID FLOW IN LANDFILLS USING STABILIZED FINITE ELEMENT METHOD

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ABSTRACT

A numerical method for simulating pore flow in landfills is presented. The Navier–Stokes equation is used as a governing equation and is discretized using the streamline upwind Petrov–Galerkin/pressure stabilizing Petrov–Galerkin stabilized finite element method (FEM). We focus on the relationship between the geometry of porous media and the fluid dynamics of a landfill. A porous structure model is constructed from micro X-ray computed tomography images of waste materials (e.g., bottom ash and incombustible residue). The 3-dimensional (3-D)-stabilized FEM is a powerful tool for flows with complex geometries, such as porous landfill structures. However, it leads to a huge computational cost. In this study, we examined methods to accelerate the 3-D stabilized FEM by using a multi-graphics processing unit to achieve a 16.3-fold speed-up over one central processing unit. Moreover, wall-shear stress was calculated to elucidate fluid-flow dynamics, affecting the geometry of porous media in waste materials.

Keywords: Navier-Stokes equation, SUPG/PSPG, micro-CT, multi-GPU, WSS

INTRODUCTION

As a result of recent improvements in computer performance, computational fluid dynamics (CFD) have contributed to the understanding and modeling of complex flow phenomena, which are otherwise difficult to be measured experimentally or theoretically. In the field of waste management, CFD have become a powerful and useful tool for predicting water and gas transfer in landfills, allowing more appropriate design and operation. Because various waste materials are dumped, the pore structures in the waste-filled layer create a geometry much more complex than sand or soil. The micro-scale structure of pores, in turn, affect the flow dynamics of the landfill. The finite element method (FEM) offers flexibility in handling complex geometries (Zienkiewicz, 1977). However, for incompressible viscous flows, Galerkin's formulation suggests that, for large Reynolds numbers, FEM may suffer from numerous instabilities dominating the advection. To prevent numerical oscillation in the advective-dominant problem, Hughes and Tezduyar et al. (1984, 1991, 1992) proposed a stabilizing method known as streamline upwind Petrov–Galerkin/pressure stabilizing Petrov–Galerkin (SUPG/PSPG), wherein a stabilized FEM allows us to solve incompressible viscous flows.

However, FEM leads to a huge computational cost. To overcome this, general-purpose graphics processing units (GPUs) have been drawing a lot of attention. GPUs were originally designed to render graphical displays; they have several hundreds and thousands of cores upon which millions of threads can be executed in parallel. Thus, GPU parallelization provides considerable speed-up. Therefore, multiple-GPUs have been widely adopted in various fields (e.g. Cárcamo, M., et. al., 2018).

In this study, we investigate pore-fluid flow in landfills using CFD. The SUPG/PSPG stabilized FEM is employed for finite-element discretization. Furthermore, we attempted to speed-up computational simulations by using multiple GPUs. We developed a general-purpose GPU-accelerated implementation of the pore flow in landfills and compared the results of our GPU and CPU implementations.

MATERIALS AND METHODS

CFD modeling

Samples were collected from a municipal solid-waste incineration facility; collected bottom ash and incombustible residue were used as samples for this research. To define the geometry of the computational CFD domain, micro X-ray computed tomography (micro-CT) and image processing software was used. Micro-CT is a useful non-destructive technique for scanning complex pore shapes in waste samples. Our sample was introduced via a tube (diameter: 10 mm, height: 10 mm). For micro-CT, the sample is rotated to provide 2-dimensional (2-D) projection images. Then, a 3-dimensional (3-D) voxel dataset is inversely reconstructed from the 2-D images. The image processing software was thus applied to extract a 3-D surface model from the obtained voxel datasets. The surface geometry of the pore structure in the waste was exported as a stereolithography (STL) file. Figure 1 shows the 3-D image reconstruction of the micro-structural geometry of bottom-ash pores. A triangular mesh was then generated from the STL file using meshing tool available in Gmsh (Geuzaine, C. and Remacle, J.F., 2009). Figure 2 shows the tetrahedral mesh of the bottom ash.

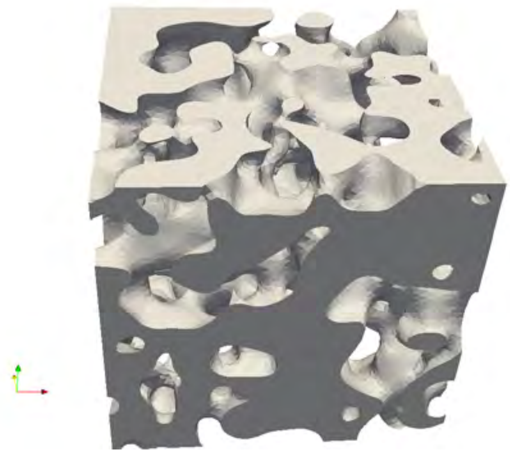


Figure 1 3-D reconstruction of the micro-structural geometry of pore in the bottom ash (STL format)

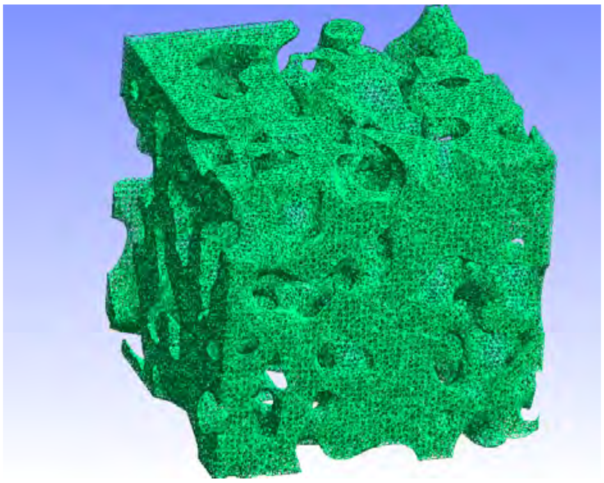


Figure 2 Tetrahedral mesh generation with Gmsh (bottom ash for municipal solid-waste incinerator)

Governing equations

The incompressible viscous Navier–Stokes equation and the continuity equation were used.

$$\frac{\partial u_i}{\partial t}+u_j\frac{\partial u_i}{\partial x_j}=-\frac{1}{\rho}\frac{\partial p}{\partial x_i}+\frac{\mu}{\rho}\frac{\partial}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)$$

$$\frac{\partial u_i}{\partial x_i}=0$$

where u, p, t, ρ, and μ respectively denote velocity, pressure, time, density, and viscosity.

Stabilized FEM

We use the stabilized FEM based on SUPG/PSPG to discretize the governing equations. Its weak forms are

$$\int_\Omega w_i\left(\frac{\partial u_i}{\partial t}+\overline{u_j}\frac{\partial u_i}{\partial x_i}\right)d\Omega$$
$$-\frac{1}{\rho}\int_\Omega \frac{\partial w_i}{\partial x_i}p d\Omega+\frac{\mu}{\rho}\int_\Omega \frac{\partial w_i}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)$$
$$+\sum_{e=1}^{n_{el}}\int_{\Omega_e}\left(\beta\overline{u_k}\frac{\partial w_i}{\partial x_k}\right)\left(\frac{\partial u_i}{\partial t}+\overline{u_j}\frac{\partial u_i}{\partial x_j}+\frac{1}{\rho}\frac{\partial p}{\partial x_i}\right)d\Omega=0$$

$$\int_\Omega q\frac{\partial u_i}{\partial x_i}d\Omega$$
$$+\sum_{e=1}^{n_{el}}\int_\Omega\left(\beta\frac{\partial q}{\partial x_i}\right)\left(\frac{\partial u_i}{\partial t}+\overline{u_j}\frac{\partial u_i}{\partial x_j}+\frac{1}{\rho}\frac{\partial p}{\partial x_i}\right)d\Omega=0$$

where w_i, q, and u_i respectively denote weight functions to the governing equations and advection velocity. Additionally, β is the SUPG/PSPG stabilization parameter, given by

$$\beta=\left[\left(\frac{2}{\Delta t}\right)^2+\left(\frac{2\left\|\overline{u_i^e}\right\|}{h_e}\right)^2+\left(\frac{\mu}{\rho}\frac{4}{h_e^2}\right)^2\right]^{-\frac{1}{2}}$$

$$\left\|\overline{u_i^e}\right\|=\left[\sum_{i=1}^{n_d}\overline{u_i^e}\right]^{-\frac{1}{2}}$$

where $\left\|\overline{u_i^e}\right\|$, h_e and n_d respectively denote the norm of the element advective velocity, the element length, and the number of spatial dimensions.

General-purpose GPU-accelerated implementation

The system of linear equations was solved iteratively at each time step via the generalized product bi-conjugate gradient (GPBi-CG) algorithm. A multi-GPU implementation of the GPBi-CG algorithm was performed using the compute unified device architecture (CUDA) framework for parallel programing, invented by NVIDIA. When developing parallel programing, we used basic libraries, such as CUDA Basic Linear Algebra Subroutines (cuBLAS) and CUDA Sparse Matrix Library (cuSPARSE). Calculations were carried out on the TSUBAME supercomputer at the Global Scientific Information and Computing Center (GSIC), Tokyo Institute of Technology.

Wall Shear Stress (WSS)

WSS was calculated using the following equations.

$$\tau_{ij} = p\delta_{ij} + \mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$$

$$\sigma_i = \tau_{ij} n_j$$

$$\sigma^n = \tau_{ij} n_j n_i = \sigma_i n_i$$

$$\sigma^{\tau_i} = \sigma_i - \sigma^n n_i$$

where τ_{ij}, n, δ_{ij}, σ_i, σ^n, and $\sigma^{\tau i}$ respectively denote stress tensor, normal vector of triangular element of wall, Kronecker delta, wall stress vector, and WSS vector.

NUMERICAL RESULTS

Multi-GPU

We analyzed the performance of the GPU implementation, measuring the simulation time of GPU and CPU during the first 100 time steps ($\Delta t = 1.0 \times 10^{-2}$ s), as shown in Table 1. The simulation was performed with mesh size: node 99,560, element 437,386. The results show that one GPU achieved a 9.0-fold speed-up, whereas two GPUs achieved a 16.3-fold speed-up over one CPU. These considerable speed-ups can be attributed to the effective parallelization and the mounting of the matrices and vectors of the linear system.

Furthermore, Figure 3 shows the vector distributions with GPU and CPU implementation. These distributions were quite similar in every detail.

Table 1 Simulation time of GPU and CPU

Number of GPUs/CPUs	Simulation time (s)
1CPU	1.48×10^{5}
1GPU+1CPU	1.65×10^{4}
2CPU	7.69×10^{4}
2GPU+2CPU	9.06×10^{3}

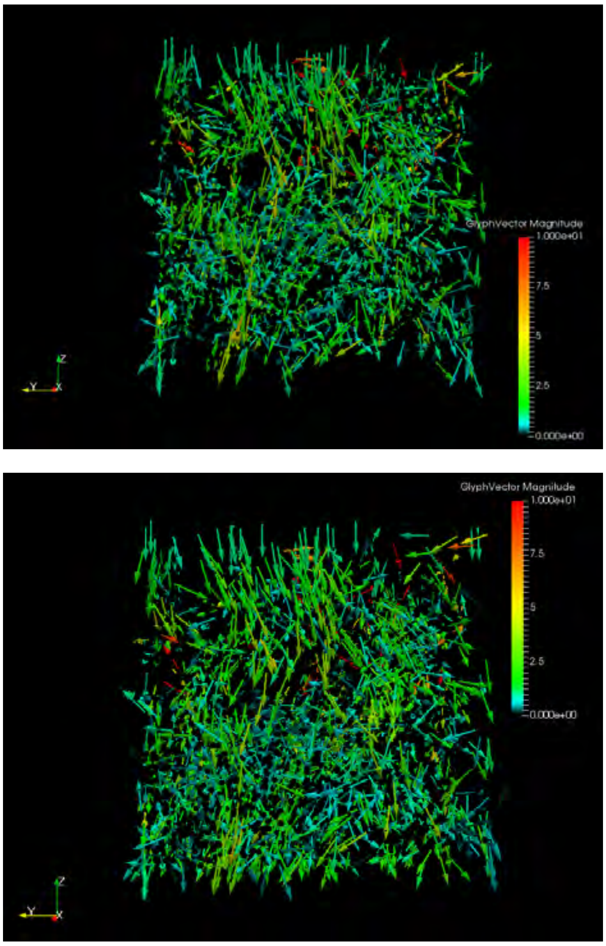


Figure 3 Velocity vector distribution at the time step 100 of the GPU implementation (upper) and only CPU implementation (below)

Pore flow and WSS

To elucidate the flow dynamics of a landfill, the numerical results are visualized. Figure 4 shows the flow pattern in the waste material. We also calculated the WSS of these wastes, as shown. Figure 5 shows that a higher WSS occurred in the narrow part, because the velocity gradient was higher, owing to turbulent or swirl flows at the narrow part. Additionally, the distribution WSS of the bottom ash differed from that of the incombustible residue. The WSS was affected by the porous morphology in the waste materials.

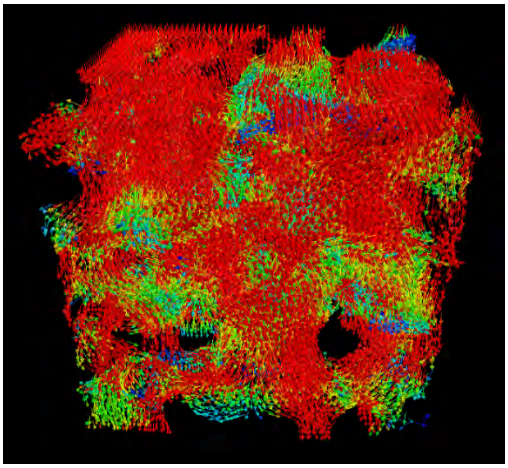
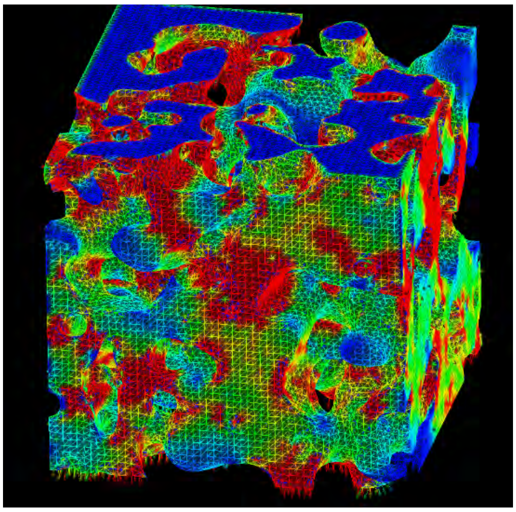


Figure 4 Velocity vector distribution of the bottom ash



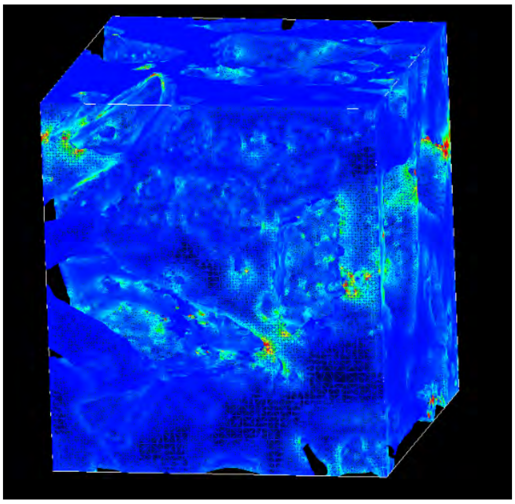


Figure 5 WSS distribution of the bottom ash (upper) and incombustible residue (below)

CONCLUSIONS

The main results are summarized as follows.

1) We constructed a simulation system based on SUPG/PSPG-stabilized FEM to elucidate the pore-flow mechanism in a landfill.
2) We proposed an efficient implementation of multi-GPU based on the GPBi-CG algorithm. The multi-GPU implementation achieved a 16.3-fold speed-up over one CPU.
3) We established the relationship between pore-flow dynamics, including WSS and pore morphology in the waste materials.

ACKNOWLEDGMENT

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The numerical calculations were carried out on the TSUBAME3.0 supercomputer at Tokyo Institute of

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The Development of Leachate Desalting Treatment Design Method by Landfill Cell Model

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ABSTRACT

As design conditions, leachate treatment facility scale and leachate raw water quality setting are the only examined items in the project for the leachate treatment facility in landfill sites. In the case of open type landfill sites (hereinafter referred to as "Open type"), based on the calculation by only using meteorological data of about the past 15 years, leachate treatment facility scale has been researched. In the case of close system landfill sites (hereinafter referred to as "Closed type"), as same as open type, the methods which using meteorological data of about the past 15 years or liquid-solid ratio of one to three times (Liquid-solid ratio of above three time in the case of desalting treatment) have been used. Furthermore, there is less scientific basis for leachate raw water quality setting, especially the concentration setting of Cl^-. It is usually based on the precedent of other cities. However, regarding the amount of leachate water and the quality of raw water of landfill sites, a close relationship with Cl content and landfill order can be found, and change depends on landfill method and dilution area or the amount of water.

Based on the landfill shape (the height of one level), dilution area (dislandfill area), landfill order and property of the waste, the Landfill Cell Model can set the expected concentration value of leachate. In this research, we will use the leachate treatment facility scale calculation method and the Landfill Cell Model together to investigate an early stabilization method for landfill and dilution area in the case of open type. On the other hand, it is possible to find an early stabilization method for landfill and adjust or reduce the amount of water spray in the case of close type.

As a result, it is possible to set the optimal leachate treatment facility scale, balancing reservoir scale and the expected concentration value of Cl^-in raw water for both open type and closed type. Besides, the amount of spraying water for closed type can also be established.

Keywords: Landfill Cell Model, leachate treatment facility, Cl^-, Open type, Closed type

INTRODUCTION

As design conditions, the scale of the leachate treatment plant and the setting of leachate raw water quality are the only examined items in the design project for the leachate treatment plant in landfill sites. In the case of open type landfill sites (hereinafter referred to as "Open type"), based on the calculation by only using meteorological data during the last decade and a half, the scale of leachate treatment plant has been researched. In the case of closed system final disposal sites (hereinafter referred to as "Closed type"), as same as open type, the methods which using meteorological data of about the past 15 years or liquid-solid ratio of one to three times (Liquid-solid ratio of above three time in the case of desalination treatment) (Japan Waste Management Association, 2010) have been used. Furthermore, there is a less scientific basis for the setting of leachate raw water quality, especially the setting of Cl^{-}concentration. It is usually based on the precedent of other cities. However, in the case of the amount of leachate water and the raw water quality in the actual landfill sites, a close relationship with Cl content and inning order can be found, furthermore, and it changes depending on the landfill method and dilution area or the amount of water.

The conventional method of calculating the scale of leachate treatment plant can set the planned raw water quality according to the landfill shape (the height of one landfill layer), dilution area (unlandfill area), landfill order and leachate landfill property. By combining the Landfill Cell Model (Kazuo, T et al, 2016 and 2017), it is possible to set the optimal leachate treatment plant scale, balancing reservoir scale and the expected concentration value of Cl^{-} in raw water for both open type and closed type. Besides, the volume of water for sprinkling in closed type can also be established in this research.

The setting of leachate raw water qualitys

<u>Calculation Methods</u>

(1) The Calculation Methods of the peak concentration of Cl^{-} in leachate (Kazuo, T et al, 2016 and 2017)

The peak concentration of Cl^{-} can be predicted according to the conditions which consist of "The Cl content in incineration residues", "The peak concentration of Cl^{-} in the height of one landfill layer", "The dilution area in landfill sites" and "The addition landfill". The predicted flow is shown in Figure 1. In this research, in order to estimate the peak concentration of Cl^{-}, a landfill cell model is used. As shown in Figure 2, Hi~Hn integrated in X directions.

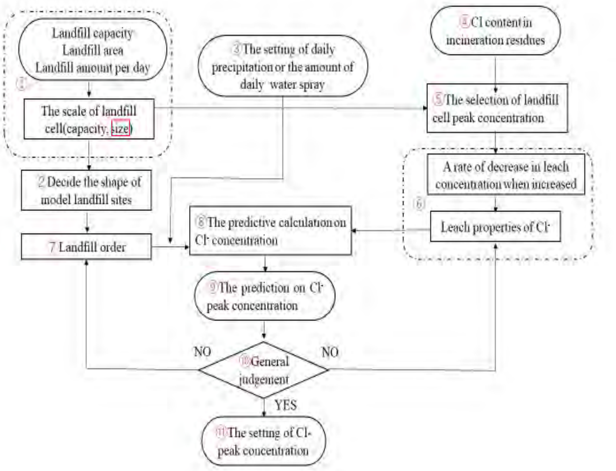

Figure 1 The setting flow of the peak concentration of Cl^{-}

Vi~Vn integrated in Y directions. Di~Dn integrated in Z direction. The assumed calculation steps are

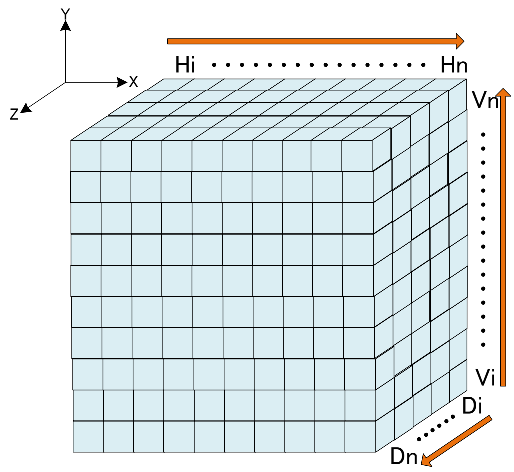

Figure 2 Landfill Cell Model

explained as follows.

Step①Calculating the daily landfill capacity of the target landfill site and set the capacity and size(length×width×height) of the landfill cell model(Capacity per cell is about 10～30 days).

Step②Setting the number of cells in the X direction (Hi~Hn), Y direction (Vi~Vn) and Z direction (Di~Dn) of the landfill cell model to make sure the shape of landfill sites.

Step③Setting the volume of water for sprinkling according to the daily precipitation of the landfill cell model in the case of open type or through the liquid-solid ratio in the case of closed type.

Step④Setting the peak concentration of Cl^- by the Cl content in incineration residues from the landfilled target.

Step⑤Producing a predicting formula for landfill cell peak concentration from the Cl content in Step ④ and using the results of temporal changes in the leachate quality in the experiment on simulated landfill layer which filled with incineration residues. At the branching point of diminution rate of Cl^- concentration, it is divided into the initial stage, the intermediate stage, the end stage and the stable stage of the landfill. The predicting formula is produced in Figure 3. Depending on the conditions, sometimes, the prediction formula from the initial stage to the stable stage is the same.

Step⑥Setting the leach properties by increasing the landfill cell.

Step⑦Setting the landfill order by considering the addition timing. (X direction indicates the landfill process and Y direction expresses the addition timing).

Step⑧Making a predictive calculation on the Cl^- concentration according to the landfill order in Step⑦.

Step⑨Estimating the peak concentration of Cl^- during the landfill duration.

Step⑩Making a general judgment on peak concentration of Cl^-, consequently, proceed to Step⑪ or back to Step③and Step⑦to do the examination again.

Step⑪Setting the peak concentration of Cl^-.

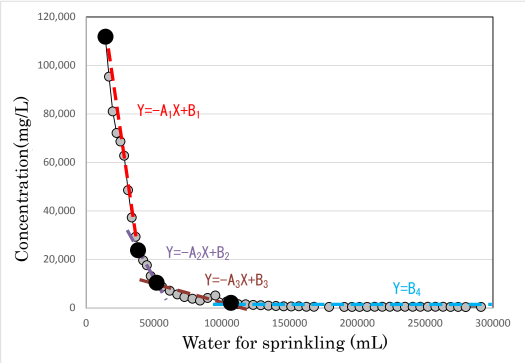

Figure 3 Conceptual diagram of prediction formula for landfill cell peak concentration

(2) The Calculation Method for Setting the Planned Raw Water Quality in Open Type (Kazuo, T et al, 2017)

Figure 4 shows the design flow of the leachate treatment plant (the scale of the leachate treatment plant, the scale of adjustment dam, the quality of planned raw water).

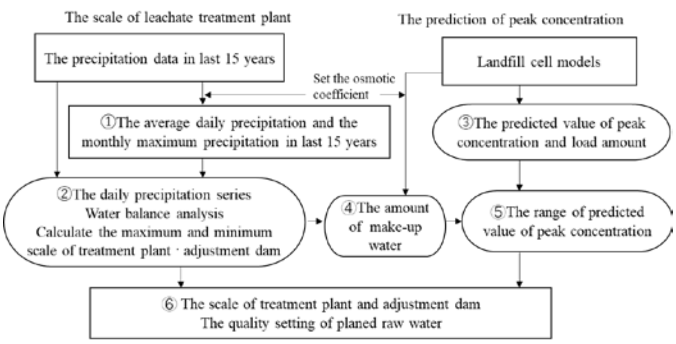

Figure 4 The design flow of leachate treatment plant

①Calculating the maximum and the minimum scale of both leachate treatment plant and adjustment dam from the average daily precipitation and monthly maximum precipitation in latest 15 years. (The possible amount of evaporation can be calculated by using the Blaney Cridle method and the osmotic coefficient C can be set).

②As same as the conventional method, the scale of both leachate treatment plant and adjustment dam are calculated within the scale range in Step① from water balance analysis using the daily precipitation series in latest 15 years.

③ Using the landfill cell model to calculate the predicted peak concentration and load amount.

④Calculating the possible daily precipitation through the osmotic coefficient from the scale of the leachate treatment plant which was calculated in Step②. Then, the amount of make-up water is calculated by subtracting the daily precipitation which was set in the landfill model for this amount.

⑤ Calculating the range of the predicted peak concentration which was considered the amount of make-up water.

⑥Setting the optimum scale of leachate treatment plant, adjustment dam and the quality of planned raw water through Step②and Step⑤.

(3) The Calculation Method for Setting the Planned Raw Water Quality in Closed Type (Kazuo, T et al, 2018)

Figure 5 shows the design flow of the leachate treatment plant (the scale of the leachate treatment plant, the scale of adjustment dam, the quality of planned raw water).

①Using landfill cell model to calculate the predicted peak concentration and load amount.

②Setting the scale range of the leachate treatment plant by using the same method in [(2) ①].

③Calculating the daily leachate amount from the volume of water for sprinkling according to the liquid-solid ratio.

④According to the predicted concentration of Cl^- in Step①, the target Cl^-concentration can be set and the dilution amount can be calculated.

⑤Calculating the daily amount of leachate by the sum of the amount in Step③ and Step④, and the total number should be less than or equal to the amount in

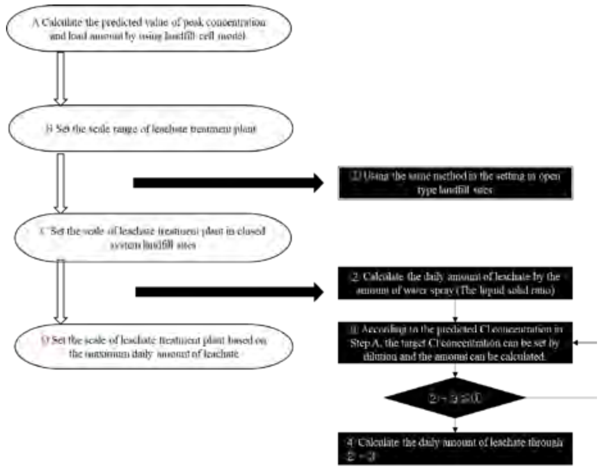

Figure 5 The design flow of leachate treatment plant

Step②.

Case Study

(1) The Investigation Conditions in Case Study

In this research, with a population of 100,000 people, the capacity of MSW landfill sites is nearly 90,000m^3, the landfill area is about 9,000m^2, the height of landfill is 10m, the landfill duration is 15 years, incineration residues with a Cl content of 48g/kg (The mixing ratio=bottom ash: Flying ash=8:2). The one-cell landfill duration of the landfill cell model was set to 10 days (Landfill capacity is about 160m^3).

The scale of the leachate treatment plant is examined by using the past meteorological data of F city. As a result, in the latest 15 years (2002~2016), the mean annual precipitation is 1,702mm (4.7mm/ day), the maximum monthly precipitation is 620mm (20mm/day) in July 2009, the seepage coefficient is 0.63 during the landfill duration and becomes 0.38 when the landfill is completed. The minimum scale of leachate treatment plant is $20m^3$/day and the maximum scale is $90m^3$/day (Sotaro, H, 2017). Within this range, the investigation is carried out.

(2) Open type (Kazuo, T et al, 2016 and 2017)

The peak concentration of Cl^- in leachate and the load amount of Cl are set by using the method in 2.1. As a result, as shown in Figure 6, the concentration fluctuates drastically at the initial stage of landfill, the peak concentration of Cl^- is about 24, 863 mg/L and the load amount of Cl has increased to about 7, 640 kg/10 days when the volume of water for sprinkling is 107, 520 m^3.

Then, the scale of the leachate treatment plant is set. As mentioned in 2.2(1), the minimum scale of the leachate treatment plant (Qop) is $20m^3$/day and the maximum scale is $90m^3$/day. As a result, the target peak concentration of Cl^- is below 10,000mg/L, dilution water was added to the leachate treatment plant, and the peak concentration of Cl^- was adjusted. When the daily precipitation is $38m^3$, the amount of dilution water is $40m^3$ and the scale of the leachate treatment plant is $65m^3$/day.

The desalination treatment installation determines the scale of membrane surface area based on the load amount obtained from the product of the water quantity and the water quality. Therefore, finding the peak load amount and using the maximum load amount to determine the equipment scale makes it possible to create an economic scale. In other words, even the peak value of water quality is high, if the load amount at this time is smaller than the maximum value, a stable processing can be performed.

For this reason, the quality of Cl^- planned raw water is set from the maximum load amount. However, under this condition, as the landfill method affects a lot, it is necessary to connect the maximum load amount with the landfill methods. Besides, since the unpredictable situations often occur in actual fields, it is important to have a margin so that it can respond to changes in the landfill method.

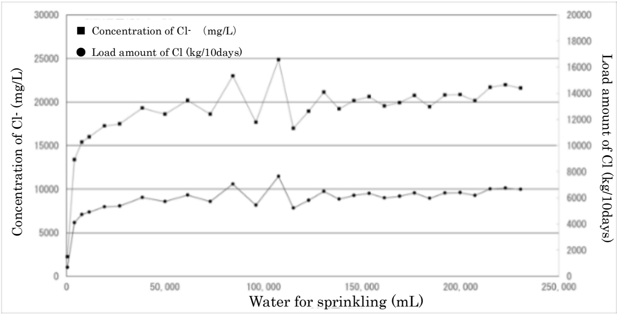

Figure 6 The daily changes of the peak concentration of Cl^- and load amount of Cl

Table 1 The scale of leachate treatment plant

Items	Values
The predicted value of Cl^- peak concentration mg/L	24.863
The predicted value of load amount kg	7.638
Daily precipitation of landfill cell model m^3	38
The target peak concentration of Cl^- mg/L	10.000
The amount of make- up water m^3	40.0
The peak concentration of Cl^- after dilution mg/L	9.742
Possible amount of the precipitation m^3	78.40
Osmotic coefficient C	0.8
The scale of leachate treatment plant m^3/day	63

(3) Closed type (Kazuo, T et al, 2018)

Based on the method in 2.1, the peak concentration of Cl^- and the load amount of Cl in leachate are set. In this case, the liquid-solid ratio used for setting the volume of water for sprinkling is 3 times (advanced treatment).

As shown in Figure 7, the predicted concentration of Cl^- becomes the maximum at the initial stage of the landfill, it reaches about 101,200mg/L. The load amount of Cl becomes the maximum at the end of the landfill, it is 2,260 kg/day. At that time, the volume of water for sprinkling is about 137,670m^3 and the total

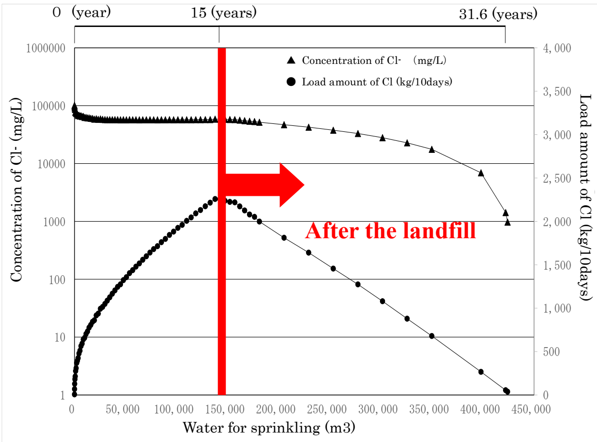

Figure 7 The predicted peak concentration of Cl^- and the load amount of Cl(The liquid solid ratio is 3 times)

The maximum predicted value of Cl^- concentration: nearly 101,200mg/L
The maximum load amount of Cl：After landfilling: about 2,260kg/day
The volume of water for sprinkling: about 137,670m^3
The liquid solid ratio: 1.5 times
The predicted concentration of Cl^- below 1,000mg/L:
After the landfill 11,540days(About 31.6 years)
The volume of water for sprinkling: about 424,090m^3
The liquid solid ratio: 4.8 times

liquid-solid ratio is 1.5 times. Besides, 11,540 days (about 31.6 years) after the end of the landfill, the predicted concentration of Cl^- is below 1,000mg/L, the volume of water for sprinkling is about 424,090m^3 and the total liquid-solid ratio is 4.8 times. Then, the setting of the volume of water for sprinkling and the quality of Cl^- planned raw water is made.

In the setting of the volume of water for sprinkling, the solid-liquid ratio is increased by three times (desalination treatment), and in this setting, the solid-liquid ratio is 1.5 times at the end point of the landfill. In this study, the quality of Cl^- planned raw water and the scale of leachate treatment plant in closed system landfill sites are set, and we estimate the scale of leachate treatment plant at first. We used the result of setting the scale of the leachate treatment plant in the case of the open type in 2.2(1). The minimum scale of leachate treatment plant is 20m^3/day, while the maximum value is 90m^3/day. Our study is conducted within this range. Besides, in the case of setting the volume of water for sprinkling, when the liquid-solid ratio is increased by three times (desalination treatment), the predicted peak concentration of Cl^- is 101,200mg/L at the initial stage of the landfill. In order to reduce the burden on the leachate treatment plant, dilution water was added to reduce the concentration of Cl^-. In the case of the amount of dilution water to be added, we should make sure that the scale of the leachate treatment plant is within the range of 20~90m^3/day. Considering the volume of dilution water under the above conditions, the upper limit for the reduction of Cl^- concentration is 26,000mg/L. However, when the value is above 26,000mg/L, the volume of

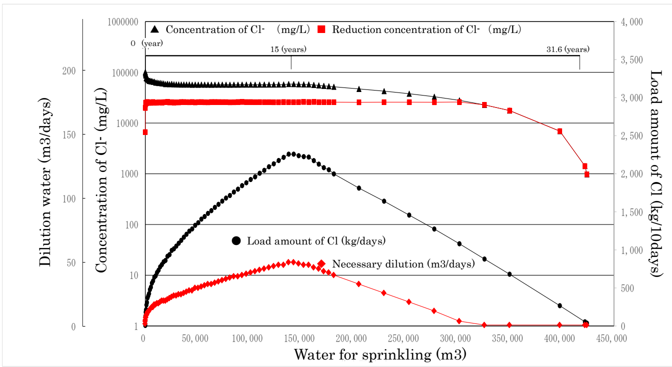

Figure 8 The amount of dilution water and the reduction of predicted peak concentration of Cl^-

Peak concentration:101,200mg/L
(at the initial stage)
The maximum load amount:2,260kg/day
Reduce the peak concentration
: set below 26,000mg/L
The maximum volume of dilution water：49m^3/day
The scale of leachate treatment plant：90m^3/day

dilution water to be added is set to below 49m^3/day in the leachate treatment plant. The result is shown in Figure 8. In the case of the volume of dilution water, the maximum value is 49m^3/day. At the same time, the volume of water for sprinkling is 137,665m^3. Then, when the volume of water for sprinkling is 325,720m^3, the volume of dilution water gradually decreased to 0m^3/day. Therefore, when the scale of leachate treatment plant which is a sum of the amount of leachate and dilution water reach to 90m^3/day, the quality of Cl^- planned raw water is 26,000mg/L.

CONCLUSIONS

1) In the design project for MSW landfill sites, it is possible to estimate the peak concentration of Cl^- and make a quality prediction of Cl^- concentration raw water through the Cl content in landfill incineration residues and landfill methods.
2) When the predicted peak concentration of Cl^- is generated, it is possible to reduce the peak concentration by adjusting the dilution area in the case of open type or adjusting the volume of water for sprinkling and dilution in the case of closed type.
3) In the design of a closed type leachate treatment plant, referring to the peak concentration of Cl^- and the load amount of Cl which is predicted by landfill cell model and the scale of open type leachate treatment plant, it is possible to calculate the volume of dilution water to reduce the concentration of Cl^-. As a result, the optimal quality of Cl^- planned raw water and the optimal scale of leachate treatment plant can be set.
4) By using the landfill cell model in the open type, it is possible to find a landfill method with the viewpoint of early stabilization.
5) By using the landfill cell model in closed type, it is possible to find a landfill method, adjust the volume of water for sprinkling and reduce the Cl^- concentration with the viewpoint of early stabilization.

Further studying

1) As the predicted peak concentration by landfill cell model is greatly influenced by the landfill order, a study on desirable landfill pattern will be carried out.
2) Considering the actual shape of the landfill(slope), we will improve the accuracy of the landfill cell model.
3) Making a comparison between the quality of Cl^- planned raw water which predicted by the landfill cell model and the quality of planned raw water in the actual MSW landfill sites.
4) Setting the landfill methods and the volume of water for sprinkling with the viewpoint of early stabilization by water sprinkle methods(Divide area to sprinkle water).

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QUANTITY OF OUTBREAK ESTIMATION OF THE BY-PRODUCT SALT FROM MSW INCINERATOR

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ABSTRACT
With the spread of MSW incinerator and innovation of exhaust gas treatment facility, the salts in incineration residue is increasing. The concentration of Cl- in leachate is rising while the incineration residue is landfilled. Therefore, more desalination apparatuses are required. However, the by-product salt will be generated as concentrated salt when the desalting treatment is performed. Then, it will be filled in flexible containers and landfilled after drying. In order to provide a recycling system for by-product salt in the future, as the basic material, the quantity of outbreak estimation of the by-product salt from MSW incinerator is necessary. As a result, the total discharge of the by-product salt accompanying MSW incineration is estimated as 147 thousand tons per year as the incineration residue in terms of the equivalent amount of Cl-. Among this, the amount of Cl- in the atmosphere is 5 thousand tons per year, the amount of Cl- in treating effluent sewerage is 21 thousand tons per year (equals to 96 tons per day) and the amount of Cl- in the quantity of landfills is 121 thousand tons per year which is the highest among all.

Keywords: Municipal waste,Incineration plant, By-product salt,Incineration ash, Fly ash

INTORODUCTION
The amount of municipal solid waste discharged in 2016 in Japan is 43.17 million tons per year. The incineration amount of combustible waste is 32.94 million tons, it is about 34.29 million tons including the incineration of incombustible treatment residues. Among this, the final disposal quantity is about 3.05 million tons and the recycle quantity is 1.23 million tons. The by-product salt is generated by chlorine in waste (vinyl chloride, salt which contained in kitchen waste), and alkaline agent (slaked lime, caustic soda) which added in the incineration plants. As a flow of by-product salt, some discharged as incineration ash (bottom ash) and fly ash from incineration plants, some as molten fly ash from melting plants, some as desalted residues from wet type smoke washing apparatus or acid gas removal through double stage bag filter apparatus, and some as exhaust gas discharged a little bit into the atmosphere. When the by-product salt produced by wet type smoke washing, excluding some plants discharge it in sewer, others landfill it at the final disposal sites. It becomes a factor causing the salt damage in public water area of the lower reach of the water treatment plants and agricultural lands.
In this study, as a basic material for future recycling system of by-product salt, the generation amount of by-product salt from MSW incineration plants in 2016 can be estimated according to the past literature and questionnaire survey results on incineration plants 2).

METHODOLOGY
In order to grasp the mass balance of by-product salt generated by refuse incineration, a questionnaire has been sent to 113 nationwide incineration plants in 2012, and 79 incineration plants (70%) make a response. We analyze the 68 stoker furnaces excluding gasification furnace and fluidized bed furnace. Based on the questionnaire results in 2012, the estimates for the content of bottom ash and fly ash are carried out. The steps are as follows:

- The generation amount is adjusted depending on the presence of absence of pretreatment of bottom ash(such as metal removal)
- The generation amount varies depending on the moisture content of bottom ash, therefore, it expresses in terms of dried ash.
- The amount of fly ash is converted to dried ash, and dosage of cement is excluded.
- Fly ash generation amount is divided by desalination method (dry type, wet type) of exhaust gas.
- In the plants which neither the moisture content of

bottom ash nor fly ash is listed, the moisture content has been set based on the incineration plant register[3] and similar examples.

・The ash melting furnace is arranged with bottom ash, fly ash, molten fly ash.

・The design amount of exhaust gas per furnace is using the mentioned data in the plant register.

AN ESTIMATION OF BY-PRODUCT SALT GENERATION AMOUNT

Based on the results of questionnaire survey on incineration plants nationwide and the incineration results of combustible waste in 2016, an estimation of the by-product salt generation amount by refuse incineration nationwide in 2016 is conducted by the following procedures.

The incineration amount of combustible waste

The incineration amount of combustible waste is 32, 940 thousand tons/year. After adding 1,350 thousand tons/year of the incombustible treatment residues, it becomes 34,290 thousand tons/year. Besides, according to the data in the Refuse Incineration Plant Register3), the annual incineration amount of the wet type smoke washing plant among 70 plants is 6, 587 thousand tons/year (19.1%), it this case, we calculate it by 20%.

The ratio in emissions of exhaust gas (Dry type treatment 80%; Wet type treatment 20%)

Based on the survey conducted by Ministry of the Environment in 2012[2], the hydrogen chloride concentration in exhaust gas is $26.3 mg/m^3$ through dry type treatment and $3.9 mg/m^3$ through wet type treatment in 2011. The average value among all is $11.6 mg/m^3$. The average value for the emissions of exhaust gas is 6.1 thousand m^3/t.

In this estimation, according to the questionnaire result, the emissions of exhaust gas is 6 thousand m^3/t, the hydrogen chloride concentration is estimated to be $30 mg/m^3$ (18.4 ppm) in dry type and $5 mg/m^3$ (3.1 ppm) in wet type, besides, the chlorine content also can be calculated.

Dry type : 34,293 thousand t/year×0.8×6 thousand $m^3/t \times 30 mg/m^3 \times 35.5/36.5 \times 10\text{-}6 \fallingdotseq 4.8$ thousand t/year

Wet type : 34,293 thousand t/year ×0.2×6 thousand $m^3/t \times 5 mg/m^3 \times 35.5/36.5 \times 10\text{-}6 \fallingdotseq 0.2$ thousand t/year

The blowing amount of slaked lime

The questionnaire result shows that the blowing amount of slaked lime is 6.9kg/t by dry type treatment method or 8.0kg/t by mainly dry type treatment method. The addition amount of caustic soda in wet type treatment is 9.6 kg/t as an average value.

The generation amount of incineration ash and fly ash (incineration 8%, fly ash 2%)

In the case of the generation amount of incineration ash and fly ash, according to the Maintenance Plan and Design Guidelines of the Waste Treatment Plant (Revised edition)4), 90% of the ash content in waste is incineration ash, and the remaining content after adding 2 times of slaked lime becomes the fly ash. The ash content is 6.7% which is the national average value (1996 ~2005) calculated by the Japan Environmental Sanitation Center. Therefore, the incinerator ash is 6% and the fly ash is 2% (6.7 × 0.1 × 3), the total amount is 8%.

According to questionnaire survey, in the stoker furnace, the generation amount of incineration ash is 12.7% (the moisture content is 25.9%), the dried ash after iron removal is 9.0%. On the other hand, the generation amount of fly ash is 2.4% (the moisture content 20.8%), the dried ash without adding cement is 1.9%. In addition, the result value of incineration residue is 8.9%, the dried ash is 6.6% when the moisture content is 26%. After adding 3.6% recycled amount, the predicted value is 10.2% which is almost as same as the value 10.9% in questionnaire result.

Considering these facts, the generation amount of incineration ash (dried ash) is 8% and the generation amount of fly ash is 2% in this estimation.

The chlorine content of incineration ash and fly ash (Incineration ash: 1.4%; Fly ash: 15.0%)

The chlorine content of incineration ash and fly ash is introduced in the Maintenance Plan and Design Guidelines of Waste Treatment Plant (Revised edition) through the value in dust treatment manual. Since the chlorine content in the ash is hardly measured in the questionnaire survey, the value in dust treatment manual which incinerator ash is 1.4% of and fly ash is 15.0% are used. (There was an answer that fly ash is 11% in the questionnaire survey)

Through the estimation value, the chlorine content in the refuse is 0.43% which divided into 0.32% of volatile chlorine (fly ash + exhaust gas) and 0.11% of non-volatile chlorine (bottom ash). The total amount of chlorine in combustible waste is 0.37% in the questionnaire survey, since it is 0.39% in stoker furnace, the values are almost the same.

The others

The by-product salt in the incineration residues which will be disposed of is generated as a mixed salt of NaCl and KCl, chlorine in this case is converted to NaCl (1.65 times).

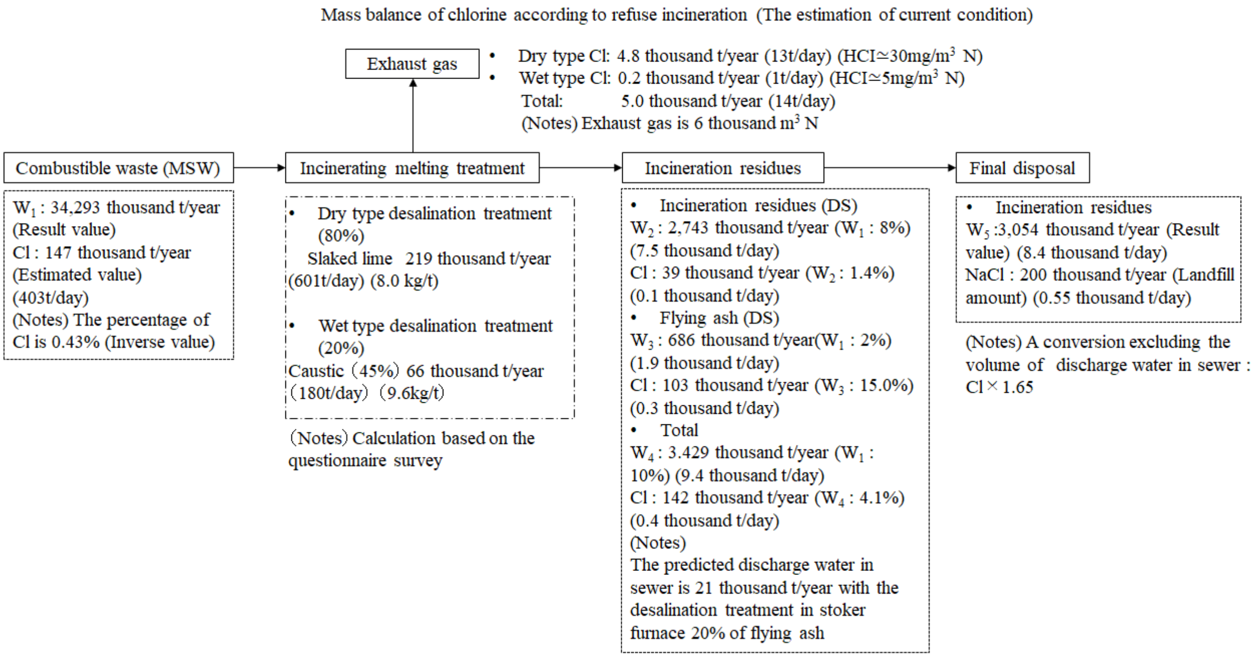

Figure 1 Mass balance of chlorine
(Converted to NaCl)

CONCLUSIONS

The estimated value of the total amount of chlorine generated by refuse incineration is 147 thousand tons/year (403t/day). The annual amount of chlorine in the atmosphere is 5 thousand tons, occupying 3.4% of all. It is easy to understand the salts generation amount excluding chlorine exhausted to the atmosphere. In this estimation, since the salts from which the calcium component has been removed by landfill disposal of incineration residues is generated as a mix salt (by-product salt) of NaCl and KCl, the chlorine in this case is converted to salt (1.65 times of chlorine), estimated as the salt generation amount.

The generation amount of chlorine according to refuse incineration is calculated to be 234 thousand tons/year (642 tons/day), including the discharge water in sewer. The amount to be land disposal is 200 thousand tons/year (around 550 tons/day) excluding discharge water in sewer which is 34 thousand tons/year.

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EXPERIMENTAL EVALUATION OF AERATION VOLUME CONCERNING SUPPRESSION OF HYDROGEN SULFIDE GAS GENERATION IN LANDFILL WASTE

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ABSTRACT

We focused on the anaerobic condition which is the cause of generation of hydrogen sulfide gas at the final disposal site. We decided to carry out experiments to verify whether generation of hydrogen sulfide gas can be improved by sending air. We conducted a vial filled with waste gypsum board. In this experiment, generation of hydrogen sulfide gas could be suppressed by aeration of 0.532L/min/m^3 per unit volume of waste. We also performed a lysimeter experiment. In this experiment, the anaerobic condition was improved by ventilation. It was found that the gypsum board of the landfilled waste is stabilized early. The managed final disposal site has equipment of leachate drainage pipe and degassing pipe. It is considered that generation of hydrogen sulfide gas can be controlled by ventilating using these facilities. Regarding the improvement of the pH condition, the suppressing effect of hydrogen sulfide gas generation by inactivation of sulfate reducing bacteria using high pH fly ash was confirmed.

Keywords: waste gypsum board, hydrogen sulfide gas, semi-aerobic structure, aeration, fly ash

INTRODUCTION

In recent years, Development of recycling technology progresses with respect to waste gypsum board such as residual material of new materials. However, Many of the waste gypsum boards discharged by dismantling are still disposed of at the final disposal. The waste gypsum boards had been landfilled in a stable final disposal site, accidents resulting from the generation of hydrogen sulfide occurred. Currently in Japan, waste gypsum boards are landfilled in controlled final disposal sites because reclaiming of least-controlled final disposal sites with waste gypsum boards has been totally banned in accordance with the notification “Handling of waste gypsum boards from which the attached paper has been removed” (June, 2006). This has resulted in a concern about hydrogen sulfide gas generation also at controlled final disposal sites due to poor design and maintenance management. Under these circumstances, it is thought to be imperative that the measures for suppressing hydrogen sulfide gas at a controlled final disposal site be studied. In addition, early stabilization of waste gypsum boards, which are the actual generating source, landfilled in a controlled final disposal site have not been studied, although the measures for suppressing hydrogen sulfide gas generation have been studied partly because they had been landfilled in least-controlled final disposal sites.

The mechanism of hydrogen sulfide gas generation is the reduction of sulfate by sulfate-reducing bacteria, utilizing organic matter containing sulfate as the base material. Sulfate-reducing bacteria are activated to emit hydrogen sulfide gas when all of the following 5 conditions: the material conditions on the sulfate-reducing bacteria and the low-molecular organic matter, the anaerobic condition under which sulfate-reducing bacteria live, and the environmental conditions on temperature and pH are met.

Looking at these conditions in the context of a final disposal site, regarding material conditions, sulfate-reducing bacteria are indigenous bacteria. Besides, it is not possible to rule out the possibility that low-molecular organic matter containing sulfate is mixed with landfilled construction waste gypsum boards. On the other hand, regarding the anaerobic condition as an environmental condition, hydrogen sulfide gas generation is presumed to be suppressed by alleviation of anaerobic condition with artificial aeration, e.g., hydrogen sulfide gas generation would be suppressed when oxygen remains. The antimicrobial activity suppression activity is particularly expected since sulfate-reducing bacteria are members of a strictly anaerobic bacterial community. The temperature condition is less likely to be controlled since the growable range of a sulfate-reducing bacterium is as wide as from 15 to 65 ℃. Meanwhile, the pH condition could be controlled through utilization of wastes including high pH flying ash because growth of sulfate-reducing bacteria is inhibited at a high pH or, in the opposite way, at pH 6.0 or lower.

This study focused on aeration which can be relatively easily controlled artificially as the way for suppressing hydrogen sulfide gas generation at final disposal sites and it verified the effect of suppressing hydrogen sulfide gas generation. In particular, since controlled final disposal sites have a semi-aerobic structure including a leachate drainage pipe and degassing pipe, aeration at controlled final disposal sites utilizing the above-mentioned equipment could be possible. In addition, We decided to verify the feasibility of control using fly ash 、 in order to improve the artificially controllable pH condition.

We conducted an experiment confirming the unit aeration amount necessary for hydrogen sulfide gas generation using a vial bottle and a lysimeter aeration experiment simulating the landfill condition of waste gypsum boards and evaluated the aeration amount needed for suppression of hydrogen sulfide gas generation. In addition, the impact of aeration on waste gypsum board decomposition and salt-washout were also verified in the lysimeter experiment in order to understand the stabilization effect of the landfilled waste gypsum boards that occurred simultaneously with the effect of suppressing hydrogen sulfide gas generation. In addition, About verification possibility of control by high pH fly ash、We conducted an experiment assuming actual utilization of fly ash using a vial bottle. We decided to check the occurrence of hydrogen sulfide by laying fly ash over the waste gypsum board.

Hydrogen Sulfide Gas Suppression Experiment with Aeration

Experiment Method

The experiment method was as follows: As a test specimen, 880 g of waste gypsum boards landfilled in final disposal site was crushed into the size of 20 mm or less. The equipment reproducing an atmosphere generating hydrogen sulfide gas induced by the sulfate-reducing bacterial activity in a sealed condition was prepared by packing the test specimen in a 2,000-ml vial bottle, and 400 ml of pure water was added to it to make the water saturated, and then keep it in an incubator at 35 ℃. Subsequently, the equipment was aerated by introducing the air in the vial bottle using a vacuum pump, hydrogen sulfide gas was collected, and its generation amount was measured. Photo-1 shows the experiment status.

The conditions for the vial bottle experiment are indicated in Table-1. In the experiment, an anaerobic vial bottle in which the inside air was replaced with nitrogen was set as blank, and the aeration amounts for other vials were set to 0.6 ml/min, 0.8 ml/min, and 1.0 ml/min. (Each of them is referred to as RUN 1, RUN 2, RUN 3, and RUN 4. The experiment was conducted in April to May in 2016 using waste gypsum boards which were collected in October 10, 2015 and had been stored since then.

Experimental Results

Fig.-1 shows the hydrogen sulfide gas generation status in the vial bottles. In the blank vial RUN 1 that reproduced an anaerobic state, hydrogen sulfide gas was first generated on Day 3, and high concentrations of hydrogen sulfide gas at 3,000 ppm and 24,000 ppm were detected on Day 20 and Day 40, respectively.

Photo -1 Experimental Status for Hydrogen Sulfide Gas Generation Suppression with Ventilation

Table-1 Vial Bottle Experimental Conditions

Specification \ Experiment case	(unit)	RUN 1	RUN 2	RUN 3	RUN 4	Remarks
		Without aeration	With aeration			
Vial bottle volume	L	2				
Amount of waste (gypsum board landfill) packed	g	880	880	880	880	400 ml of pure water was poured.
Aeration amount	ml/min	-	0.6	0.8	1.0	

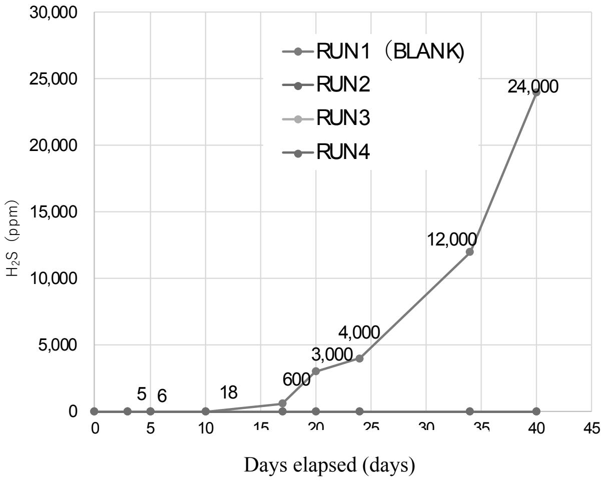

Fig.-1 Sulfide Gas Generation Status in Vial Bottles

On the other hand, no hydrogen sulfide gas was detected during the measurement period in any aerated case (RUNs 2 to 4), which confirmed the suppression effect by aeration on hydrogen sulfide gas generation. Meanwhile, in the measurement of hydrogen sulfide gas in the anaerobic vial bottle experiment using the same gypsum board, the concentration sharply dropped at the stage where the inside state temporarily became an open state instead of the active aerated state, and 2 days later, the concentration gradually increased.

From these results, the aeration amount for suppressing hydrogen sulfide gas was determined to be the minimum aeration amount 0.6 ml/min for RUN 2 in this experiment. This value was 0.532 L/min/m^3 if it was converted to a value per the waste unit volume.

SO_4^{2-} Leachate Property Confirmation Experiment in Lysimeter Experiment

Next, in order to grasp the effects of decomposing landfilled waste gypsum boards by aeration and of stabilization such as salt-washout, the aeration experiment and the confirmation of the leachate salt change were conducted using lysimeters packed with waste gypsum boards.

Experiment Method

A transparent acrylic lysimeter having a diameter of 20 cm and a height of 200 cm was used. The change in water quality was identified by filling waste gypsum board specimen to this lysimeter (packing density: 0.78 g/cm^3) and sprinkling water that assumes rainfalls. Water was sprinkled once a week and the sprinkling amount was determined to be 1,018 ml/week, referring to the average precipitation in Japan 1,718 mm.

The waste gypsum boards landfilled in final disposal sites were used after they were crushed to 20 mm or less.

In order to confirm the impact of the thicknesses of the landfilled waste gypsum board layer on stabilization of the waste gypsum boards, the layer thicknesses were determined to be 45 cm, 90 cm, and 180 cm (for RUN 1, RUN 2, and RUN 3), respectively. For RUNs 4 to 6, the aeration amount was changed with the layer thickness of waste gypsum boards remaining unchanged from 180 cm. These conditions were set for the purpose of identifying the organic matter decomposition condition for the hydrogen sulfide gas generation suppression effect and the landfilled waste gypsum board stabilization effect simultaneously. Table˜2 indicates the lysimeter experiment conditions. Note that the lysimeters were aerated by pumping air with a vacuum pump through the bottom portion of each lysimeter to the landfilled waste gypsum boards through a cross-shaped aeration pipe in the crushed stone layer.

Leachate was collected and analyzed once a week. Six analysis items (pH, EC, COD, TOC, SO_4^{2-} , and Ca^{2+}) were determined. For $Ca^{2+}$and SO_4^{2-}, leachate was collected and analyzed once a month. Fig.-2 is a schematic of the lysimeter experiment.

Table-2 Lysimeter Experiment Conditions

Specification / Experiment case (unit)		RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	Remarks
		Without aeration			With aeration			
Shape and material of lysimeter	cm	20 (in diameter) X 20 (in height) (made of transparent acrylic)						Sample of demolded building gypsum boards delivered to the final disposal site
Layer thickness	cm	45	90	180	180	180	180	
Amount of waste (gypsum board) packed	kg	1.103	2.205	4.410	4.410	4.410	4.410	
Specific gravity	t-dry/m^3	0.78	0.78	0.78	0.78	0.78	0.78	
Water sprinkling amount	L/one sprinkling, week	↓	↓	↓	↓	↓	↓	
Aeration amount	L/min/m^3	-	-	-	0.731	0.532	0.731	
Leachate measurement items		pH, ET, COD, TOC, SO_4^{2-}, CA^{2+}						

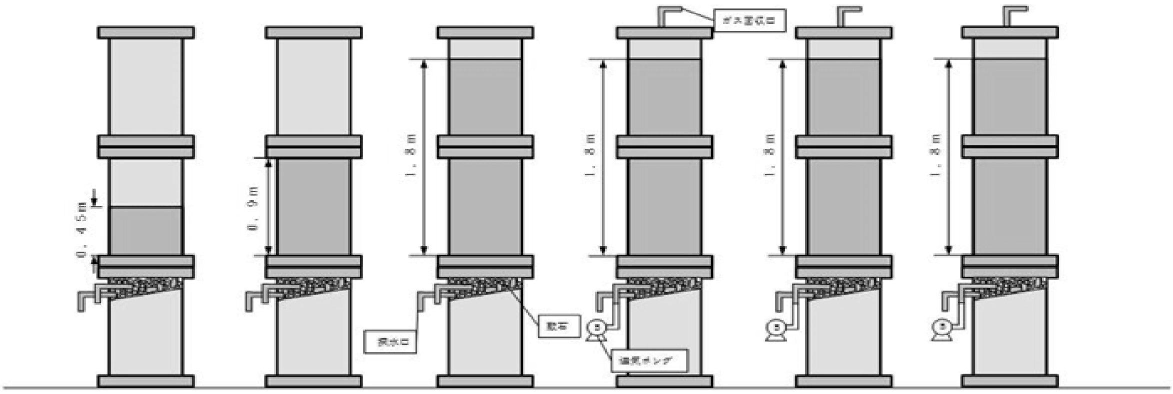

Fig.-2 Schematics of Lysimeter Experiment

Experimental Results

The analysis results on the leachate from the lysimeters are shown in Figs. 3 to 8.

Daily change of pH and EC in the leachate : The trend of pH changed in the range between 7.4 and 8.1 in the non-aerated RUNs 1 to 3, maintaining a neutral range (Fig.-3). On the other hand, the pH in the aerated RUNs 4 to 6 gradually increased although its trend maintaining a neutral range between 7.0 and 8.5.

SO_4^{2-} was presumed to be dissolved in the leachate due to washout from the landfilled waste gypsum boards on around Day 150 and onward partly because the EC value has been stable since around Day 150 (Fig.-4).

Daily change of Ca^{2+} and SO_4^{2-} in the leachate : The initial value of Ca^{2+} in the aerated RUNs 4 to 6 were 950 to 1,028mg/L, which were lower compared to 1,256mg/L in the non-aerated RUN 3 (Fig.-5).

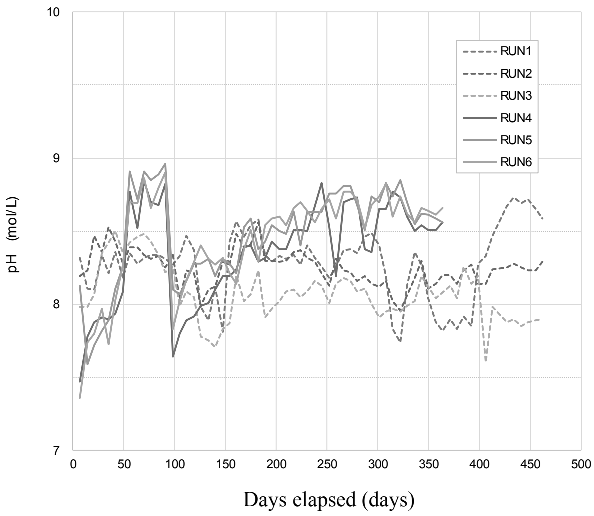

Fig.-3 pH of Leachate

Meanwhile the SO_4^{2-} concentration showed the declining tendency from the start of the experiment until about Day 150, and contrary to the Ca^{2+}phenomenon, its initial values in the aerated RUNs 4 to 6, 4,536 to 4,794mg/L were higher than 3,336mg/L for the non-aerated RUN 3 (Fig.-6). Also given the opposite behavior as previously mentioned that the aerated groups had a lower initial Ca^{2+} concentration, it seems that the carbon dioxide injected to the landfilled waste gypsum board layer by means of aeration reacted with calcium sulfate ($CaSO_4$) generating calcium carbonate which is the main component of gypsum, and as a result, the Ca^{2+} concentration in the leachate lowered, and, at the same time, SO_4^{2-} was generated and its concentration increased. After the initial stage, the SO_4^{2-} concentrations were stable within the range of -1,100 to 1,300 mg/L for the non-aerated RUNs 1 to 3.

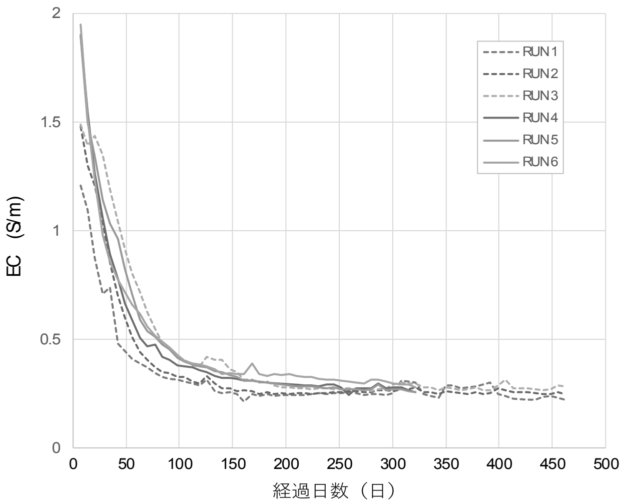

Fig. -4 EC in Leachate

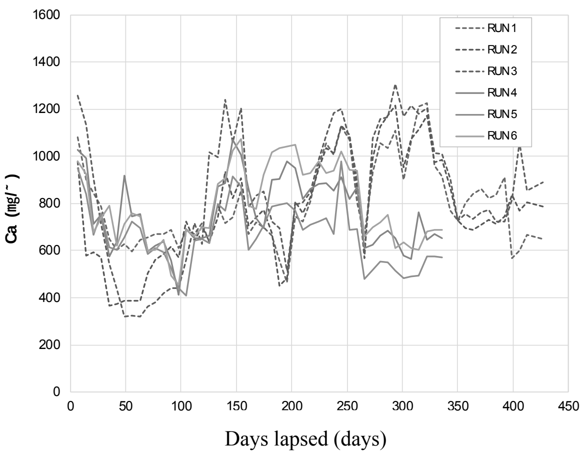

Fig.-5 Ca^{2+}in Leachate

On the other hand, the SO_4^{2-} concentrations in the aerated RUNs 4 to 6 were 1,400 to 1,800mg/L, showing a gradual declining tendency while the group maintained a higher concentration than the non-aeration group. The SO_4^{2-} concentrations remained at a high concentration exceeding 1,000 mg/L in all lysimeters. As for $CaSO_4$, it was found that it took a long time for SO_4^{2-} to be eluted because of its very low solubility.

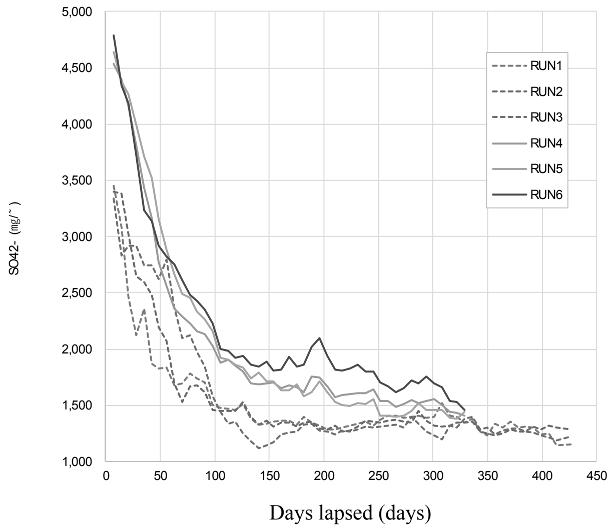

Fig.-6 SO_4^{2-} in Leachate

<u>Daily Changes of TOC and COD in the leachate</u>

Next the concentrations of the organic matters TOC and COD showed similar behaviors in the non-aerated RUNs 1 to 3 and the aerated RUNs 4 to 6. The TOC and COD concentrations in the non-aerated RUNs 1 to 3 dropped to 3.8 to 37.7mg/L, and 12.6 to 63.1mg/L, respectively, at around Day 200. On the other hand, in the aerated RUNs 4 to 6, the TOC and COD concentrations were 80.5 to 106.5mg/L and 135.3 to 166.2mg/L, respectively, both of which were higher than the non-aerated RUNs 1 to 3 (Fig.-7,8).

The sharp drop of the SO_4^{2-} concentration at the initial stage after start of the experiment continued until about Day 150, the cause of which was presumed to be the

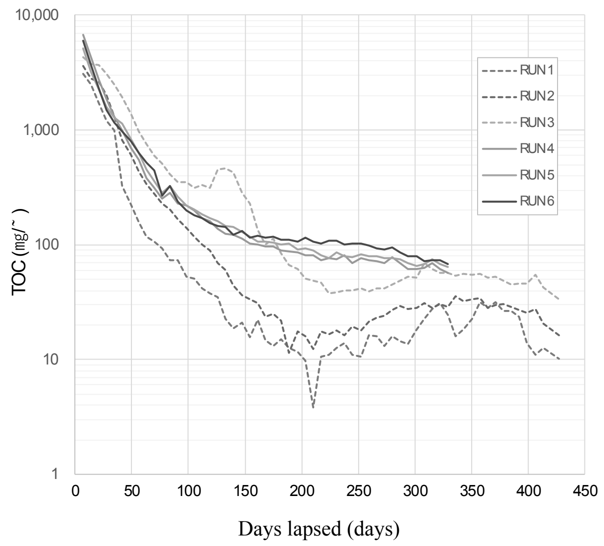

Fig.-7 TOC in Leachate

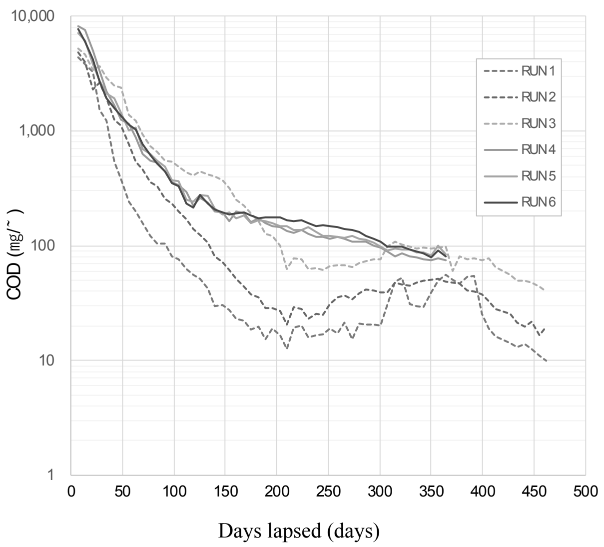

Fig.-8 COD in Leachate

movement of fine powders due to the initial water channel until the landfilled waste gypsum boards in the lysimeter got stable and due to water sprinkling. The reason for slower reduction of the concentrations in the aerated RUNs 4 to 6 than in non-aerated RUNs 1 to 3 was thought to be the suppressed movement of fine powders from the landfilled waste gypsum boards due to water channels and due to water sprinkling by aeration, partly because the aeration was performed through the bottom portion of each lysimeter. Incidentally, the salt overflow suppressing effect by aeration through the bottom portion was also observed for Calcium. Regarding the behaviors on Day 150 and onward, the both TOC and COD concentrations increased again and then gradually dropped in the range of approx. 20 to 50 ppm in all lysimeters in RUNs 1 to 3. On the other hand, in RUN 4s to 6, they showed the tendency to continuously and gradually drop starting with relatively high concentrations of 100 to 200 ppm. Such continuous overflow behavior of organic matter in the aerated RUNs 4 to 6 was presumed to be due to progress of decomposition of organic matter by aeration in the same way as the decomposition of easily-degradable organic matter using the air blow-in method as an aerobic countermeasure against hydrogen sulfide gas4). Regarding the relationship between the layer thickness and the concentration, the TOC and COD concentrations increased as the layer thicknesses of the landfilled waste gypsum boards RUN 1, RUN 2, and RUN 3 increase in this order. The cause of the layer thickness-concentration relationship was presumed to the washout effect.

An Experiment on Suppression of Hydrogen Sulfide Production by Mixed Landfill of Fly Ash

Experiment Method

Table-4 indicates the Mixed Fly Ash experiment conditions.

As an experimental method, the waste gypsum board embedded in the final disposal place was pulverized to 20 mm or less, and 880 g of the sample was filled in a 1 liter vial. The remaining three RUN 11, RUN 12, RUN 13 placed fly ash on the waste layer for the treatment of hydrogen sulfide gas by the formation of metal sulfides and the pH regulating effect. The amount of fly ash was 10% (44 g) in run 11, 20% (88 g) in run 12, 40% (176 g) in run 13, based on the weight of the filled waste gypsum board. Pure water was added to this and saturated.

Thereafter, the air in the bottle was replaced with nitrogen gas, and the bottle was aged in an incubator at 35 ° C. In this way, a device for reproducing hydrogen sulfide generating atmosphere by sulfate reduction bacterial activity was prepared.

In addition, 50 ml of water was sprayed every week, and leachate was collected from the outlet set at the bottom of the vial bottle and analyzed. The generated gas was collected by inserting an injection needle into the waste layer and sucking it. No ventilation was done.

Experimental Results

Experimental results Fig. 9 shows the change with time of hydrogen sulfide gas in the vial.

In blank RN 10, 500 ppm of hydrogen sulfide gas began to e emitted from the third day, and the concentration of hydrogen sulfide gas was 2,000 ppm at the end of 12 days. On the other hand, hydrogen sulfide gas was generated at 600 ppm at RUN 11, 250 ppm at RUN 12, and 80 ppm at RUN 13, respectively, but the effect of suppressing the generation of hydrogen sulfide gas was recognized as compared with RUN 10. The pH of RUN 10, RUN 12, and RUN 13 of the leachate was pH 7.1 to 7.7, while the pH was 7.5 to 8.2, which was higher than that of the blank (Fig.-10).

Table-4 Mixed Fly Ash Experiment Conditions

Specification \ Experiment case	(unit)	RUN10 (BLANK)	RUN11	RUN12	RUN13
Fly ash addition amount	g	0	44	88	132
Total filling amount	g	440	440	440	440
Filling volume	ml	186	186	186	186
Packing density	g/cm^3	1.0	1.0	1.0	1.0
Amount of water sprayed	ml/Week	50	50	50	50
Airflow rate	ml/min	0	0	0	0

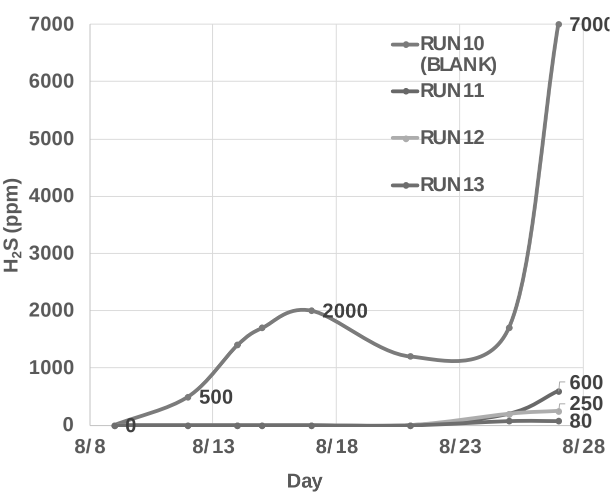

Fig.-9 Sulfide Gas Generation Status in Vial Bottles

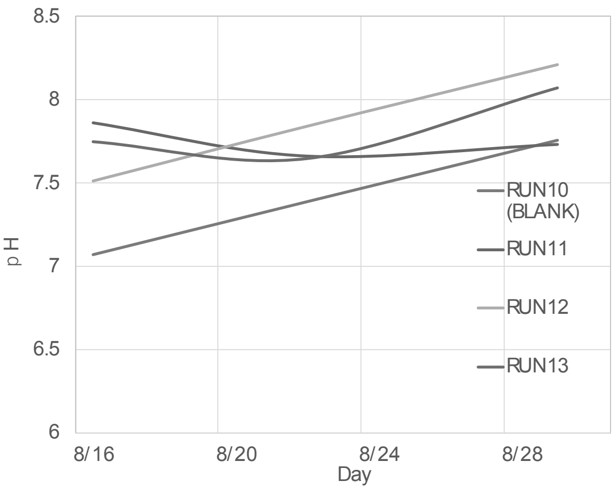

Fig.-10 pH of Leachate

Results and Discussion

In experiment confirming the unit aeration amount volume needed for suppressing hydrogen sulfide gas generation using a vial bottle, hydrogen sulfide gas generation was able to be suppressed by aeration of 0.532 $L/min/m^3$ per unit volume of the waste. Researches related to stabilization of waste at final disposal sites often include the measurement of wind volume in water collecting pipes and the conversion of the air inflow amount to the waste in order to verify the semi-aerobic state, with examples of 8.6 to 26.8 $L/min/m^3$ per unit volume of the waste and the maximum air inflow amount 1.5 $L/min/m^3$ fed through a leachate drainage pipe in semi-aerobic landfill. The values obtained from this experiment were below these values, supporting that hydrogen sulfide gas generation can be suppressed by aeration with less air amount.

On the other hand, regarding the waste stabilization effect in the aerated state, the result of the lysimeter experiment shows that a high concentration of organic matters dropped sharply due to water channel or movement of fine powders during the early stage of the experiment and then gradually decreased, implying the progress of decomposition of organic matter by aeration and its stabilization effect at the early stage.

In addition, the SO_4^{2-} washout effect by aeration was confirmed based on the SO_4^{2-} behavior that its initial concentration increased by aeration and then continuously and gradually dropped.

Attempts have been made to reproduce high pH conditions in a mixed landfill test of waste gypsum board and fly ash so as not to activate sulfate reducing bacteria.

The inhibitory effect of hydrogen sulfide gas was confirmed by mixing 20% fly ash.

Since the pH of the leachate is neutral, it is considered that the generated hydrogen sulfide gas reacted with the metal. We will elucidate these suppression mechanisms and confirm the suppression effect under high pH conditions.

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PROBLEMS AND COUNTERMEASURES AGAINST CHELATED FLY ASH TO MSW LANDFILL MANAGEMENT

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ABSTRACT

The occupancy rate of incineration residues is above 87% among all waste at MSW landfill sites. For fly ash, it is obligated to do a stabilization treatment at the stage of disposal at MSW landfill sites. At present, medical treatment with chelating agents is the mainstream in Japan, and many local governments are using this method. In recent years, at the MSW landfill sites which receiving fly ash, dysfunction of leachate treatment facilities become tangible because of nitrification inhibition. The high concentration of salts is thought as the cause, while the effect of chelating agent on biological inhibition has also been found as the factor affecting leachate treatment facilities. However, there are still some unclear points about the actual situation. Therefore, the effects of chelating agents and their countermeasures have been investigated and reported in this research.

QUESTIONNAIRE SURVEY RESULTS[1)]

The MSW incinerators

The utilization situation of chelating agents

A survey was made on 151 MSW incinerators which were randomly selected from 1153 incinerators in Japan. 122 incinerators answered the questionnaire, the response rate is 80.8%. The results show the ratio of chemical treatments which is using in MSW incinerators exceeds 80% among all the intermediate treatments. The details of chemical treatments are

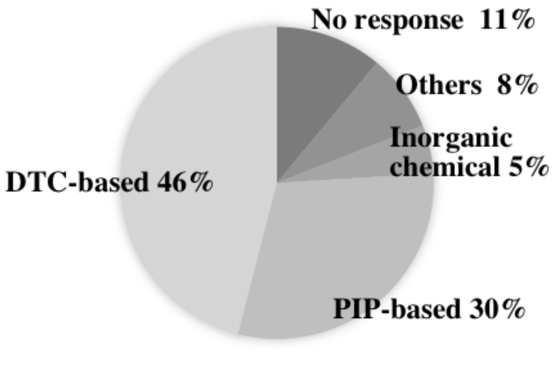

Figure 1 Details of chemical treatment

shown in Figure 1. The ratio of DTC-based chelating agents is about 46% and the ratio of PIP-based chelating agents is 30%. In addition, the inorganic chemical such like phosphorus-based occupied 5% among all while the ratio of others such like calcium hydroxide is 8%. 11% of MSW incinerators didn't answer this question. Moreover, it is more frequently for incinerators to add 2.5～3.0% of chemicals during the treatments, 21.3% of them chose this value. The maximum dosage is 11.5～12.0% of chemicals , 2.5% of incinerators chose this value.

The MSW Landfill Sites

Leachate conditions

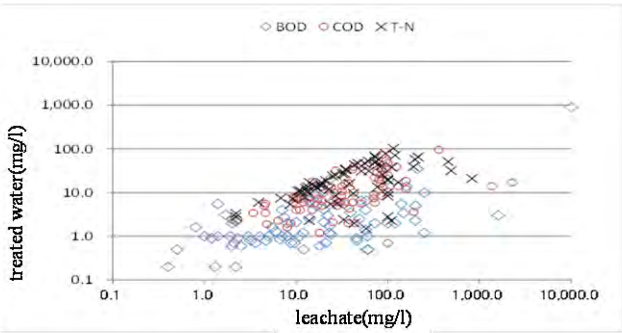

Figure 2 Processing status of leachate treatment plants

A survey was made on 107 MSW landfill sites which carrying out denitrification treatment among 1691 MSW landfill sites in Japan. 69 sites answered the questionnaire, the response rate is 64.9%. Figure 2 shows the leachate quality and leachate treatment in each site. Through the results, the BOD average removal rate is 69.3%, there is relatively no problems during the treatments. Besides, the COD average removal rate is 58.2%. However, the T-N average removal rate is 38%, problems can be found in the processing of nitrogen treatments.

CHEMICAL COMPOSITION OF CHELATING AGENTS[2)]

Table 1 explains the composition results of chelating agents. Based on the data, the pH showed a high alkali around 14. In the case of COD, COD_{Cr} is two times more than COD_{Mn} in DTC-based. On the other hand, COD_{Cr} is three times more than COD_{Mn} in PIP-based. The ratio of T-N in DTC-based is 2.4wt% and it is 2.8wt% in PIP-based. The ratio of T-S is 15.4wt% in PIP based which is 1.5 times higher than 9.3wt% in

Table 1 Composition result of organic chelating agent

Items	Organic Chelating		Inorganic Chelating	
	DTC-based	PIP-based	phosphorus-based	Iron series
pH	>14	13.6	<1	<1
COD_{Mn}	222,000mg/l (18.6wt%)	111,000mg/l (8.9wt%)	3.2mg/l	28,000mg/l (2.1wt%)
COD_{Cr}	460,000mg/l (39.0wt%)	380,000mg/l (30.8wt%)	14mg/l	30,000mg/l (2.2wt%)
Cl^-	130,000mg/l (11.0wt%)	110,000mg/l (8.9wt%)	<40mg/l	290,000mg/l (21.4wt%)
T-P	12mg/l	<10mg/l	410,000mg/l (26.1wt%)	16mg/l
PO_4^{3-}	<50mg/l	<50mg/l	1,200,000mg/l (76.4wt%)	Unmeasurable
T-N	28,000mg/l (2.4wt%)	35,000mg/l (2.8wt%)	<40mg/l	<66mg/l
T-S	110,000mg/l (9.3wt%)	190,000mg/l (15.4wt%)	<320mg/l	<30mg/l
T-Fe	-	-	-	200,000mg/l (14.8wt%)
Thiourea substances	10,000mg/l (0.85wt%)	5,300mg/l (0.43wt%)	<2.5mg/l	Unmeasurable
Specific gravity	About 1.18	About 1.23	About 1.57	About 1.35

DTC-based. This is because DTC-based contains one S molecule per chelate molecule, while PIP-based contains two S molecule. In addition, DTC-based contains 0.85wt% of thiourea and PIP-based contains 0.43wt% of thiourea. It is suggested that the chelating agents contain thiourea which occurs nitration inhibition in leachate treatment at MSW landfill sites. In the case of inorganic chemicals, there is extremely small amount of COD components in phosphorus-based and the amount of PO_4^{3-}(phosphoric acid-based component) is 76.4%. Besides, the thiourea have not been detected in inorganic chemicals. In the iron series, the amount of COD_{Mn} is 2.1wt% and the amount of COD_{Cr} is 2.2wt%, most of them are readily decomposable COD components. In the case of pH, both phosphoric acid-based and iron series exhibit strong acidity.

LEACHING BEHAVIOR OF INCINERATION ASH WITH CHELATING AGENTS[3)]

An experiment was carried out by using lysimeter to discover a long-term leaching behavior of each chelating agent (2 types of organic chelating agents, 1 type of inorganic chelating agent). In order to understand the behavior of the chelating agents, the filling rate of the chelating agents in lysimeter is about 15%. The lysimeter is mainly filled up with fly ash. Further, in order to prevent the solidification of fly ash, after adding chelating agent, the fly ash has been made a screening separation with a 2 mm screen and solidified for 24 hours. Then, the bottom ash is mixed and filled with the crushed stone which is nearly 10mm across in a diameter and used as a bulk material for water channel prevention. The lysimeter has an outer diameter of 300 mmφ × height 1,150 mm. The water sprinkling condition are 2,800ml/week referring to the rainfall amount in the city of Kitakyushu over the past 5 years. The leaching condition of COD components from the start of the experiment to the 1126th day is shown in Figure 3.

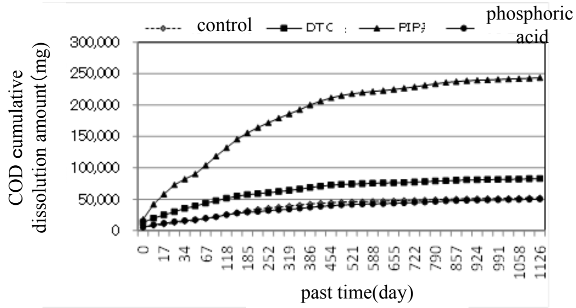

Figure 3 Changes in COD component

The leaching ratio of COD components in control group is 19.4% (52444mg out of 269990 mg). The ratio is 17.8% (113965mg out of 640404 mg) in DTC-based and 54.9% in PIP-based (243204mg out of 443185mg). In phosphorus-based, 19.2% (50078 mg out of 261377mg) have been leached.

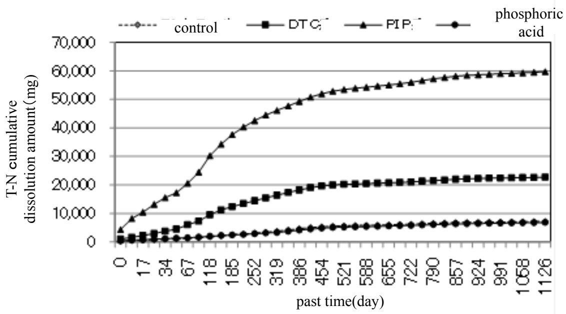

Figure 4 Changes in T-N

As shown in Figure 4, the leaching ratio of T-N in control group is 17.3% (7222mg out of 41846mg). The ratio is 24.7% (22631mg out of 91677mg) in DTC-based, while 58.2% (59681mg out of 101602mg) in PIP-based. In phosphorus-based, 16.3% (6830 mg out of 41899mg) have been leached.

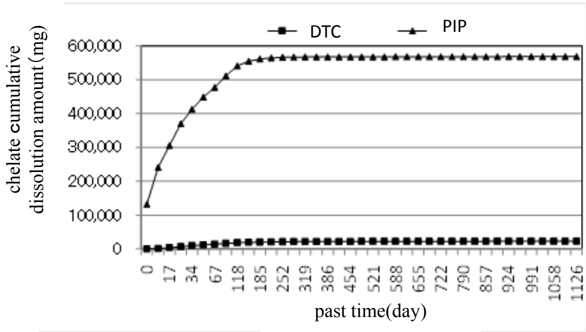

Figure 5 Changes in chelate component

The leaching condition of chelate components is shown in Figure 5. The total amount for each content is 2100000mg. 2300 mg (1.1%) of DTC-based and 567000 mg (27.0%) of PIP-based have been leached. Besides, the leaching ratio of T-N until now is about 0.002% (26mg) in phosphorus-based. It is equivalent to the leach amount in control group and organic chelating agent. To summarize the results of above, comparing with the data in DTC-based and inorganic-based, although the leaching ratio of each component in PIP-based is decreasing gradually, the leaching ratio of both COD_{MN} and T-N is three times more than in either DTC-based or inorganic-based. The condition of chelate components is quite same even in a small lysimeter. The concentration of unreacted chelating agent at the initial stage in PIP-based is a high value. Although it decreased gradually, the concentration is still about 10 times higher than the chelating agent in DTC-based. And it is advanced at a high concentration of 1300mg/L. Through these data, it is suggested that the problem related to COD component and nitrogen content due to a long-term leach in leachate at MSW landfill sites is likely to be caused by chelating agent in PIP-based.

BIOLOGICAL NITRIFICATION EXPERIMENT ON CHELATING AGENTS[4)]

Nitrification experiments were conducted by using 2 types of organic chelating agents (DTC-based and PIP-based). The concentration of each chelating agent is 0～10mg/L. As shown in Table 2, the leachate using in experiments is a simulated leachate. The returned sludge which comes from the leachate treatment plant at MSW landfill sites is used in experiments instead of activated sludge. The MLSS is 3,000mg/L and the total

Table 2 The composition of simulated leachate (mg/L)

Reagent adding component	Dosage	Concentration
Ammonium carbonate($(NH_4)_2CO_3$)	343	N:100
Dipotassium hydrogen phosphate (K_2HPO_4)	50	K:14, P:11
Sodium bicarbonate ($NaHCO_3$)	183	Na:50, HCO_3^-:133
Magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$)	200	Mg:20, SO_4^{2-}:78
Calcium chloride dihydrate($CaCl \cdot 2H_2O$)	279	Ca:100, Cl:89
D(+)-glucose($C_6H_{12}O_6$)	250	C:100

amount of leachate is set to 5L. Based on the following reaction formula, the aeration amount of sample is 800 ml/min.

2NH4+3O2→2NO2+2H2O+4H+

2NO2+2O2→NO3+H2O+2H+

After 6 hours of aeration, the nitrification efficiency of the 2 samples in control group reach about 100%, and the different kinds of chelating agents haven't influenced the results a lot. The different concentration of additives(1,3,5,10mg/L) cause different nitrification efficiency in each chelating agent after 6 hours of aeration. It becomes 100%, 87.4%, 52.1% and 29.2% in DTC-based and 97.8%, 93.7%,83.8% and 54.4% in PIP-based. In the case of 2 types of inorganic chemicals, the inhibitory effects on nitrification are confirmed when the concentration of additive is 10ml/L. As the nitrification efficiency is about 100% for the phosphorus-based and about 97.5% for the iron series, it is suggested that there isn't any inhibitory effect on nitrification of the inorganic chemicals. The concentration decays up to 6 hours for each chelating agent is shown in Figure 6 and Figure 7 by using ammonia nitrogen as an index.

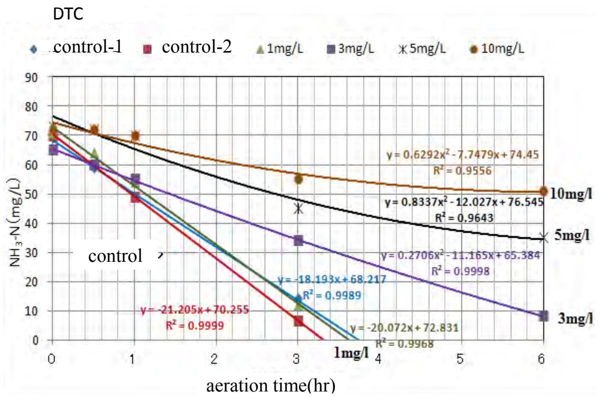

Figure 6 The nitrification condition (DTC-based)

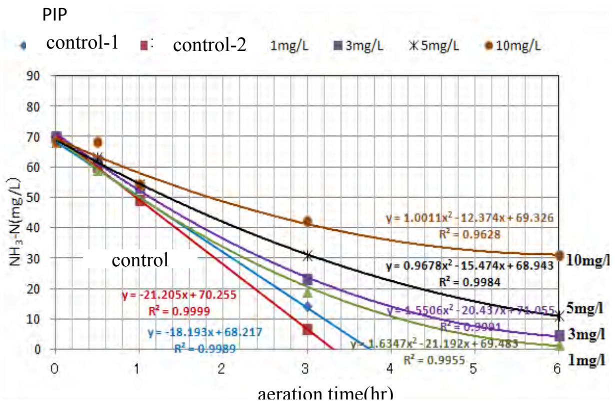

Figure 7 The nitrification condition (PIP-based)

The experiment results reveal that subjects without nitrification inhibition such like the subjects in control group shows almost linearly concentration decay, otherwise, concentration decay is in a quadratic curve. It is also suggested that a remarkably nitrification inhibition can be found when the addition concentration of chelating agent is above 5mg/L in DTC-based or above10mg/L in PIP-based. In addition, the nitrification efficiency becomes 7.75% in DTC-based and 4.63% in PIP-based while adding 1mg/L of each organic chelating agent. It shows a reducing in the nitrification efficiency.

DEVELOPMENT OF SEPARATE DERTERMINATION METHOD OF CHELATING AGENTS[5)]

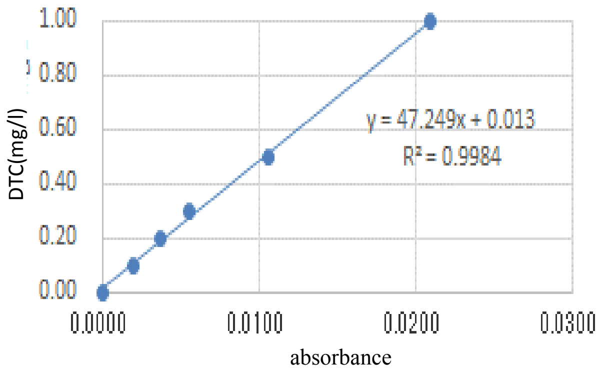

Figure 8 The DTC-based chelating agents

The DTC-based chelating agent can be concentrated by a solvent. Using this property, cooper is added to the sample to which organic chelating agent have already been added. Then, a copper chelate complex is produced and extracted with toluene. After these steps, the extraction solvent is heated to dryness, decomposed with nitric acid or perchloric acid, and then the quantitative determination of copper can be measured by using ICP-AES and AA.

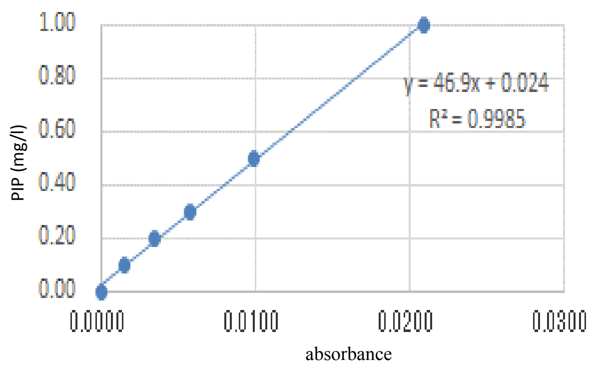

Figure 9 The PIP-based chelating agents

As it is difficult to dissolve in other solvent in the case of PIP-based, in this method, cooper sulfate is added to the chelating agents and a copper chelate complex can be produced. Then, filtered it by a 0.45μm membrane filter and the complex which remained on the filter paper was treated with acid. After these steps, the quantitative determination of copper can be measured by using ICP-AES and AA. The results can be referred to Figure 8 and Figure 9. In addition, the preparation of working curve is made a similar operation of the sample which added a certain amount of chelating agent, the amount of chelate can be calculated from the concentration of copper.

A REMOVAL EXPERIMENT ON CHELATING COMPONENT[5)]

In order to improve the inhibitory effect on nitrification of residual organic chelating agents, a chemical decomposition was carried out by using hydrogen peroxide (including air oxidation) and various types of oxidizing agents of ozone to destroy the chemical bonds of chelating agents (DTC-based and PIP-based). The used oxidizing agents are shown in Table 3.

Table 3 Types of oxidizing agents

Types of oxidizing agents	
1	Air
2	Hydrogen peroxide (H_2O_2)
3	Ozone (O_3)
4	Hydrogen peroxide+Ozone (Promoted oxidation)

After chemical reaction equivalent of each chelate substance and each oxidizing agent had been determined by beaker test, a chemical decomposition treatment was carried out by advanced oxidation process. Additionally, a proper quantity(50~150mg) was added to a certain quantity of chelating agent concentration in the oxidative decomposition of hydrogen peroxide water, and each analysis item was quantitative test after standing for 24 hours. In the oxidative decomposition of air and ozone gas, a continuous test on 10L sample was carried out for 60 minutes, and a quantitative test was made on each sample at each time. In advanced oxidation process, after adding a proper quantity of hydrogen peroxide at the beginning of the experiment, tests were carried out in the same way as air and ozone.

Hydrogen peroxide water

Figure 10 describes the decomposition experiment on chelating agents by hydrogen peroxide water. The average value of the reaction equivalent is about 6.8mg/mg in DTC-based and about 5.9mg/mg in PIP-based. When the dosage of hydrogen peroxide water is 50mg/L, the reaction equivalent becomes 11.6mg/mg and 8.6mg/mg. It is suggested that the reaction equivalent tend to decrease while the dosage is increasing.

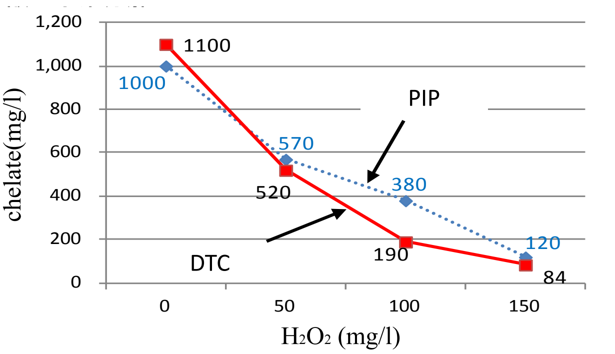

Figure 10 Experient on oxidative decomposition (H_2O_2)

Air oxidation

In the case of oxidative decomposition experiment by air oxidation, there isn't any decomposition efficiency of chelating agents by air oxidation (5L/min), neither DTC-based nor PIP-based.

Ozone oxidation

In the case of oxidative decomposition (14.2g/m3×2L/min) by ozone gas, the reaction equivalent of each chelating agent in oxidative decomposition treatment(60min) is different.

As shown in Figure 11, the reaction equivalent in DTC-based is 0.55mg/mg, and it is 0.56mg/mg in PIP-based. In the initial stage of reaction, it is 1.32mg/mg in DTC-based and 2.57mg/mg in PIP-based. It has a highly reaction efficiency at the beginning as same as hydrogen peroxide water, then the reaction equivalent has decreased while the treatment reaction is proceeding. Generally speaking, the oxidation reduction potential of ozone (2.07V) is higher than that of hydrogen peroxide water (1.77V). Although the superiority was found in hydrogen peroxide water in this time, it was thought to be caused by the lower dissolution efficiency of the ozone dissolving device used in this experiment.

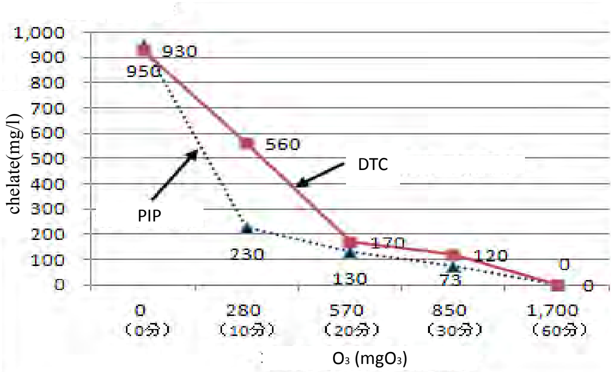

Figure 11 Experient on oxidative decomposition (O3)

Promoted oxidation

As a method for improving the reaction efficiency of each oxidizing agent, a decomposition experiment of chelating agents by promoted oxidation method was carried out.

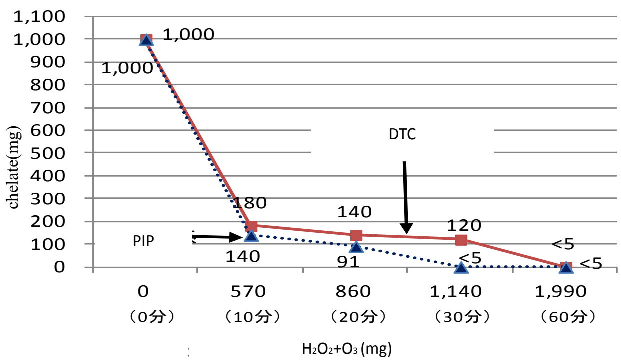

Figure 12 Experient on oxidative decomposition (AOP)

Referring to Figure 12, the results show the reaction equivalent of each chelating agent is about 0.48mg/mg in both DTC-based and PIP-based. In the initial stage of reaction, it is 1.44 mg/mg in DTC-based and 1.51mg/mg in PIP-based. Although it is only inferior to hydrogen peroxide and ozone in terms of the oxidizing dosage, the chelating agent has the fastest decomposition rate among all. In the case of ozone, the decomposition rate of each chelating agent in the treatment for 10 minutes in the initial stage of the reaction is about 40% in DTC-based and about 76% in PIP-based. In the case of promoted oxidation method, the decomposition rate is 82% in DTC-based and 86% in PIP-based. In addition, each chelating agent is decomposed at a speed of about 2 times in the DTC-based and about 1.1 times in the PIP-based. From these results, the promoted oxidation method is considered as the most efficiency method in decomposing chelating agents.

CONCLUSIONS

1) The ratio of chemical treatment approximately 80% among all the intermediate treatments for fly ash. The chelating agents occupy 76%. The most frequently dosage of chelating agents is 2.5-3.0%, 21.3% of the incinerators chose this value. The maximum dosage is 11.5~12.0%, 2.5% of incinerators chose this value. Problems can be found in the processing of nitrogen treatment in leachate at MSW landfill sites, the treatment efficiency is about 38% on average and the possibility of nitrification inhibition in leachate treatment is suggested.
2) Based on the composition analysis of the chelating agents, the result shows the chelating agents are producing thiocyanate ion as same as thiourea. Therefore, it is suspected that the chelating agents also have inhibitory effects on nitrification. It has been suggested that COD and nitrogen content in fly ash will be increased and abolition criteria will be influenced by adding a chelating agent.
3) For the long-term leaching property of lysimeter, the COD is 52.4g in control group;114g in the DTC-based; 243 g in the PIP-based and 50g in phosphorus-based on the 1126th day of experiment. The amount of COD in the PIP-based is about 5 times more than in the control group. In the case of T-N, the amount in control group is 7.2g. It is 22.6g in DTC-based and 6.8g in phosphorus-based. The amount in PIP-based is 59.7g which is 8 times more than control group. Besides, leach amount of DTC-based chelate component is 1.1% and leach amount of PIP-based chelate component is 27.0%. It is suggested that the chelating agents have a great influence on the leach amount of COD and T-N.
4) The nitrification efficiency of the chelating agent has been reduced to 52.1% when the dosage of DTC-based chelating agent is 5mg/L. On the other hand, the nitrification efficiency has been reduced to 54.4% when the dosage of PIP-based chelating agent is 10mg/L. Based on these data, a remarkable nitrification inhibition can be found. Inhibitory effect on nitrification is not observed for inorganic chemicals when the concentration of dosage is 10mg/L. In addition, it is suggested that when the concentration of each chelating agent has been increased by 1mg/L, the nitrification efficiency will reduce by 7.75% in the DTC-based and 4.63% in the PIP-based. The above results revealed that each chelating agent in DTC-based and PIP-based contains nitrification-blocking substance as same as thiourea.
5) When the nitrification inhibition of chelating agent

is about 1 mg/L, its affect can be found. Since it is necessary to establish a quantitative method for chelating agents, quantitative methods for each chelating agent have been developed. As a result, it becomes possible to quantify the concentration below 1mg/L by separation determination method of DTC-based and PIP-based chelating agents. And it also becomes possible to monitor the inhibitory effect on nitrification at the front stage.

6) In order to reduce the inhibitory effect on nitrification of chelating agents, a treatment method has been developed by decomposing the chelating agents with oxidizing agents. Results reveal that the effect of chelating agent can be destroyed by each kind of oxidizing agent and the promoted oxidation method is considered as the most efficient method in decomposing chelating agents.

FURTHER RESEARC

After decomposing chelating agent with oxidizing agent, the existence of the inhibitory effect on nitrification of the sample should be checked and a series of measures against nitrification inhibition should be discussed. Besides, an efficient intermediate treatment method of fly ash with phosphorus chemicals need to be established.

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IMPACT OF NANOMATERIALS ON BIOCHEMICAL METHANE PRODUCTION FROM MUNICIPAL SOLID WASTES

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ABSTRACT

This investigation was conducted to evaluate methane production from municipal solid waste (MSW) containing three commonly used nanomaterials. Biochemical methane potential (BMP) tests were conducted on manufactured MSW exposed to different concentrations of nanomaterials: multi-walled carbon nanotubes (< 8 nm) and nanoparticles of titanium dioxide (anatase, 10-30 nm) and silver (20-30 nm). The waste samples were manufactured using waste fractions consistent with conditions in the USA. Three concentrations of each nanoparticle type were added to the waste samples prior to BMP testing: 0.2, 2.0, and 20 mg of nanoparticle per kg of waste. Midway through testing, the vessels containing low concentrations of nanoparticles were spiked with higher concentrations (100 and 200 mg/kg). The BMP vessels were incubated at 35°C. Gas samples were collected over time to determine gas volume and composition. Transformations of nanomaterials in the test media were characterized using thermogravimetric analyzer (TGA), Fourier transform infrared (FTIR) spectroscopy, and dynamic light scattering (DLS). Negligible difference was observed between methane production of MSW control and the samples containing nanomaterials. This is likely a result of aggregation of nanomaterials as indicated by the DLS results. The FTIR and TGA data suggested the lack of coating on the nanomaterial surfaces, which explains the particles tendency to aggregate in the test media. Aggregation significantly reduces bioavailability and toxicity of nanomaterials.

Keywords: Municipal solid waste, Methane, Nanomaterials, Toxicity, Landfill

INTRODUCTION

Nanotechnology has become widespread and nanomaterials are present in thousands of consumer products such as sunscreen, cosmetics, and paint (Contado, 2015, El Badawy et al., 2010). Among the most utilized nanomaterials in consumer products and industrial applications are silver, titanium dioxide and carbon nanotubes (Contado, 2015, Keller et al., 2013). Previous research reported toxic effects of these nanomaterials on various types of organisms (e.g., Pietroiusti et al., 2018). Therefore, the potential harmful health and environmental effects of nanomaterials are a great concern when considering their end-of-life fate (Brar et al., 2010). A significant amount of nanomaterials is predicted to end up in municipal solid waste (MSW) landfills (Keller et al., 2013, Mueller and Nowack, 2008). In landfills, microbes anaerobically degrade the organic fraction of wastes and produce landfill gas, which is one of the major byproducts of landfilling of MSW, mainly consists of methane and carbon dioxide. Toxic effects of nanoparticles have been previously reported on various microbial species in different environmental media (Kühnel et al., 2018). However, nanomaterials can undergo transformations that lead to significant reduction in their toxic effects (Cheng et al., 2011, Keller et al., 2010). Nanomaterial transformations include physical (e.g., aggregation) and chemical (e.g., sulfidation) transformations that are governed by the chemistry of the surrounding environment (Levard et al., 2012). Aggregation, for example, results in increased particle size and thus, nanoparticles become less bioavailable and consequently, less toxic (Cheng et al., 2011, Keller et al., 2010). The response of landfills to nanomaterials including the effects on microbial populations and landfill gas production has not been well documented.

The specific objectives of this research are to 1) investigate the impact of multi-walled carbon nanotubes (MWCNTs) and nanoparticles of silver (Ag-NPs) and titanium dioxide (TiO_2-NPs) on methane yield from MSW landfill systems and 2) correlate the methane production results with the physicochemical properties of the nanomaterials investigated herein.

MATERIALS AND METHODS

Nanomaterials and MSW

Multi-walled carbon nanotubes (< 8 nm) and nanoparticles of titanium dioxide (anatase, 10-30 nm) were purchased from Nanostructured and Amorphous Materials Inc. (Texas, USA). The silver nanoparticles (20-30 nm) were purchased from SkySpring Nanomaterials Inc. (Texas, USA). All nanomaterials were purchased in powder form and the size listed above is provided by the manufacturer. These specific materials were selected as they represent commonly used nanomaterials in consumer products. Biochemical methane potential (BMP) tests were conducted on MSW samples manufactured based on waste composition data from the USA. (Yesiller et al., 2014). The percentage (wt/wt %) of each waste category used in the study is presented in Figure 1.

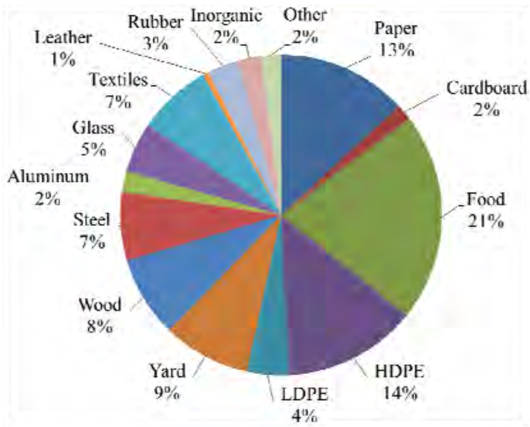

Figure 1 Composition of the manufactured MSW (Food: dog food, Yard: leaves, Other: soil)

Nanomaterial Characterization

Baseline characteristics of the nanomaterials were determined to assist with interpretation of the BMP test results. The hydrodynamic diameter (HDD) of the nanomaterials was measured using a DynaPro NanoStar dynamic light scattering instrument (Wyatt Technology Corporation, USA). Dynamic light scattering (DLS) was used herein to provide information on the aggregation of TiO_2-NP and Ag-NPs nanomaterials. The aggregation of MWCNTs was not tested because DLS measures the diameter of a spherical shape particle that diffuses at the same rate as the particle of interest. Thus, DLS data are not meaningful for tubular shape nanomaterials such as MWCNTs. To conduct the DLS measurements on the titanium and silver nanoparticles, suspensions of TiO_2-NPs and AgNPs were prepared by adding the nanoparticles to deionized water and sonicating the mixture using a probe sonicator to break up the aggregated powder nanomaterials. Unfiltered aliquots of the nanoparticles were then tested for size distribution using DLS. In addition, filtered (using 0.45 µm filter) samples of the sonicated nanomaterial suspensions were tested in order to detect the smaller size particles in the suspension because extremely large aggregates disproportionally scatter more light than small particles.

Surface characterization of the nanomaterials was conducted using Thermal gravimetric analysis (TGA) (TA Instruments Inc., USA) and Fourier Transform Infrared (FTIR) Spectroscopy (Nicolet FTIR spectrometer, Thermo Fischer Scientific, USA). For the TGA, samples of the nanomaterials powder were heated and the weight loss of the sample was recoded as a function of temperature. For the FTIR analysis, samples of nanomaterials (in powder form) were placed flat (< 4 mm thick) on the attenuated total reflectance (ATR) crystal and the FTIR spectra was then acquired. The purpose of the surface characterization of the nanomaterials was to evaluate the presence of an organic coating on the surface of the nanomaterials. Surface coatings on nanomaterials improve their stability (resistance to aggregation) and consequently the toxicological impacts of the nanomaterials are expected to increase as the particles maintain their small nanoscale size (El Badawy et al., 2010).

Biochemical Methane Potential Test

The BMP assay was used to examine the effects of nanomaterials on methane production from MSW landfills. The test was conducted according to the procedure described by Wang et al. (1994) with modifications in waste sample mass, volume of serum bottles used, microbial seed source, and the purging gas used for initiating anaerobic conditions in the test bottles for establishing representative conditions for the intended use of the test method.

In the experimental program, 2 g of manufactured waste was placed in 250 mL serum bottles. The following media were added to each of the waste specimens: 1) 120 mL of liquid containing nutrients and trace minerals and 2) 30 ml of anaerobically digested sludge obtained from the Water Resource Recovery Facility in San Luis Obispo, California. The nutrients and trace minerals solution was prepared following the composition reported in Wang et al. (1994). Three concentrations (0.2, 2, and 20 mg of nanomaterials per kg of MSW) of the three types of nanomaterials (MWCNTs, TiO_2-NPs, and Ag-NPs) were added to the BMP serum bottles that contain the MSW specimens, the nutrients and trace minerals solution, and the anaerobically digested sludge. Afterwards, the bottles were purged with nitrogen gas to initiate anaerobic conditions, sealed, and incubated at 35°C. The tests were conducted in triplicates. Cellulose controls and blank controls composed of only inoculated medium were also tested.

Gas samples from the BMP serum bottles were initially collected after four days and every 7 days afterwards to measure the volume of gas produced and percentage of methane in the gas. The gas volume was measured using a water displacement setup composed of an inverted 250 mL graduated cylinder immersed in a 1000 mL glass column filled with water. The inverted graduated cylinder was connected to a plastic tube fitted with a 22-gauge needle. At the time of measurement, the needle was inserted through the rubber stopper of the serum bottle. The gas in the headspace of the bottle was allowed to equilibrate to atmospheric pressure and the volume of gas was recorded. The percentage of methane in the gas was determined by injecting 1 mL of headspace gas collected from the bottles into a gas chromatograph (GC) (SRI Instruments, CA, USA). The GC was equipped with a packed column and a thermal conductivity detector (TCD). Argon was used as the carrier gas.

Midway through the active phase of methane production (on Day 18), the BMP serum bottles containing low concentrations of nanomaterials were spiked with higher concentrations (100 and 200 mg/kg) to evaluate the impacts of nanomaterials concentrations above 20 mg/kg on biodegradability of the MSW in landfill systems. After 46 days of incubation, gas production became negligible and the BMP testing was concluded.

RESULTS AND DISCUSSION

The volumes of methane produced from the anaerobic biodegradation of waste exposed to MWCNTs, TiO_2-NPs, and Ag-NPs at concentrations ranging from 0.2 to 20 mg nanoparticles/kg waste for 18 days after incubation are presented in Figure 2.

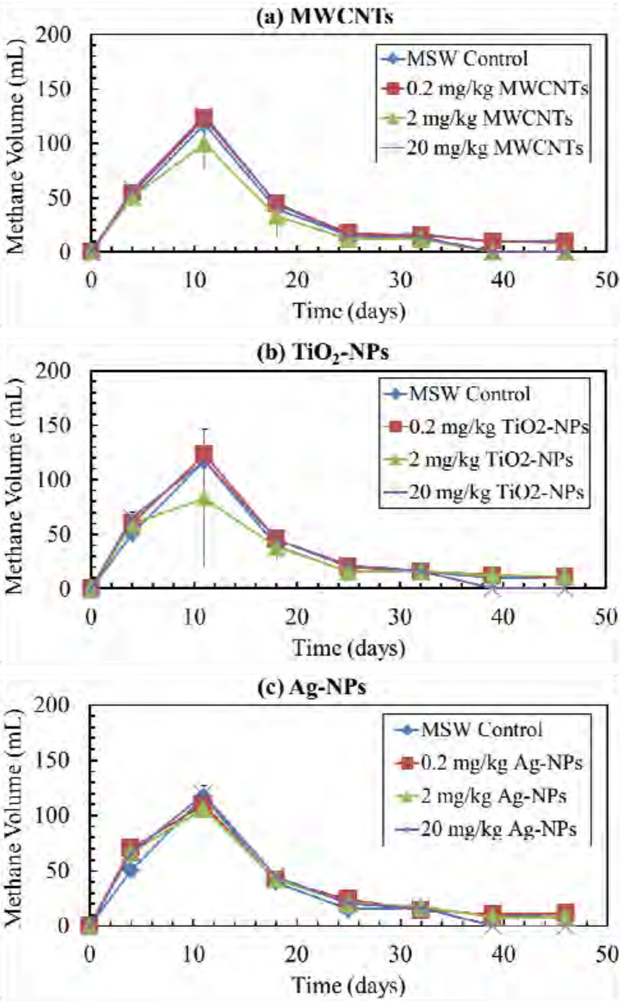

Figure 2 Effect of nanomaterials on methane production a) MWCNTs, b) TiO_2-NPs, and c) Ag-NPs

Through day 18 of the tests, no impacts on methane gas production due to presence of nanomaterials were observed. The BMP serum bottles exposed to 0.2 and 2 mg nanoparticles/kg waste were spiked with the respective nanomaterials to raise their concentrations to 100 and 200 mg nanoparticles/kg MSW, respectively to investigate whether elevated concentrations of nanomaterials in MSW would have impacts on gas production. It was observed that elevated nanomaterial loadings did not have significant impacts on methane gas production as presented in Figure 2.

In summary, the BMP test results indicate negligible difference between methane production of baseline MSW (i.e., control condition) and methane production of MSW exposed to nanomaterial concentrations ranging from 0.2 - 200 mg nanoparticles per kg of waste. However, a noticeable difference was observed at day 11 between the methane produced from the MSW control and the MSW exposed to 2 mg TiO_2-NPs/kg MSW (Figure 2b). This difference was caused by a significantly lower gas production from one of the replicate samples exposed to 2 mg/kg TiO_2-NPs compared to the other two samples. The reduction in methane yield from this sample could be a result of toxic effects of the nanoparticles or from random variation between the samples. Additional testing is warranted to verify the cause of this difference in behavior between the replicates at this concentration.

The DLS results are presented in Table 1. The unfiltered nanomaterial suspensions, which simulate the manner the nanomaterials were added to the BMP test reactors, had a large size distribution. Also, the dominant size of TiO_2-NPs and Ag-NPs suspensions was significantly larger than 100 nm, the traditionally used threshold for the nanoscale effects to take place. For example, the HDD of the majority of both TiO_2-NP and Ag-NPs exceeded 250 nm, which is considerably larger than the primary size (20-30 nm) reported by the nanoparticle manufacturers. On the other hand, the HDD of the nanoparticles in the filtered suspensions was smaller compared to the unfiltered suspensions and a significant fraction of the nanomaterials was in the nanoscale. The filtered suspensions contained approximately 30 nm Ag-NPs, which is within the primary size range reported by the manufacturer. All of the DLS measurements were conducted instantaneously after sonication of the nanomaterials suspensions. It is expected that the nanomaterials will keep increasing in size in the suspension over time. This suggests that the size of the nanomaterials in the BMP test media may have been even larger than the sizes reported in Table 1.

Table 1 Particle size distribution of nanomaterials

Nanomaterial Suspension		HDD (nm)	% Intensity
TiO_2-NPs	Unfiltered	24.4	0.8
		265.4	49.6
		459.2	27.9
		863.1	14.5
		> 6 μm	7.2
	Filtered	5.9	7.5
		73.2	86.7
		219	5.8
Ag-NPs	Unfiltered	10	4.9
		251.2	92.1
		> 2 μm	3.1
	Filtered	3.8	0.9
		29.4	52.8
		118.4	46.4

The aggregation behavior observed in the DLS analysis indicates that the nanomaterials tested lack a sufficient stabilization mechanism to prevent their aggregation. This is likely an indication of the absence of an organic surface coating that can provide a strong stabilization mechanism for the nanomaterials.

To verify the assumption that the nanomaterials used in the study were uncoated, as reported by the manufacturer, the results of the TGA and FTIR analyses were used. The TGA results for the three nanomaterials under investigation are presented in Figure 3. The MWCNTs started to decompose at 400°C and the oxidation temperature was 470°C (Figure 3a). This oxidation temperature is within the range of 400-650°C reported in the literature for multiwalled carbon nanotubes (Lehman et al., 2011). The slight weight loss observed below 400°C for MWCNTs could be attributed to loss of water and/or some hydrocarbons adsorbed on the surface of the nanotubes (Figure 3a).

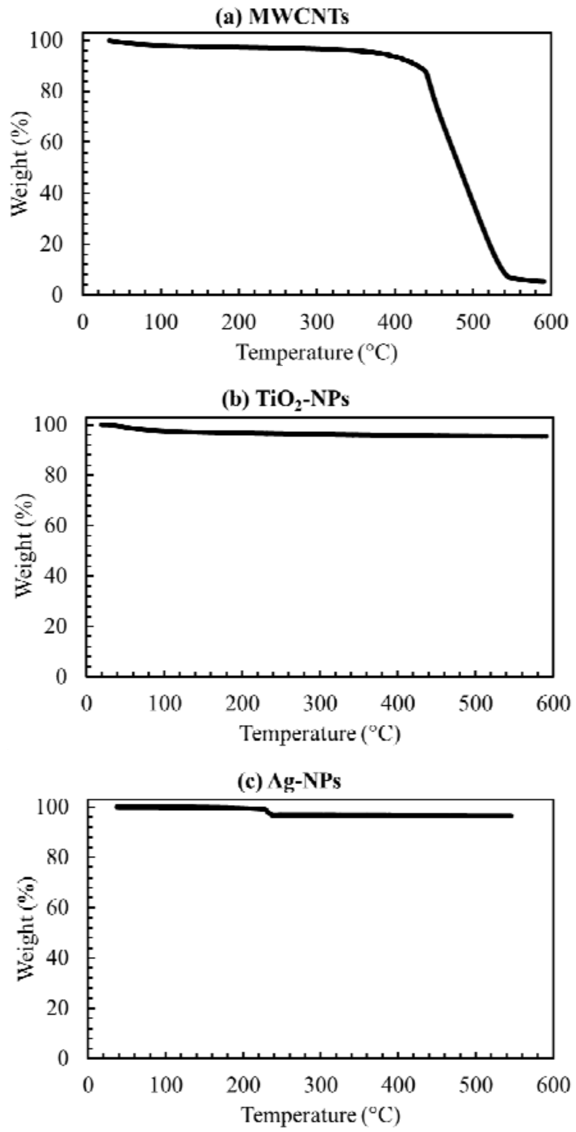

Figure 3 TGA thermograms for the nanomaterials investigated in the study a) MWCNTs, b) TiO_2-NPs, and c) Ag-NPs

For TiO_2-NPs, a slight weight loss was observed as a function of temperature in the range of 50 to 300°C (Figure 3b). This small reduction in weight is likely a result of loss of physically and chemically bound water molecules (Siwinska-Stefanska et al., 2014). The TGA thermogram for Ag-NPs shows a relatively small weight loss at 230°C (Figure 3c). This data is not conclusive with regards to the availability of an organic surface coating on the surface of Ag-NPs. However, if this weight loss is a result of decomposition of an organic coating, it is only an approximately 3% loss, which may indicate that the amount of coating is not sufficient to provide stability to the nanoparticles. Research conducted on stable silver nanoparticles coated with different organic chemicals showed more significant weight loss in TGA theromgrams than the amounts observed in the current study (Nymark et al., 2013, Wu et al., 2011, Habeish et al., 2013).

The FTIR spectrum of TiO_2-NPs is presented in Figure 4. The spectrum demonstrated two distinct bands. The band centered at 3318 cm^{-1} corresponds to O-H stretching vibrations and the other band centered at 1634 cm^{-1} corresponds to bending modes of water (León et al., 2017). More importantly, no peaks were observed in the FTIR spectrum at 2900 cm^{-1}, which correspond to the C-H groups (Bagheri et al., 2013, León et al., 2017).

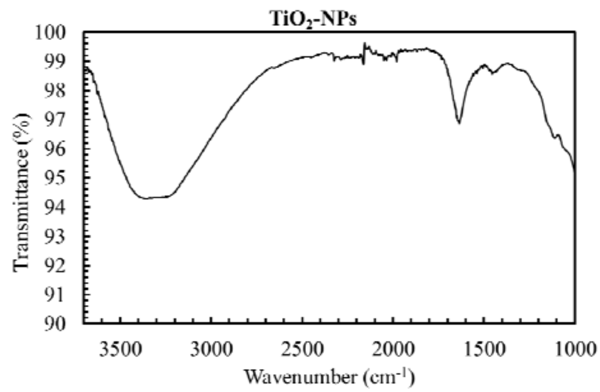

Figure 4 FTIR spectrum for TiO_2-NPs

The FTIR data suggest the lack of organic coating on the surface of TiO_2-NPs. Furthermore, the FTIR spectrum presented in Figure 4 is similar to previously published FTIR data on pristine TiO_2-NPs (León et al., 2017). Overall, the surface characterization data (TGA and FTIR) combined with the DLS aggregation data presented in this study suggest that the nanomaterials lacked sufficient stabilization mechanisms to prevent their aggregation in the test media. Thus, the nanomaterials were likely less bioavailable and their toxic effects to the BMP assay, which simulates anaerobic landfill systems, were suppressed.

CONCLUSIONS

The effects of three types of nanomaterials on gas generation from microbial decomposition of municipal solid waste were investigated using biochemical methane potential tests. The nanomaterials did not have significant impacts on the anaerobic biodegradation of MSW. The observed behavior likely resulted from nanomaterial transformations, mainly aggregation, which minimizes the toxic effects of nanomaterials. The data suggest that uncoated- or weakly stabilized-nanomaterials do not pose risk to the landfill systems with regards to methane production. Further research is needed to evaluate whether or not similar conclusions can be reached for the effects of stable nanomaterials that maintain their nanoscale size on landfill systems.

ACKNOWLEDGMENTS

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MODELING FOR WATERING CONTROL IN CLOSED SYSTEM DISPOSAL FACILITIES

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ABSTRACT

It has been 20 years since a closed system disposal facility (CSDF), which means a landfill site with a roof, was constructed, in 1998. In 2010, the guidelines for the planning, design and management of landfill sites were revised, showing the design concept of watering and a leachate treatment facility based on the liquid-solid ratio in the CSDF. However, a report based on a field investigation of real CSDFs indicates that the relationships between leachate quality and the liquid-solid ratio are different from what is specified in the guidelines. So, a method of watering should be developed based on observation data of real CSDFs. This study investigated two existing models for watering control in CSDFs, namely, a washout model based on Richard's equation and the convective-dispersion equation for the fate and transportation of pollutants in an unsaturated zone, and a simple box model based on the mass balance of pollutants. These models were compared in terms of advantages and disadvantages for their application in the actual management of real CSDFs. As a result, the simple box model was found to be appropriate for watering control in the management of CSDFs. An example analysis for applying the simple box model to real CSDFs to predict future leachate quality is shown.

Keywords: Closed system disposal facilities, Watering, Modeling, Simple box model

INTRODUCTION

The prediction of waste stabilization in a landfill site is important in the estimation of landfill gas emissions, as well as the quantity and quality of the leachate and settlement of the ground surface, all of which can contribute to a cost-effective design, operation and maintenance.

Most landfill sites in Japan receive mainly incineration residue and incombustible residue because combustible waste is burned at incineration facilities. In addition, Japan has much rain, which generates a large amount of leachate. Heavy rain in particular, such as a typhoon, generates a higher amount of leachate than expected. In this case, leachate that cannot be treated should be stored within waste layers, which cause a high probability of leachate leakage.

In 1990, Hanashima proposed a new type of landfill site, i.e., closed system disposal facility (CSDF), which has a barrier, such as a roof, to prevent rainfall from infiltrating the waste layers (Figure 1).

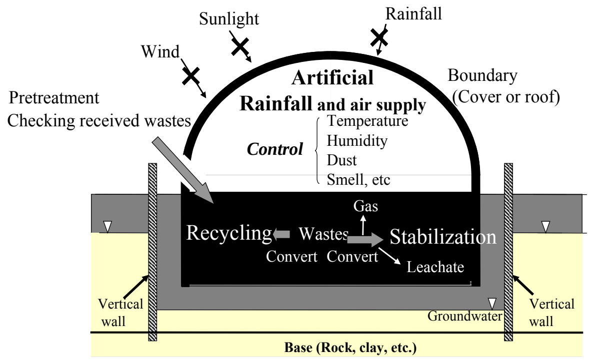

Figure 1 Schematic diagrams of CSDFs

The first CSDF was constructed and started to operate in 1998. At present, the total number of CSDFs in Japan is more than 60. In 2010, the guidelines for the planning, design and management of landfill sites was revised, showing the design concept of watering and leachate treatment facilities based on the liquid-solid ratio in the CSDF. However, a report based on a field investigation of real CSDFs showed that the relationships between leachate quality and the liquid-solid ratio are different from that in the guideline (Ishii et al., 2017). Thus, a method of watering should be developed based on data observed in real CSDFs.

This study investigated the two existing models for watering control in CSDFs, namely a washout model based on Richard's equation and the convective-dispersion equation for the fate and transportation of pollutants in an unsaturated zone (Ishii et al., 2009), and, a simple box model based on the mass balance of pollutants (Ikeda et al., 2015; Takahashi et al., 2016).

NECESSITY OF WATERING IN CSDFs

Incinerated residue in Japan accounts for about 50% of the total amount of landfill waste. The incinerated residue has a low concentration of organic matter that can be degraded by microorganisms, but the chemical oxygen demand (COD) level in its leachate is significant and has to be treated. A long-term leaching of COD causes a long period of operation of leachate treatment facilities, even in post-closure care (PCC).

Therefore, watering needs to be conducted artificially to reduce the risk of leachate leakage, reduce the length and cost of PCC and control dust and temperature for the safety of workers.

EXISTING MODELS FOR PREDICTING QUANTITY AND QUALITY OF LEACHATE

Category of modeling

Modeling approaches are divided into three types; 1) models based on unsaturated water flow and convective-dispersion of pollutants, 2) box models and 3) neural network models, a kind of artificial intelligence. This study investigated a washout model (Ishii et al., 2009) as one of the models based on unsaturated water flow and convective-dispersion of pollutants, and a simple box model based on the mass balance (Ikeda et al., 2015; Takahashi et al., 2016) as a box model.

Washout model

The washout model is schematically illustrated in Figure 2. The solid phase (S-phase) is covered with a water film (called the immobile water phase or

L1-phase). Total organic carbon (TOC) constituents in the S-phase transfer to the L1-phase, from which they transfer to the mobile water phase (L2-phase) during watering. The Washout model assumes that the mass transfer rate from the S- to the L1-phases is much slower than that from the L1- to the L2-phase. This idea was similar to that in the convective-dispersion model with internal diffusion that presents fluid-solid mass transfer in packed beds (e.g., Peev and Tzibranska, 1997).

Parameters should be determined by experiments, such as a one-dimensional column experiment (Ishii et al., 2009).

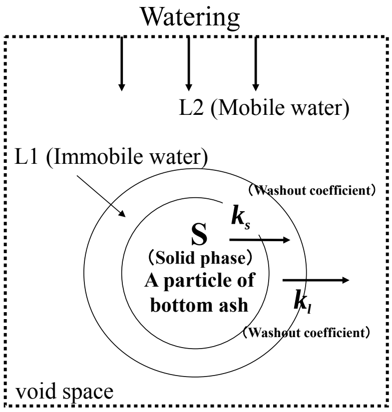

Figure 2 Concept of the washout model (Ishii et al., 2009)

Simple box model

A concept of the simple box model is shown in Figure 3. The total amount of water-elutable COD disposed of at a landfill site in the first year was assumed to be COD_{in}^{1}, a part of which is eluted to leachate and is washed out of the landfill site with the elution rate of *R*, as noted as COD_{out}^{1}. Some part of COD can be degraded by microorganisms and/or chemical reaction, and can be increased because of low-molecularizing of the solid phase. This study dealt with the amount of COD increase and decrease by using a correction term as COD_{co}^{1}, using k as the correction factor. After subtraction of COD_{out}^{1} and COD_{co}^{1} from COD_{in}^{1}, the rest is remaining COD, which can be eluted from the second year onward, noted as COD_{res}^{1}. In the second year, the remaining COD (COD_{res}^{1}) is reduced by washing out ($COD_{out}^{1,2}$) and by correction ($COD_{\mathrm{co}}^{1,2}$) and the total amount of COD disposed of at the landfill site is also decreased by washout ($COD_{out}^{2,1}$) and correction ($COD_{\mathrm{co}}^{2,1}$). Therefore, the total amount of COD washed out of the landfill site through leachate (COD_{out}^{2}) is presented as the sum of $COD_{out}^{1,2}$ and $COD_{out}^{2,1}$. In a similar way, the total corrected amount of COD (COD_{co}^{2}) is the sum of $COD_{\mathrm{co}}^{1,2}$ and $COD_{\mathrm{co}}^{2,1}$. Then, the remaining COD at the end of the second year (COD_{res}^{2}) is calculated.

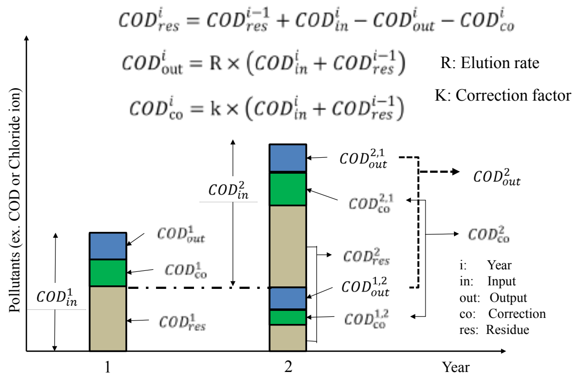

Figure 3 Concept of the simple box model (Ikeda et al., 2015; Takahashi et al. 2016)

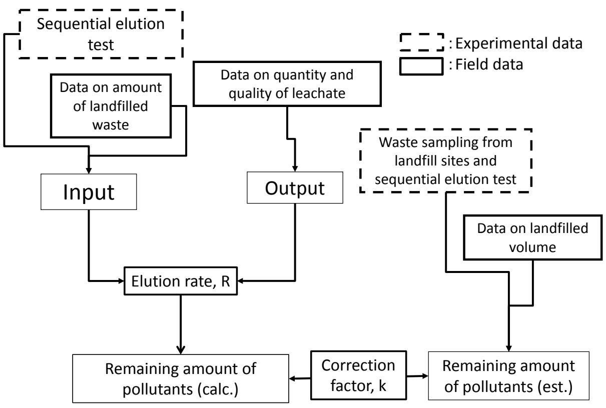

Figure 4 Procedure of parameter determination

In the simple box model, two parameters, namely the elution rate, R, and the correction factor, k, should be determined through field investigation. The elution rate can be determined by using the data on the amount of landfilled waste, the sequential elution test for landfilled waste and the data on the quantity and quality of the leachate. Next, the remaining amount of pollutants is calculated. In a different manner, the remaining amount of pollutants can be estimated by waste sampling from the landfilled waste, sequential elution test and the data on the landfilled volume. The correction factor is determined by comparing the calculated and estimated remaining amount of pollutants.

COMPARISON OF THE TWO MODELS

A comparison between the washout and simple box models is shown in Table 1. The washout model is suitable for clarifying the mechanisms related to the transport and fate of the pollutants within the waste layer, such as elution, movement, biodegradation, sorption and desorption, chemical reaction, etc. In addition, according to the analysis objectives, a detailed calculation can be conducted considering the daily operation and daily climate conditions. The washout model can be used for the development of an ideal design method for watering in CSDFs.

In contrast, the simple box model is less accurate than the washout model because it represents a whole landfill site as a homogeneous box. However, a smaller

Table 1 Comparison between Washout model and Simple box model

	Washout model	Simple box model
Appropriateness regarding phenomena	If parameters related to elution, movement of pollutants within waste layers are determined, this model represents them with high accuracy.	This model is less accurate than the washout model because phenomena that occurred in landfill sites, such as elution, movement, degradation of pollutants, are simplified into two parameters.
Parameter determination and heterogeneity	Numerous parameters related to unsaturated flow, mass transfer coefficient, should be determined. If heterogeneity is considered, the number of parameters increases significantly.	Only two parameters, i.e., the elution rate and correction factor, are needed. They can be determined by simple laboratory experiments and field investigation. Heterogeneity is not considered.
Verification by observation data	This model can be verified by field data on the quantity and quality of leachate.	This model can be verified by field data on the quantity and quality of leachate.
Time scale	Any time-scale can be applicable, according to the analysis objective (day, week, month, year).	As the landfill site is regarded as a box, a monthly or yearly scale can be applicable.
Consideration of landfilling operation	Landfilling operation is considered according to the time scale and reflected in the modeling.	Monthly or yearly landfilling operation is considered, but spatial landfilling operation order is not considered.
Effort for modeling	Much effort is needed by specialists, such as researchers.	Less effort is needed than for the Washout model. Specialists with some degree of knowledge are needed.

number of parameters and less modeling effort are needed for the simple box model. These are significant advantages for the practical design and operation in CSDFs.

From the above comparison, this study introduces the simple box model for watering control in CSDFs and shows an example of the application of the simple box model to landfill sites.

APPLICATION EXAMPLE OF SIMPLE BOX MODEL TO LANDFILL SITES

Objective landfill sites

The description of landfill sites in this study is presented in Table 2. The landfill site E is only a conventional landfill site without a roof. We call it an "open system landfill site". The three studied town and villages use the same incineration and shredding facilities. Thus, the quality of the incineration residues and shredded incombustibles is the same.

Table 2 Description of objective landfill sites

Site	C	D	E
Type	CSDF	CSDF	OSLS
Operation start	2002 Dec.	2002 Dec.	2002 Dec.
Area [m^2]	1000	900	2,800
Volume [m^3]	4,500	3,825	7,100
Depth [m]	5.8	5.4	3.6
Leachate treatment [m^3/day]	5	4	15
Landfilled waste	MSW incineration residue and shredded incombustible		
Watering conditions	1 -3 m^3/day (Rainfall 1 -3 mm/day)	1.5-4 m^3/day (Rainfall 1.7-4.4 mm/day)	11 m^3/day (Rainfall 4.9 mm/day)

Municipal solid waste (MSW)

Determination of the elution rate

According to the procedure of parameter determination in the simple box model (Figure 4), samples of fresh incineration residues and shredded incombustibles before landfilling were used for the sequential elution test to estimate the potential amount of COD and chloride ion elutable to leachate. The annual potential amounts of COD and chloride ion elutable to leachate were estimated from 2002 to 2013 by using data on the amount of incineration residues and shredded

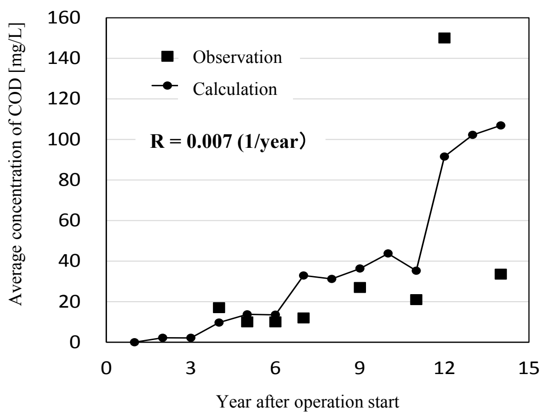

Figure 5(a) Comparison between observed and calculated value in the average concentration of COD in landfill site C

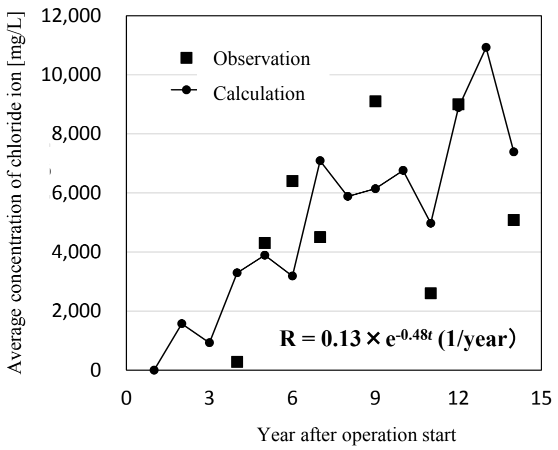

Figure 5(b) Comparison between observed and calculated value in the average concentration of chloride ion in landfill site C incombustibles landfilled to each landfill site, whereas the annual amount of COD and chloride ion eluted to leachate was calculated by data on the quantity and quality of leachate. The elution rate was determined so that the difference between the calculated and observed values in the annual amount of COD and chloride ion eluted to leachate was minimized. The comparison between the observed and calculated values of the average COD and chloride (Cl) ion concentrations in landfill sites C, D and E, respectively, are shown in Figures 5, 6, and 7.

It is noted that three functions of the elution rate were considered; a constant, a power function of time, t and an exponential function of t.

Determination of the correction factor

According to the procedure in Figure 4, the remaining amounts of COD and Cl ion (Est.) were estimated by waste sampling from the objective landfill sites, the sequence elution tests, and data on the landfilled volume, which was compared with the remaining amount of COD and Cl ion (Calc.) calculated by the

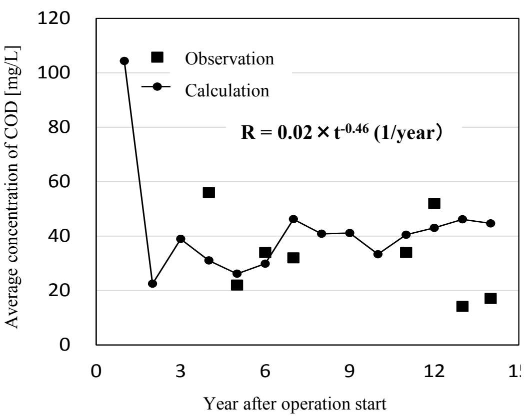

Figure 6(a) Comparison between observed and calculated value in the average concentration of COD in landfill site D

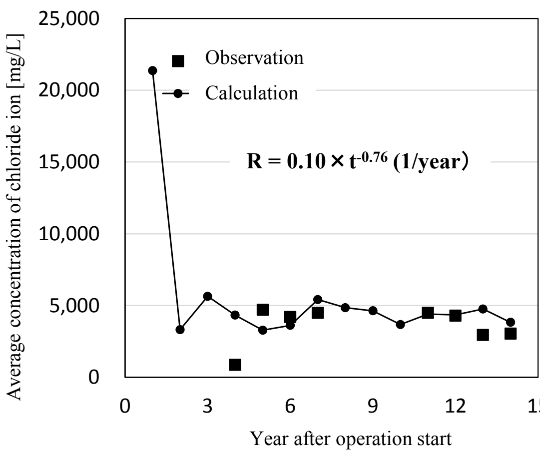

Figure 6(b) Comparison between observed and calculated value in the average concentration of chloride ion in landfill site D

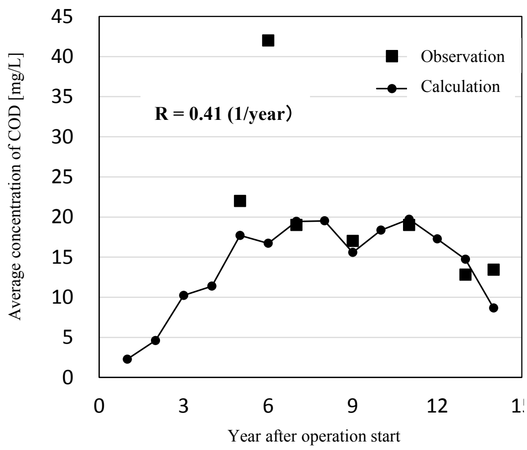

Figure 7(a) Comparison between observed and calculated value in the average concentration of COD in landfill site E

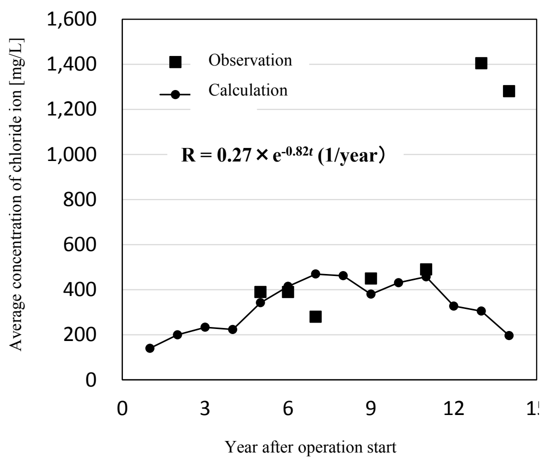

Figure 7(b) Comparison between observed and calculated value in the average concentration of chloride ion in landfill site E elution rate (Figure 8).

The comparison in Cl ion (Figure 8(b)) can be used for discussion on the mass balance in each landfill site. Landfill sites D and E showed a good mass balance of the Cl ion since the ratios of Cal./Est. were 1.36 and 0.90, respectively. The Landfill site C did not show a good mass balance of the Cl ion. The reason for this might be the heterogeneity of the waste layers.

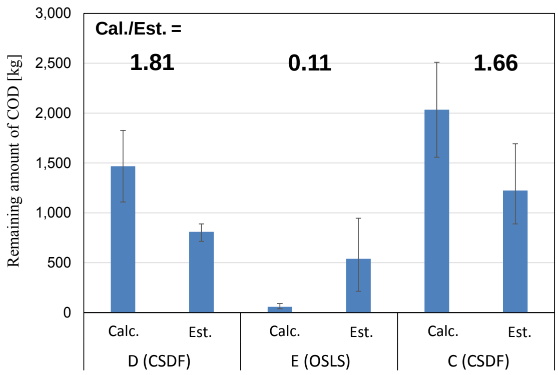

Figure 8(a) Comparison the calculated and estimated remaining amount of COD

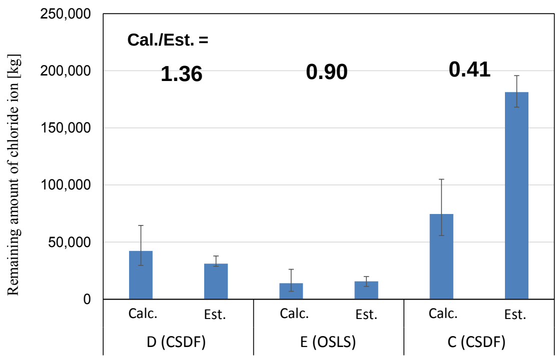

Figure 8(b) Comparison the calculated and estimated remaining amount of chloride ion

Table 3 Correction factors in each landfill site

Landfill site	Correction factor
C (CSDF)	0.083
D (CSDF)	0.074
E (OSLS)	-0.29

As described before, COD can be decreased by biodegradation and/or chemical degradation and can be increased by low molecularization of the solid phase. As shown in Figure 8(a), the ratios of the Cal./Est. were 1.66, 1.81 and 0.11 in landfill sites C, D and E, respectively. The correction factor for each landfill site is shown in Table 3. The positive value in a correction factor means that COD decreasing is stronger than its increasing, suggesting that aerobic conditions promoted COD decomposition. In contrast, a negative value in the correction factor means that anaerobic conditions worsen the quality of leachate.

<u>Prediction of COD and chloride ion concentration</u>

Figure 9 shows the prediction of Cl ion concentration in leachate at landfill site C, which had a good mass balance. Assuming that landfilling is stopped at the year of 14th years, only watering will continue. The difference between the observed concentration (red circle) and the calculated concentration (blue circle) during landfilling was relatively small, suggesting that the simple box model presented the Cl ion concentration with the time scale of one year. During the post-closure period, the Cl ion concentration would decrease because no waste is landfilled. A large amount of water reduces the Cl ion concentration faster. If a target value is set at 500 mg/L, it will take about 6 years after landfilling is stopped for the concentration to reduce to the target.

The prediction of COD concentration in the leachate at landfill C is shown in Figure 10; the difference between the observed and calculated values was not that small. If a target value is set to 20 mg/L in COD

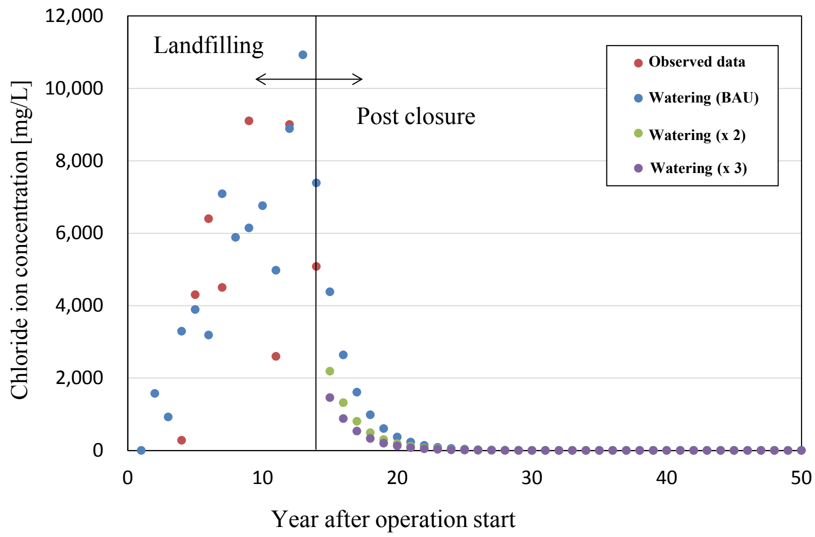

Figure 9 Prediction of Cl ion concentration in leachate at landfill site C

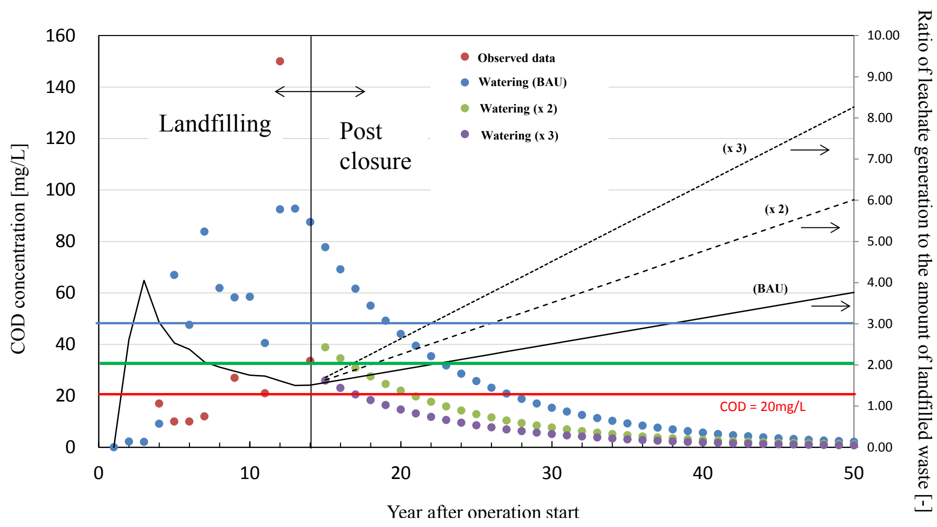

Figure 10 Prediction of COD ion concentration in leachate at landfill site C

concentration, it would take about 14 years after landfilling was stopped for the COD concentration to decrease to the target, the ratio of leachate generation to the amount of landfilled waste was about 2.4, suggesting that the amount of water needed for waste stabilization was 2.4 times the amount of landfilled waste. If the watering was doubled, the required time would be shortened to 7 years after landfilling is stopped.

CONCLUSION

To develop a model for predicting the concentration of pollutants in CSDFs, this study investigated the existing two models; washout model and simple box model. Based on a comparison of the advantages and disadvantages between the two models, the simple box model is preferred for application to practical design and operation in CSDFs.

This study showed an example of the application of the simple box model to real CSDFs and to a conventional landfill site without a roof. Further study is needed to increase the application cases of the simple box model to actual observation data in CSDFs.

ACKNOWLEDGMENT

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CURRENT SITUATION ON INTRODUCTION AND OPERATION RESULTS OF LEACHATE LEAKAGE DETECTION SYSTEMS FOR LANDFILL SITES

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ABSTRACT

Most landfill sites in Japan have a liner on the bottom and the slopes in order to prevent groundwater contamination by leachate, which is generated by infiltration of rainfall into the waste layers. Since damage to the liner may cause groundwater contamination, leachate leakage detection systems (LLDS) are widely used to detect liner damage as quickly as possible. In Japan, LLDS were introduced over 20 years ago. However, the actual operation benefits of LLDS have not been clearly identified. This study conducted a questionnaire survey for managers of landfill sites in Japan to clarify the results of the introduction and operation of LLDS. The type of LLDS introduced and the ways in which LLDS has been managed were clarified for each landfill site. In addition, the frequency with which LLDS actually detected leachate leakage, and the occurrence of erroneous detection as a result of system error, are tabulated. The implications of the findings for on-going LLDS management are discussed

Keywords: Landfill sites, Leakage detection system, Installation result, Operating status

INTRODUCTION

Landfill sites in Japan are categorized into four types depending on the characteristics of the landfilled waste. The two main types, which account for 70% of landfill sites, employ liner sheets (geomembrane sheets) to retard leakage of leachate. However, leachate leakage through damage to liner systems became a evident 25 years ago, and it is an on-going social problem. Since then, leachate leakage detection systems (LLDS) have been installed at landfill sites that use geomembrane sheets as a liner system.

There are several kinds of LLDS and some have been in use for over 23 years. Currently, there are over 200 landfills using LLDS in Japan. The manufacturers of LLDS only have information on the installation and operation of LLDS, but the extent and status, for the whole of Japan, of the installation, operation and maintenance of LLDS remains unclear. Therefore, our research group in The Landfill System & Technologies Research Association of Japan, NPO (NPO, LSA), sought understanding of the actual situation of operational LLDS by investigating past installation records of LLDS. Our research group then conducted a questionnaire survey to determine the current operation and maintenance of LLDS in landfill sites equipped with LLDS and to identify the reasons why LLDS was not installed in some landfill sites (Ebihara, 2017.1; Ebihara, 2017.9). This paper clarifies the extent of installation of LLDS and actual situation of operation and maintenance of LLDS.

WASTE MANAGEMENT FLOW IN JAPAN

Figure 1 shows waste management flow in Japan. Wastes are categorized into two types: municipal solid waste (MSW), which is mainly from households and is managed by municipalities from collection to landfill disposal; and industrial waste, which is from business activity and managed by the waste generators. These wastes are collected, intermediately treated (incineration, shredding, etc.), recycled by the municipalities or by business entities, and any remaining material taken to landfill.

Landfill sites are categorized into four types: 1) sites for MSW, 2) least-controlled sites, 3) controlled sites, and 4) isolated sites. The least-controlled landfill sites receive inert industrial waste, such as concrete and metals, without any potential leachate pollution. The controlled landfill sites receive industrial waste that could generate polluted, but treatable, leachate, such as papers, woods, sludge, and ash. The isolated landfill sites permanently store hazardous waste.

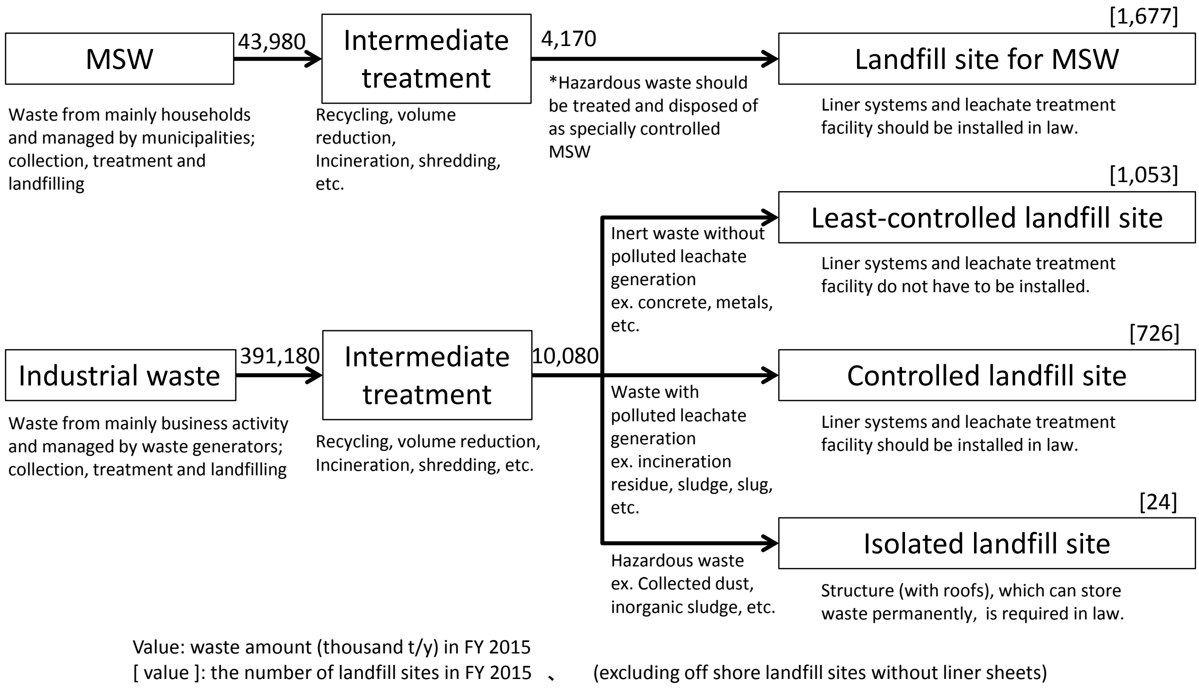


Figure 1 Waste management flow in Japan

(Ministry of Environment in Japan, 2017.3, 2018.1, 2018.3)

In the inert, least-controlled, landfill sites, as shown in Figure 2, liner systems and leachate treatment facilities are not required by law because no generation of polluted leachate is anticipated. Thorough checking occurs at reception so that wastes that could potentially generate polluted leachate are not accepted. The isolated landfill sites, as shown in Figure 3, are required to be double concrete pits that can be monitored on six surfaces, and roofed, so that waste is stored permanently. Since controlled landfill sites receive degradable waste, as shown in Figure 4, they are legally required to install liner systems and leachate treatment facilities to manage polluted leachate and to protect neighboring environments.

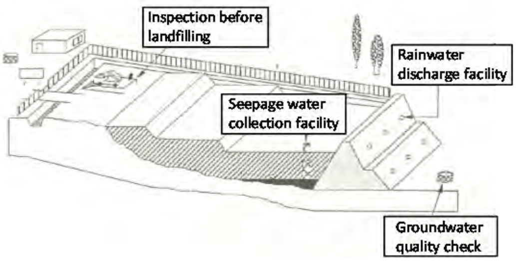


Figure 2 Least-controlled landfill site

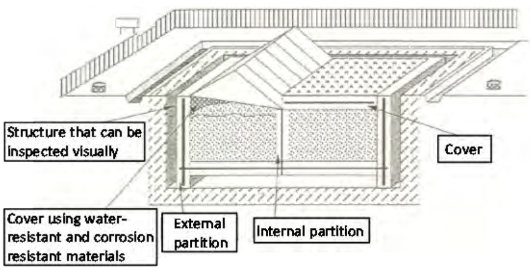


Figure 3 Isolated landfill site

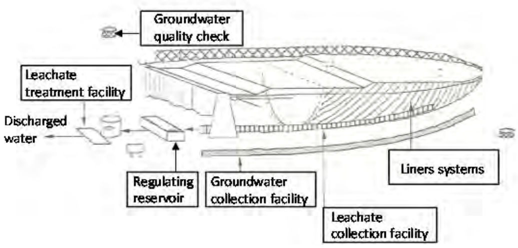
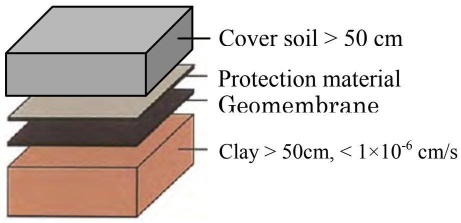


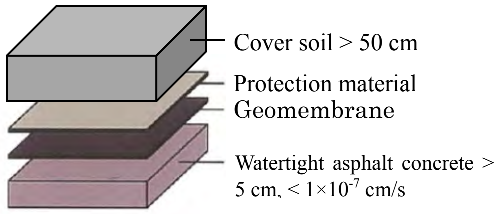
Figure 4 Landfill site for MSW and Controlled landfill site

CONCEPT OF LINER SYSTEMS IN JAPAN

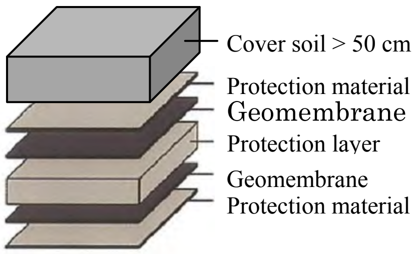
The concept of liner systems supposes that geological features have continuous and constant impermeable layers, such that vertical barriers reaching the impermeable layers are sufficient and liner systems are not needed at the base of the fill. Japan, however, has few such impermeable geological strata, except at sea. Therefore, in many landfill sites for MSW and controlled landfill sites, liner systems are installed covering the bottom and slopes of the landfill sites. These must be based on one of the structures shown in Figure 5. In all cases, geomembrane sheets are used. If the sheets are damaged, there is a high possibility of leachate leakage causing groundwater pollution. In order to check the on-going soundness of the geomembrane sheets, LLDS have been installed in many such landfill sites.



A. Geomembrane + clay



B. Geomembrane + Watertight asphalt concrete



C. Double geomembrane

Figure 5 Structure of liner systems in Japan

PAST RECORDS OF INSTALLATION OF LLDS

Past records of installation of LLDS were obtained through discussion with manufacturers of LLDS, as shown Table 1. There were seven types of LLDS: including electrical and physical systems. The number of landfill sites that have installed LLDS was found to be 289. One additional site with an experimental LLDS was not included.

Table 1 Past records of installation of LLDS

Systems	Number of landfill sites			Area for LLDS (m^2)	
	Public	Private	Total	Total	Average
A	48	17	65 [47]	1,011,554	15,562
B	15	0	15 [11]	474,670	31,645
C	63	5	68 [48]	849,386	12,491
D	23	1	24 [20]	348,630	14,526
E	27	2	29 [26]	432,459	14,912
F	23	2	25 [23]	631,340	25,254
G	60	3	63 [32]	305,093	4,843
Total	259	30	289 [207]	4,053,132	119,233

[ ]: number receiving the questionnaire

RESULTS OF QUESTIONNAIRE SURVEY

Summary of the survey and response rate

A questionnaire survey was used to clarify the current situation of LLDS. The subject landfill sites were selected as follows: (a) landfill sites with LLDS and that were managed by the public sector and had contact information (207 sites in Table 1), and (b) landfill sites without LLDS and that had a capacity of over 100,000 m3 and had been operated for over 15 years by municipalities (38 sites). The questionnaires were sent to the managers of the landfill sites at the beginning of February 2015, and were returned up to the end of February 2015. The response rate was 58.0% and the details are shown in Table 2.

Table 2 Response rate

LLDS	Number sent	Number of responses and rate (%)	
		Number	Rate
Installed	207	123	59.4%
Not installed	38	19	50.0%
Total	245	142	58.0%

Reasons why LLDS was installed or not

The responders could select a maximum of three reasons. The results are shown in Table 3. Most respondents selected "safety and trust" as the reason for using LLDS. "High safety and trust of liner systems" was the predominant reason given for not using LLDS.

Table 3 Reason why LLDS was installed or not

Reason LLBS installed or not installed		Number	Rate
Installed	Safety and trust	98	45%
	Regulatory guide	34	16%
	Requirement by neighboring people	29	13%
	Promoted by design company	19	9%
	No response	12	6%
	Other	24	11%
	Total	216	100%
Not installed	High safety and trust of liner systems	5	24%
	Did not consider so necessary	2	10%
	No response	9	43%
	Other	5	24%
	Total	21	100%

Actual operation of LLDS

Table 4 shows the actual operation of installed LLDS. About 90% of landfill sites continued to operate LLDS with a permanent measuring device. At seven sites (6%), the LLDS were operated at the time of completion and thereafter when deemed necessary..

Table 4 Actual operation of LLDS

Content	Number	Rate
Continuously operating	109	89%
Operating only at the time of completion, if necessary operating after the completion	7	6%
Operating only at the time of completion	1	1%
No response	6	5%
Total	123	100%

Frequency of operation

Frequencies of LLDS operation are shown in Table 5. Most landfill sites (64%) operated LLDS once a day or more frequently.

Table 5 Frequency of LLDS operation

Frequency	Number	Rate	
All the time	2	2%	64%
Two times a day	26	21%	
One time a day	51	41%	
> One time a week	8	7%	
> One time a month	5	4%	
> One time a year	10	8%	
If necessary	5	4%	
Other	16	13%	
Total	123	100%	

Maintenance of LLDS

Table 6 shows the approaches taken to maintaining the LLDS. Over 50% of landfill sites with LLDS conducted periodical maintenance under contracts with manufacturers.

Table 6 Situation of maintenance of LLDS

Content	Number	Rate
Periodical maintenance under contract	68	55%
Periodical maintenance without contract	3	2%
If necessary	25	20%
No maintenance	8	7%
Other	9	7%
No response	10	8%
Total	123	100%

LLDS accidents

Table 7 shows the number of landfill sites having LLDS accidents and Table 8 shows the number of accidents at those sites. Of the landfill sites with LLDS, 60% did not have any accidents but over 30% had at least one accident, and 24% of these had multiple accidents. Extrapolating from the average number of accidents in known sites (1.5), the total number of accidents across all sites reporting any accident would be 62. Based on this, the relationship between maintenance and accidents is shown in Table 9. The probability of accident occurrence was lower, 40%, in the landfill sites conducting periodical maintenance under contract with manufacturers than the 63% in landfill sites without such maintenance. Although the total number of LLDS accidents was not large, it seems impossible to prevent all accidents. However, properly planned and conducted maintenance of LLDS reduces the chance of accidents.

Table 7 Incidence of LLDS accidents

Content	Number	Rate
No accident occurred.	74	60%
Accidents occurred.	41	33%
Other	1	1%
No response	7	6%
Total	123	100%

Table 8 Number of LLDS accidents

Number	1	2	3	4	5	Unknown	Total	Total number of accidents
Sites	20	7	2	0	1	11	41	
Rate	49%	17%	5%	0%	2%	27%	100%	62
		24%						

The total number of accidents was calculated on the basis of 1.5 accidents/site at known sites and a total of 41 sites reporting accidents, giving a total of 62 accidents.

Table 9 Relationship between maintenance and accidents

Maintenance		Incidence of accidents	
Content	Number	Accidents	Rate
Periodical maintenance under contract	68	28	41%
No maintenance like the above	48	31	65%
No response	7	3	43%
Total	123	62	50%

Cases detected by LLDS but with no liner system damage

There were cases where LLDS detected possible leachate leakage with no evident damage to the liner system. Such LLDS failures and their causes are shown in Table 10.

Ninety-four landfill sites (76%) reported no such cases but 23 landfill sites (19%) reported a total of 28 failures. There were 11 (39%) failures with causes outside the LLDS itself, such as poor insulation, and 16 (57%) failures had causes within the LLDS, such as problems with electrodes and cables.

In order to keep LLDS working well, without failure, insulation of the landfill sites should be undertaken. Poor insulation issues can be prevented if enough care is taken in the design and maintenance of LLDS.

Table 10 Failure cases detected by LLDS, with no liner system damage, and their reasons

	Do you have any cases where LLDS detected damage of liner system but actually there was no damage?	Sites		Rate
	NO	94		76%
	Yes	23		19%
	No response	6		5%
	Total	123		100%
	Causes why the LLDS detected damage without no liner system damage	Sites	Sub-total	Rate
Out of LLDS	Poor insulation: Leakage current from leachate collection pipes	3	11	39%
	Poor insulation: Leakage current from safety fences	2		
	Poor insulation: Leakage current from a gate of pit for leachate	1		
	Change in insulation resistance of liner sheets	2		
	Influence of electrical noise caused by thunderbolt and blackout	2		
	Direct sunlight (High temperature)	1		
On LLDS	Accident of measuring machine	7	16	57%
	Accident of electrodes, cables and vacuum hoses	4		
	Accident of data sampling and valve control	4		
	Poor contact between measuring machine and cables	1		
	Unknown reason	1	1	4%
	Total	28		100%

Table 11 Leachate leakage detected by LLDS

First means of detection of leachate leakage	Number	Rate	Reason why LLDS was not the first to detect the damage
LLDS	28	78%	—
Visual observation	5	14%	Visual observation was possible because the leakage occurred on the slope face.
Unknown	2	6%	Before installation of LLDS/ Change in responsible persons
Measuring water quality in a groundwater pit	1	3%	Connecting failure of leachate conduit to leachate treatment facility (outside of a landfill site)
Total	36	100%	

__Actual number of incidents detected by LLDS__

As shown in Table 11, the number of liner system damage incidents detected by LLDS was 36 (i.e. 29% of the 123 reporting landfill sites with LLDS). Of the 36 landfill sites reporting liner system damage, at 28 sites (78%) the damage was first detected by LLDS, suggesting that LLDS work well. Visual observation was the next most common means of damage detection (5 sites, 14%), but this damage occurred before landfilling and was therefore found on the slopes of the landfill site and could not have been detected by LLDS. "Measuring water quality in a ground water pit" (Table 11) indicates a connection failure between the leachate conduit and the leachate treatment facility, which is located out of the landfill site. This also cannot be detected by LLDS. Therefore, this study found that when liner systems are damaged, by causes that can potentially be detected by LLDS, the LLDS identify all instances of damage to liner systems.

CONCLUSION

This is the first investigation to clarify the present operational situation of LLDS in Japan. We identified seven types of LLDS, which were installed at 289 landfill sites. A questionnaire survey of managers of landfill sites revealed that, at sites with LLDS, liner systems were commonly checked for damage more than once a day and that over 50% of landfill sites conducted periodic maintenance, suggesting that LLDS are being properly managed. In addition, periodic maintenance of LLDS was recognized as important because it decreased the probability of accidents. Although most of the LLDS contributed to the detection of leachate leakage, some cases showed false detection when there was no damage to the liner systems. Further countermeasures for this failure will be needed through planning and during maintenance of LLDS.

ACKNOWLEDGMENT

This study summarizes the findings reported in the annual research report in FY2015, conducted by a research group for understanding the introduction and operation of LLDS in The Landfill System & Technologies Research Association of Japan, NPO (NPO, LSA). The members of our research group are (Name/ Affiliation/ Position in the Subcommittee): Masaaki Ebihara/ TAISEI CORPORATION/ group leader and chief, Ryoji Matsumoto/ YACHIYO ENGINEERING CO., LTD./ subgroup leader, Tsuyoshi Kobayasi/ OYO CORPORATION/ deputy chief, Shigeo Ueda/ Individual member of LSA, NPO/ member, Kouichi Sugiyama/ TAIYO KOGYO CORPORATION/ member, Katsuhiko Hayashi/ MAEDA CORPORATION/ member, Kenji Matumoto/ MITSUBOSHI BELTING LTD./ member, Yuuitirou Yamada/ YACHIYO ENGINEERING CO., LTD./ member, Minoru Yamamoto/ TAIYO KOGYO CORPORATION/ member. We appreciate the managers of the landfills sites, who cooperated with our research.

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CURRENT SITUATION ON LAND USE AFTER CLOSURE OF LANDFILL SITES IN JAPAN

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ABSTRACT

A steep mountainous area occupies 70% of the land in Japan, so our living is limited to a narrow plain. Effective utilization of the limited land is a critical issue for us. After the closure of landfill sites, the land has a value for future potential use because it can be used effectively. In Japan, there have been numerous cases where the land has already been used after the closure of landfill sites. However, there is still too little information on the state-of-the-art of land use after the closure of landfill sites for municipal solid waste (MSW). In this study, a questionnaire survey for site managers was conducted on land use after the closure of the landfill sites for MSW in Japan. This paper reports on the current situation and tendency of land use after the closure of landfill sites in Japan based on the results of the questionnaire survey. The main results from this study are described as follows. 1) The number of cases of land use after the closure of landfill sites, in particular in mountain areas, was larger in Kanto and Tokai regions than in other regions. 2) The land use for solar power generation has been increasing. 3) In addition, some large-scale developments for land use after closure of landfill sites including the neighboring areas have been economically feasible.

Keywords: landfill, MSW, land use, controlled type landfill sites

INTRODUCTION

A steep mountainous area occupies 70% of the land in Japan and we have developed a narrow plain to live on. Effective utilization of the limited land is a critical issue for us. After the closure of landfill sites, the land has a value for future potential use because it can be used effectively. Japan has numerous cases where land has already been used after the closure of landfill sites. In the past, there were problems that methane gas suddenly belched or that hazardous materials, such as cadmium, were detected on the land after the closure of landfill sites. Thus, there is a need for guidelines for land use after the closure of landfill sites (Kinoshita, 1993). In addition, because social needs for effective land use have been recognized as social infrastructure, properties on landfill sites have been investigated gradually; high-degree use has been increasing (Okada et al., 2001).

In 2005, the investigation committee for standards in the change of the land character after the closure of landfill sites published "Guideline for change of the land character after closure of landfill sites," where a questionnaire survey on land use after the closure of landfill sites was conducted for prefectures (Nishiyama and Terai, 2010). Matsuto and Yoshida (2009) propose an ideal and sustainable land use after the closure of landfill sites.

In many cases, it takes more than 10 years from the construction of landfill sites to their closure. Thus, social backgrounds and the needs for land use can change. The optimum land use after the closure of landfill sites should be reconsidered when the landfill sites are actually closed. However, since 2005, when the latest investigation on land use after the closure of landfill sites was conducted, there is little information on the state-of-the-art for land use after the closure of landfill sites for municipal solid waste (MSW). To present the current situation on land use after the closure of landfill sites in Japan, this study conducted a questionnaire survey for site managers of the landfill sites.

METHOD OF QUESTIONNAIRE SURVEY

Objective landfill sites

By the Japanese definition, landfill closure means that receiving waste for landfilling stops. Continuous operation and maintenance, called post-closure care (PCC), is needed even if the landfill site is closed because leachate should be treated and landfill gas should be managed. Japan has criteria for judging whether or not continuous operation and maintenance is needed in terms of protection of the living environment, neighboring landfill sites, quality of leachate, landfill gas emission, temperature of waste layers, settlement, and groundwater quality, etc. Closed landfill sites are categorized into two groups, namely, closed landfill sites under post-closure care (CL-UPCC) and closed landfill sites after the PCC is finished (CL-APCC).

Table 1 shows the objective landfill sites for the questionnaire survey, considering the above categorization. From the landfill sites listed with the Japan Ministry of the Environment in the 2013 financial year (FY2013), CL-UPCC were extracted by the condition whereby they were closed after FY1999 and have leachate treatment facilities. CL-APCC were extracted by the condition whereby they were closed after FY1999 and they also finished PCC from landfill sites (from FY2007 to FY 2013) listed with the Japan Ministry of the Environment. As a result of the classification, the number of CL-UPCC and CL-APCC was 220 and 47, respectively, and the total number was 267.

Table 1 Objective landfill site for questionnaire survey

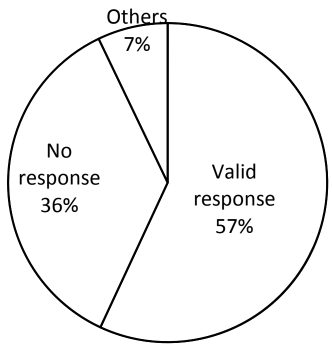
Item	Extraction conditions	Number
Closed landfill sites under post-closure care (CL-UPCC)	They were listed (FY2013) with the Japan Ministry of the Environment. They were closed after FY1999 and have leachate treatment facilities.	220
Closed landfill sites after post-closure care is finished (CL-APCC)	They were listed (FY2007 to FY2013) with the Japan Ministry of the Environment. They were closed after FY1999 and finished PCC.	47
	Total	267

Table 2 Questions in the questionnaire survey

Questions	
1. Basic information of landfill site	Name, address, etc.
2. Dimensions of landfill site	Site, structure, area, volume, etc.
3. Operation and maintenance costs	Leachate treatment, cleaning, etc.
4. Land use after the closure of landfill sites	Yes/No
5. The reason why the land is not used	Advantage, stabilization, right and interest of land, etc.
6. Category of facility for land use	Park, building land, solar panel, stockyard, etc.
7. Objective of land use	Citizen's benefit, profit-making business, public building, etc.
8. Dimensions of facility for land use	Commencement day, phase in life of landfill site, area for land use, income, profit, land owner, business entity
9. Future land use	Go/no-go

Questions in the questionnaire survey

The questions in the questionnaire survey consisted of the following (Table 2). 1. Basic information on the landfill site; 2. dimensions of the landfill site; 3. operation and maintenance costs; 4. land use after the closure of landfill site; 5. the reason why the land is not used; 6. category of facility for land use; 7. objective of land use; 8. dimensions of the facility for land use, and 9. future land use.



Others include not closed landfill sites.

Figure 1 Percentage of replies (n=267)

Table 3 Percentage of land use

Area type	Valid responses	Percentage of land use (%)
Total	152	32
Mountain	105	22
Flatland	42	50
Sea	5	80

RESULTS AND DISCUSSION

Percentage of replies

The percentage of replies is shown in Figure 1. The number and percentage of valid responses were 152 and 57%, respectively. Landfill sites that were not closed yet were categorized as "others."

Percentage of land use after closure of landfill sites

Table 3 shows the percentage of land use after the closure of landfill sites considering the area conditions. The percentages for mountain, flatland, and sea were 22%, 50%, and 80%, respectively. Overall, the percentage of land use was 32%.

The percentage of land use in each region is shown in Table 4. The percentages in Kanto and Tokai regions were relatively large, 63.6% and 44.4%, respectively, and in Kyushu and Okinawa regions were the smallest, 8.3%. In the other regions, the percentage was in the range 16.7%–25.0%. In particular, the percentages of land use in the Kanto and Tokai regions were large in flatland and mountain.

Table 4 Land use in each region

Area	Percentage of land use (%)			
	Total	Mountain	Flatland	Sea
Hokkaido	16.7	18.2	0.0	–
Tohoku	16.7	12.5	50.0	–
Kanto	63.6	62.5	60.0	100.0
Hokuriku, Koshinetsu	19.0	8.3	33.3	–
Tokai	44.4	33.3	55.6	–
Kinki	23.1	11.1	50.0	–
Chugoku, Shikoku	25.0	18.2	100.0	100.0
Kyushu, Okinawa	8.3	0.0	0.0	50.0

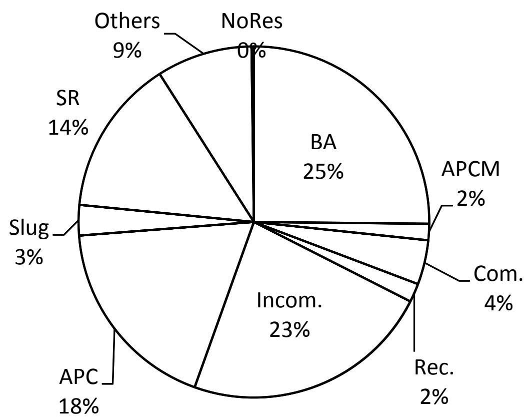


Figure 2 landfilled waste
(Answer=465 from 152 landfill sites)

Legend: BA: Bottom ash, APCM: Air pollution control ash (melting facility), Com.: Combustible, Rec.: Recyclable, Incom.: Incombustible, APC: Air pollution control ash, Slug: Slug (melting facility), SR: Shredded residue, NoRes: No response.

Relationships between landfilled waste and land use

The landfilled waste among the valid responses is shown in Figure 2. Most of the landfill sites in Japan receive various kinds of waste and the multiple responses were summarized. Bottom ash was the largest, at 25%, followed by incombustible, air pollution-control ash (APC), and shredded residue.

Table 5 shows the percentage of land use for every type of landfilled waste, where no difference in the results among the landfill wastes was seen.

Table 5 Percentage of land use for every landfilled waste

Landfilled waste	Percentage of land use (%)
BA	33
APCM	43
Com.	53
Rec.	38
Incom.	29
APC	32
Slug	31
SR	33
Others	27

Distribution of land use

Table 6 shows the distribution of land use. The percentage of sport facilities was the largest, followed by photovoltaic power plants (PPP), multipurpose squares, parks, and stockyards for disaster waste. In particular, the number of PPP and stockyards for disaster waste has increased.

Recently, there has been a focus on PPP as land use after the closure of landfill sites because they can make a profit. Since the launch of the Feed-In Tariff (FIT) scheme in 2012, the Japan Ministry of the Environment has also conducted a "Project for the promotion of installation of photovoltaic power plants at landfill sites" and recommended installation of PPP on the closed landfill sites to promote both renewable energy and land use after the closure of landfill sites. In addition, some closed landfill sites are used as a stockyard for disaster waste. In particular, regions that have not experienced disaster yet will set closed landfill sites to be used as stockyards for disaster waste.

Table 6 Distribution of land use

Land use	Percentage (%)
Sport facility (SF)	23.6
Photovoltaic power plant (PPP)	22.2
Multipurpose square (MS)	15.3
Park (P)	6.9
Stockyard for disaster waste (SYD)	6.9
Others	6.9
Other facility for business (OFB)	5.6
Agriculture (AG)	4.2
Public facility (PF)	2.8
Parking (PA)	1.4
Green land (GL)	1.4
Stockyard for waste (SY)	1.4
Camping ground (CG)	0.0
Building land (BL)	0.0
Waste treatment facility (WF)	0.0
No response	1.4

As the other facility for business, there were answers that indicated that some closed landfill sites are used as a place for barbeques, where fire is used. Some consideration is needed to prevent fire accidents that might be caused by landfill gas.

As described above, the percentage of land use in mountain areas was high in the Kanto and Tokai regions (see Table 4). Figures 3 and 4 show the land use in the mountain area in the Kanto and Tokai regions, respectively. In the Kanto region, the percentage of sport facility (SF) was high, and in the Tokai region, there was no trend in land use because the number of data points was only seven.

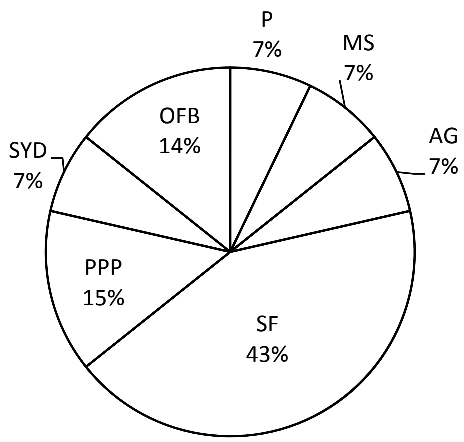


Figure 3 Land use in mountain area, Kanto region (Answer = 14 from 10 landfill sites)

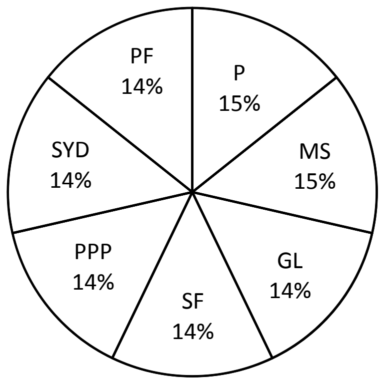


Figure 4 Land use in mountain area, Tokai region (Answer = 7 from 3 landfill sites)

Table 7 Reasons for non-use of the land

Items	Percentage (%)
No advantage because of mountain area	23.1
No planning because the site is under PCC	14.0
Problems in economic efficiency and no funding	11.6
Still planning and not yet determined	9.1
Impossible because of leased land	6.6
Land use is very distant because landfilling will continue	5.8
Not yet determined	5.0
Tree plantation by agreement with local community	4.1
Not yet discussed because lack of clarity re community needs	4.1
New landfill site will be constructed at the same site	2.5
Complex situation because of many stakeholders with rights and interests	1.7
No idea although they want to use the closed landfill sites	1.7
Others	9.1
No response	1.7

Reasons for lack of use of the land

Table 7 summarizes the reasons for not using the closed landfill sites. The answer of "no advantage because of mountain area" was the largest, 23%, followed by "no planning because the site is under PCC," 14%.

Some closed landfill sites have no planning for land use despite the land being capable of being used even after PCC. This suggests that the land value for land use after the closure of the landfill sites might be underestimated.

Phase at the beginning of land use

Figure 5 shows the phase at the beginning of land use. Most of the landfill sites began their land use when they were closed and during PCC. There were rare cases (only 10%) where land use began after PCC was finished. In addition, 6% of landfill sites began their land use during landfilling.

Land use categorized by landfill area

The percentage of land use considering the landfill area is summarized in Table 8. In the landfill sites with a large area, the percentage of land use was high.

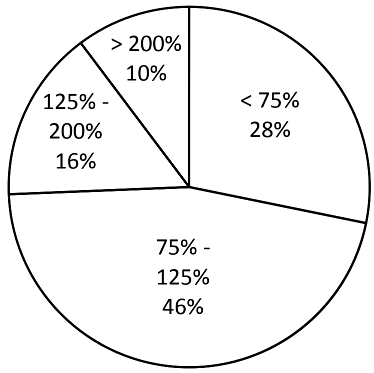


Figure 6 Ratio of land use area to landfill site area

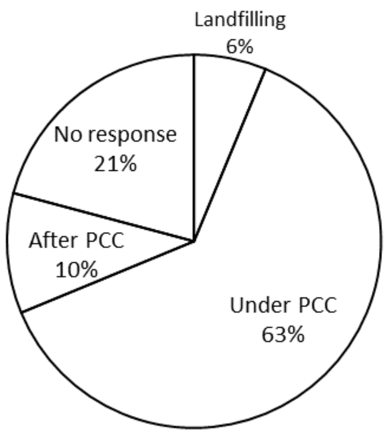


Figure 5 Phase at the beginning of land use (n=48)

Table 8 Percentage of land use categorized by landfill area

Area of landfill site (m^2)	Percentage of land use (%)
<1,000	0.0
1,000–2,500	12.5
2,500–5,000	15.4
5,000–10,000	22.6
10,000–25,000	35.3
25,000–50,000	41.2
>50,000	48.1

The relationship between landfill area and land use area

The ratio of land use to landfill area is shown in Figure 6. In about 50% of landfill sites having land use, the ratio was 75%–125%, meaning that the landfill area and the land use area were almost the same. In cases where the ratio was less than 75%, land use seemed to be limited because of the surface structure of the landfill sites, such as slope and banquette, etc. In cases where the ratio was larger than 125%, the neighboring area seemed to be also used for land use, such as large area. Four landfill sites in particular, in which the ratio was more than 200%, were used for PPP and golf courses, which require a large area. This means that large-sized land use, including the neighboring area, has been economically feasible.

CONCLUSIONS

In this study, a questionnaire survey was conducted on land use after the closure of landfill sites that are managed by local governments. The findings of this study were the following.

1) The percentages of land use after the closure of landfill sites were larger in the Kanto and Tokai regions and in particular the percentage of land use in mountain areas was high in both regions.
2) Recently, the number of photovoltaic power plants

installed as land use after the closure of landfill sites has increased.

3) Large-sized land use, including the neighboring area, to make a profit has been feasible.

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STUDY OF RISK MINIMIZATION AT FINAL WASTE DISPOSAL SITES

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ABSTRACT

The risk at a final waste disposal site is not limited to the structure and specifications of the facility. At a final waste disposal site, there are risks in the waste itself, transportation, and information transmission. Appropriate recognition and response to these risks can increase public understanding and satisfaction with the final waste disposal sites.

In this study, we first extract and organize the transportation and the detectable risks at the time of acceptance. Next, we extracted and organized the technologies introduced or that could be introduced for risk minimization. Finally, we aimed to compile these, compile consensus and formulate the risk commitment of final waste disposal site management, to raise public understanding and satisfaction.

The following issues are discussed:

1. Extraction of risks during waste transport.
2. Extraction of risks that can be dealt with by detection at acceptance time.
3. Extraction of risks that can be prevented by information communication.
4. A study of the technologies introduced or that could be introduced for risk minimization.
5. A concrete example of risk solutions or basic data for risk communication tools.

At the next stage, we will consider risk management at a site of final waste disposal that combines risk minimization solutions and will propose one form of final disposal site that could be easily accepted by local residents with high understanding and satisfaction.

Keywords: the risk at final waste disposal sites, risk countermeasures, risk communication tools

INTRODUCTION

In this study, we first extract and organize transportation risks and detectable risks at the time of acceptance. Next, we extract and organize the technologies introduced or that can be introduced for risk minimization. Finally, we aimed to compile these, compile consensus and formulate the risk commitment of final waste disposal site management to raise public understanding and satisfaction.

EXTRACTION OF RISKS DURING WASTE TRANSPORT

Inappropriate treatment, contamination risk

Risks in waste management arise when there is a mistake or a change in waste at the source. Accidents occur during waste transportation or acceptance, or during difficult leachate treatments, long stability periods, land-filling problems, or because of environmental deterioration.

Figure 1 Image of wastewater generation because of foreign matter contamination

Figure 2 Image of infectious waste contamination

Transport route deviation • illegal dumping • illegal carry-in risk

The amount of illegally dumped waste has decreased drastically in recent years, but it is still at a level of 30,000 t per year and there is a risk of illegal dumping at the time of transportation.

Figure 3 Illegal dumping in the Teshima case

Figure 4 A case of illegal dumping in Chiba City HP

Risk of traffic environment deterioration by transport vehicles

Safety is given priority during waste transportation. However, when there are pedestrians or cyclists on the road, near schools, in high traffic areas, narrow roads, roads in poor condition, or bad weather, there is a risk that the traffic environment may easily deteriorate in heavy traffic when numerous transport vehicles may drive dangerously.

Figure 5 Transportation environment with numerous transport vehicles

Figure 6 Crosswalk without traffic lights

EXTRACTION OF RISKS THAT CAN BE RESOLVED BY DETECTION AT ACCEPTANCE TIME

<u>Risk of deteriorating landfill work environment or contaminating the surrounding environment due to odor products</u>

When the received waste generates unpleasant odor, such as garbage and sludge, livestock excrement, animal carcasses, chemical substances, or if such odors are mixed in, if the odor diffuses, there is a risk of harmful effects on landfill workers and on the surrounding environment.

Figure 7 Protest against malodor

<u>Fire caused by a mixture of ignition or fire-spreader substances, risk of damaging waterproofing work</u>

When materials such as paint, spray cans, gas bottles, waste oil, putrefactive waste, chemically reactive substances are accepted or mixed in the accepted waste, they can become an ignition factor. Therefore, fires could occur at the time of transportation and final disposal causing destruction of the vehicle, the facility, or the landfill workers.

Figure 8 Fire from waste

Figure 9 Firefighting activity of a transport vehicle (Higashimurayama City HP)

Figure 10 Fire spreaders in transport vehicle (Higashimurayama City HP)

Figure 11 Lighters and spray cans (Higashimurayama City HP)

<u>Risk of deteriorating landfill work environment or surrounding environment because of contamination with gas generators</u>

Large amounts of waste gypsum (e.g., hydrogen sulfide) boards, spray cans, foam insulation (volatile organic compounds, including toluene, benzene, freon, dichloromethane, and the like are included in various solvents, adhesives, detergents, disinfectants, or pesticides, among others), or biodegradable organic matter (e.g., methane) may generate harmful gases, which can ignite and cause fire. There is a risk of adversely affecting the landfill workers' environment and the surrounding landfill environment.

Figure 12 Waste gypsum board

Figure 13 Foam and waste foam insulation products

<u>Risk of deterioration of the surrounding environment because of contamination</u>

When easily scattered waste is accepted, there is a risk that the scattering will adversely affect the surrounding landfill environment.

Figure 14 Situation at a final waste disposal site

Figure 15 Scattered waste

Risks from waterproof sheet damage, drainage pipe damage, and landfill operation obstruction because of the inclusion of large-size wastes

Risk arises when large-size wastes are mixed above the standard. This includes the risks of waterproof sheet damage, drainage pipe damage, and landfill operation obstruction.

Figure 16 Large-size wastes

Figure 17 Landfill compactor crushing large waste

Processing difficulty due to contamination of high-concentration wastes and long-term risk to landfill stability

There are risks of difficult processing and long-term risk to landfill stability when receiving high concentration substances and waste other than acceptance standards.

Example: Receipt of incineration ash or fly ash not subject to acceptance.

Figure 18 Incineration ash

Figure 19 Fly ash

Processing difficulty because of mixed hazardous materials or harmful substances and long-term risk to landfill stability

When receiving toxic and harmful waste, such as volatile substances and chemicals, there is a risk that this may affect the landfill's stabilization period, which can be difficult to handle properly.

Figure 20 Gas cylinders

Figure 21 Batteries and other products

IDENTIFYING RISKS THAT CAN BE PREVENTED BY INFORMATION COMMUNICATION

<u>NIMBY deterioration risk because of a lack of understanding</u>

Recent final waste disposal sites are equipped with the latest technologies to ensure safety, such as multiple safeguards, water-containing systems, and water leakage detection systems. However, the facility structure and system may not be understood by local residents and there is a risk of protestors opposing construction at the disposal site and opposition campaigns to stop landfill construction.

Figure 22 Action against the construction of a final waste disposal site

Figure 23 Civic briefing session

<u>NIMBY deterioration risk due to lack of information</u>

Facility and management information for the final waste disposal sites may be insufficient. There is a risk that the image the local residents have will be bad, that the information about the facility will not be understood correctly, and there will be an opposition campaign against the disposal site under operation, and damage to the reputation of final waste disposal will occur.

Figure 24 Protest action seeking cancellation of waste disposal facility

CONSIDERATION OF RISK COUNTERMEASURES

Investigation of transport risk countermeasures is shown in Table 1. Countermeasures to detectable risk at acceptance time are shown in Table 2. Countermeasures to cope with the risk that prevention activities can be expected by information communication are shown in Table 3.

The electronic manifest was started in Japan in 1998. The information to be managed is matters concerning waste disposal companies, types and quantities of wastes, transporters, and disposers. In Japan as of FY 2017, 190,000 companies joined, the introduction rate of electronic manifests has increased 5 times to 53% in the past 10 years. However, from the aspect of site agreement on the final waste disposal site, improvement of introduction rate and introduction into general waste are considered necessary.

GPS navigation management systems are being introduced to logistics, road transportation and construction vehicles including transportation of industrial waste. This system is also a point to improve the introduction rate. If the introduction rate increases, it can be said that it is a very effective measure in terms of agreement on final waste disposal site location.

Determining the risk by sensor of water quality, gas, temperature, odor and image, the method of dumping for risk detection, the accuracy of sensor and the operation method are important. Sensor introduction cases are confirmed. However, there is no example of introducing multiple sensor systems, it is necessary to conduct research in conjunction with the transportation form, receiving dumping, reloading and transporting method.

In recent years, a lot of information dissemination in real time utilizing ICT has been adopted as a countermeasure against anticipated risk due to information transmission and communication. However, it is also important to repeatedly transmit necessary information according to each stage at the time of planning, construction and operation of the final disposal site, and to provide direct information in which the face and face are combined.

Table 1 Investigation of transport risk countermeasures

Risk	Risk countermeasures	Overview of risk countermeasures
Inappropriate treatment, contamination	Tracking system with electronic manifest	The electronic manifest system performs the responsibilities of the waste disposer by discharging, handling, and disposing of persons, and sharing processing and final waste disposal information.
	A tracking system by electronic manifest using an integrated circuit (IC) tag	Store the waste in a container with an IC tag and confirm proper treatment from the stage of transportation to final waste disposal.
Transport route deviation, illegal dumping, illegal waste carry-in	GPS navigation management system of haul vehicles (route monitoring)	Route monitoring of predetermined route travel and deviation in real time, to prevent deviation from specified routes, illegal dumping, and illegal receipt.
Traffic environment deterioration by transport vehicles	Safety operation monitoring of transport vehicles	Promote safe driving by managing route, speed, sudden departure, sudden steering, sudden braking in real time.

Table 2 Countermeasures to detectable risk at acceptance time

Risk	Risk countermeasures	Overview of risk countermeasures
Environmental deterioration because of generation of factors such as malodor, high-temperature, gas, obstruction of landfilling work, occurrence of damage to waterproofing equipment	Determination of acceptance risk by sensor	Install sensors in the reception area to prevent waste from entering with odor, high temperature and gas.
Risk of improper processing because of contamination from substances with high concentration, long-term risk of landfill stability	Survey of water quality of leachate by water sensor	Analyze water quality of leachate generated by sprinkling water, and detect the effect of leachate treatment and landfill stability.
Exacerbation of landfill work environment and surrounding environment due to dangerous goods and harmful substances	Removal of dangerous and harmful substances by sensor + AI	Expand the waste at the reception site and examine the image with sensors + AI to remove hazardous materials and harmful substances.

Table 3 Countermeasures to cope with the risk that occurrence prevention can be expected by information transmission and communication

Risk	Risk countermeasures	Overview of risk countermeasures
NIMBY deterioration risk because of lack of understanding	Facility tour	Improve understanding of structure and system by tour of final waste disposal site and improve mutual understanding through direct dialogue with residents.
	Improve understanding through explanation of facility structure and system	Pamphlets, models, image diagrams to improve understanding of facility structure, system, site planning.
NIMBY deterioration risk because of lack of information	Information dissemination on operation status	Increase understanding of facilities and facility management by publishing operation information in a publicity magazine to provide operation information for HP and improving accessibility.
	Operation information dissemination by information communication technologies	ITV, helmet, or drone cameras improve understanding of facility management by providing images, improving the landfill's image by checking and preventing inappropriate management.

CONCLUSION

This study focused on vague risks to the final waste disposal site, such as "will it survive an earthquake?" "what will happen in case of heavy rain?" or "worried about pollution!" The subcommittee members appreciated the local residents' anxiety, anxiety relief, and understanding of the information communicated about the site. However, because the risk associated with the final waste disposal site is related not only to the structure and specification of the facility, the risks that may occur at the time of transportation, acceptance, location, and operation of the waste and its countermeasure was focused in this study.

At the next stage, we will consider risk management at a final waste disposal site combining these risk countermeasures. We will propose one form of a final waste disposal site that is technically acceptable and is also acceptable for citizens.

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IN-SITU MONITORING FOR EVALUATION OF PERFORMANCE OF A SEMI-AEROBIC LANDFILL

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ABSTRACT

Heat, gas and leachate are the primary products of decomposition process of organic wastes due to physical, chemical and biological reactions that occur within the wastes. However, leachate includes a complex mixture of various substances with high concentration then monitoring and analysis of BOD or COD are hardly carried out. On the other hand, gas temperature and gas composition which is mainly methane, carbon dioxide, oxygen and nitrogen, can be measured quickly by portable equipment. This study will focus on how to quickly evaluate the performance of semi-aerobic landfills based on the two indicators. In order to evaluate the performance of aerobization process, we conducted a series of surveys aimed at investigating the gas temperature and gas components at an operating semi-aerobic landfill. Gas temperature and gas components have been monitored for more than 10 years since 2005 (2 years after the beginning of landfilling in 2003). The results of surveys showed that the aerobic biodegradation happens effectively and gas temperature can reach more than 65^{o}C. In addition, the surveys also revealed that clogging phenomena happening inside gas extraction wells significantly reduces the performance of semi-aerobic landfill and possibly converts a semi-aerobic landfill into an anaerobic landfill.

Keywords: Semi-aerobic Landfill, Gas Component, Gas Extraction Wells, Aerobic Reaction.

INTRODUCTION

In the hierarchy of waste management system, waste containment facility is still the final point of unuseful refuse. In the past and today even in developing countries, landfill site is only an open dump due to lack of both understanding its risk on public health and limited financial resources. In recent years, recognizing the importance of storing the disposal waste under controlled conditions, the implementation of sustainable landfills are increasing more and more in both developed and developing countries in order to minimize the negative impacts of the waste containment facilities on surrounding environment and community (Grossule, V., Lavagnolo, M.C., 2017).

To meet the requirements of legislation relating to protecting environment during construction, operation, closure and aftercare and financial constraints, there were many researches about the landfilling technologies in all over the world. For example, bioreactor landfill method is mainly applied in North America and Europe, however, more than 70% of landfills in Japan and Korea are using semi-aerobic landfilling technology (also called Fukuoka Method) that developed by Prof. Masataka Hanashima from 1970s at Fukuoka University, Japan. And in recent years, this technology are broadened to other developing countries in Asia such as China, Thailand, Iran and Malaysia because of its benefit. Although, the semi-aerobic landfill has been applied in reality and it exhibited enormous potentiality, most of studies on the semi-aerobic concept have been implemented by using lysimeter in laboratory. There are a few researches that was carried out in full-scale so far. Therefore, this study was implemented at an operating semi-aerobic landfill in northern part of Hokkaido, Japan.

The mechanism of semi-aerobic landfill bases on air intrusion into waste layers through passive gas extraction wells (venting pipes) that connected with leachate collection pipes at the bottom of landfill and their wellhead directly open to the atmosphere. Oxygen is supplied naturally into landfill through these pipe, as a results aerobic biodegradation happens effectively and landfill gas is released into atmosphere through gas venting pipes. Heat, gas and leachate are the primary products of decomposition process of organic wastes due to physical, chemical and biological reactions that occur within the wastes. Hence, gas composition, temperature and leachate are indices for evaluating the performance of semi-aerobic landfill. This study will focus on observation indices to evaluate the performance of the semi-aerobic landfill.

DESCRIPTION OF THE LANDFILL SITE

This operating semi-aerobic landfill is located at the northern part of Hokkaido, Japan. The landfill was constructed in 2003 and it began operating from July 2003 until now (July 2018). The area is 13.2 ha, the expected volume is 1.84 million cubic meter over 27-year period (2003-2030). This landfill accepts incombustible wastes, bottom ash and fly ash, however, organic wastes included in business wastes were accepted during 2003-2007. The quantities reached 1.10 million cubic meter and the maximum depth of waste layers reached 34m in 2017.

According to the design, the landfill will be installed 73 gas extraction wells classified three types including main wells, branch wells and monitoring wells. A typical gas extraction well contains two main parts: a venting pipe and a gravel layer. The landfill gas extraction wells consist of a 200mm HDPE pipe and 200mm gravels around the pipe. These venting pipes are perforated along the pipe body, the diameter of a small hole is from 5mm to 10mm. Except for monitoring wells, which are not connected to leachate collection pipes network, the remaining gas wells are connected to leachate collection pipes in order to take air flow into the waste layers. At the present time, there were 53 of 73 gas extraction wells installed including 9 main gas wells, 39 branch gas wells and 5 monitoring wells.

Leachate is collected by leachate collection pipe system (LCPs) at the bottom of the landfill and conveyed to leachate pond before pumping to the leachate treatment plant which uses membrane technology for treatment. The diameter of main leachate collection pipe and branch pipe are 700 mm and 400 mm, respectively. The average leachate volume is 600 m3/day and the volume of leachate pond is

12,700 m3. As mentioned above, in addition to the duty collecting leachate, LCPs are in charge of conveying air flow into waste layers. Therefore, the leachate pipe end is always open to atmosphere.

SURVEY METHODS

In this study, gas temperature and gas composition in landfill gas (LFG) extraction wells have been monitored for analysis. Gas temperature was surveyed from 2005 two years after commencement of landfilling and gas composition was monitored from 2010.

Temperature is measured by thermocouple recorder and gas component is measured by portable landfill gas analyzer (GA5000, Geotechnical Instruments). The analyzer was equipped with a pump working at a sampling rate of 300 ml/min. A sampling tube and thermometer sensor was lowered into a gas vent to a depth of every 2m from ground level, and measurements were recorded after 60s of sampling. The presence of three different gases (CH_4, CO_2, O_2) were simultaneously detected. The amount of N_2 was determined by the balance of CH_4, CO_2, and O_2. The accuracy of the measurements for CH_4, CO_2, and O_2 were ±0.5%, ±3%, and ±0.1%, respectively.

RESULTS AND DISCUSSION

Gas temperature

Fifty three venting pipes had been installed in the landfill area. Some of gas wells had been built as soon as the landfilling commenced, whereas others were newer. Temperature of 34 gas wells had been monitored since 2010 (Gas wells M2 and M9 had been monitored since 2005), however, elevated temperatures were observed in a limited number of gas wells, only have 8 of the 34 wells showed high temperature above 50°C for several years.

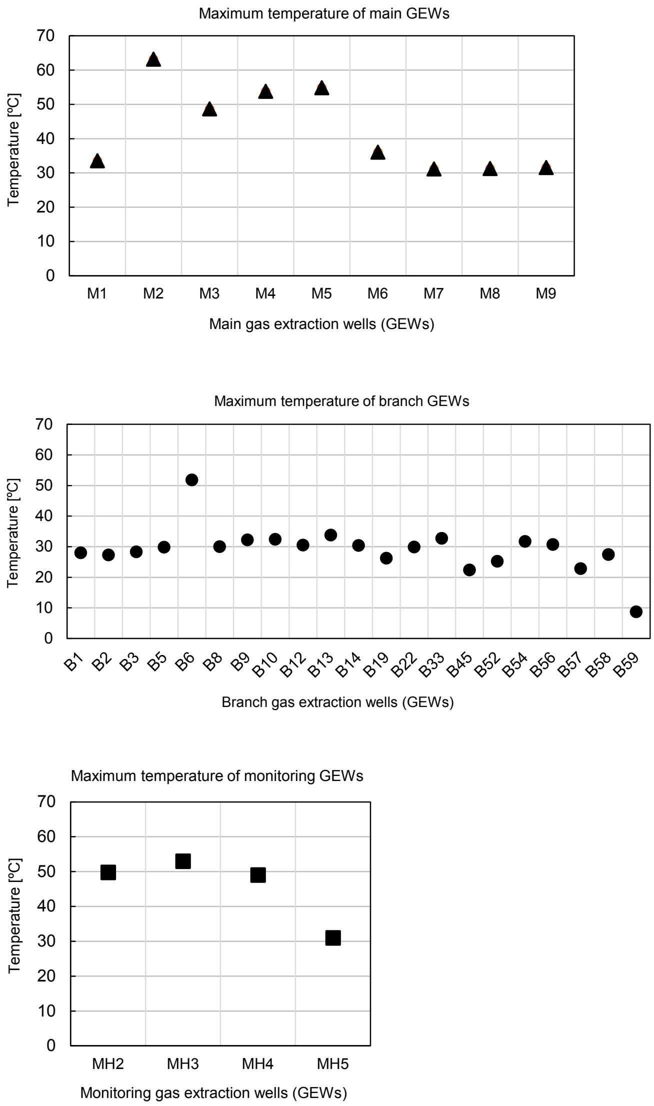

Figure 1 Maximum temperature of observed gas extraction wells

The maximum temperature of main gas extraction wells (M), branch gas wells (B) and monitoring gas wells (MH) were 63.2°C, 51.8°C and 53°C, respectively. The maximum temperatures of remaining gas wells were in the range of 20-35°C. The temperature of these gas wells are not so high due to two main reasons: (1) these gas wells are far from main leachate collection pipe, therefore air flow approaches slowly these gas wells through LCPs; (2) the amount of organic matter of waste layer was small that results in the heat generating by aerobic reactions is not large enough to raise the temperature of waste layer and gas temperature.

As can be seen in Figure 1, the gas wells with high temperature are the main gas wells M2, M3, M4, M9, branch gas well B6 and monitoring gas wells MH2, MH3, and MH4. Because the bottom of main gas wells were directly connected with the main leachate collection pipe, therefore the approaching possibility of waste to oxygen stronger than branch gas wells. The more the position of gas wells are near the main LCP, the more the exposure of waste to air is high.

Figure 2 shows that the main gas well M2 has the maximum temperature among all gas extraction wells were installed in the landfilling area which was over 60°C. The elevation of gas well M2 reached to 213m in 2008 (the height of waste mass was over 30m) before lowering to 210m because of improving the infrastructures in 2010 and was remained so far (then the height of waste mass was 27m). It should be noted that the organic waste was dumped during from 2003 to 2006. It means that the elevated temperature caused by aerobic biodegradation of organic matter.

It can be seen that the elevated temperatures occurred from November 2005 (2 years after the landfill started) and reached to 63.1°C in January 2011 and remained around over 60°C in January 2013 before jumping back to 25°C in August 2014. The elevated temperatures were remained continuously for 8 years. To explain for the elevated temperature phenomenon, Matsufuji and Tachifuji, (2007) demonstrated that oxygen was transmitted together with air through the LCPs system and intruded into waste layers near the LCPs and venting pipes to supply aerobic microorganisms for biodegradation of organic wastes.

Figure 3 shows the gas temperature distribution with depths of waste layer. The range of temperature is always higher than 50°C at depths below the ground from 2010 to 2013 and to drop down suddenly from August 2014 so far.

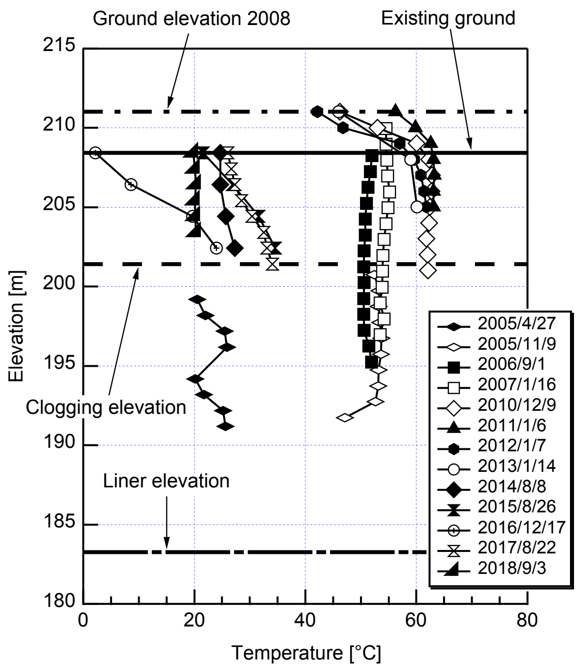

Figure 2 Temperature profile of main gas well M2

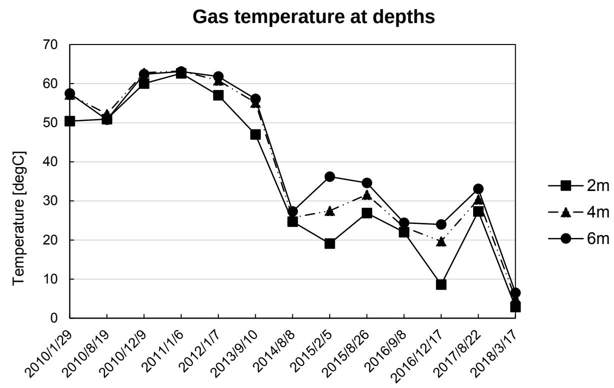

Figure 3 Gas temperature at different depths of main gas well M2

On the one hand, it might be due to the organic matter disappeared; on the other hand, in August 2014 we detected the clogging phenomena happening inside gas extraction wells. This phenomenon prevented oxygen migrating into waste mass from the bottom part, therefore there was not enough oxygen for aerobic microorganisms. Another factor could influence on the penetration rate of oxygen that is the porosity of waste mass. Clearly, the more organic wastes are near the venting pipes or the LCPs, the more their biodegradation occurs quickly and the higher temperature is.

Figure 2 also exhibited that the highest temperature detected in early January (2010, 2011, 2012, 2013) and February 2014. The duration was the winter in Japan and the average ambient temperature was from -20^{o}C to -5^{o}C. And a thick snow layer covered all the landfill. The difference of temperature inside and outside of the gas well is very large, more than 60^{o}C. However, in recent years, the temperature fluctuated around 20-35^{o}C and in March 2018 the temperature even dropped less than 10^{o}C (Figure 3). This fact affirms that the assumption of Matsufuji and Tachifuji (2007) is appropriate, they suggested that driving force of air flow in a semi-aerobic landfill is due to the temperature difference inside and outside of gas well. And it is proven by Yanase et al (2010), he measured the air flow rate in to a LCP during one year and realized that a large flow rate occurred in winter and there was no air flow in summer.

<u>Gas composition</u>

It can be seen that during period of time having the high temperature from 2010 to 2014 (Figure 4), even in winter the ground was covered by a thick snow layer, the oxygen concentration distribution with depths still remained in range of 7 to 15%. It means that oxygen intrusion through cover soil into waste mass is impossible. Therefore, the presence of oxygen inside the gas wells could be due to the connection of leachate collection pipe network and venting pipes. And buoyancy effect created the air flow moving from outside of landfill into the piping network. As analyzed above, the more the temperature difference is large, the more the intensity of air flow is strong. Therefore, aerobic biodegradation happened effectively.

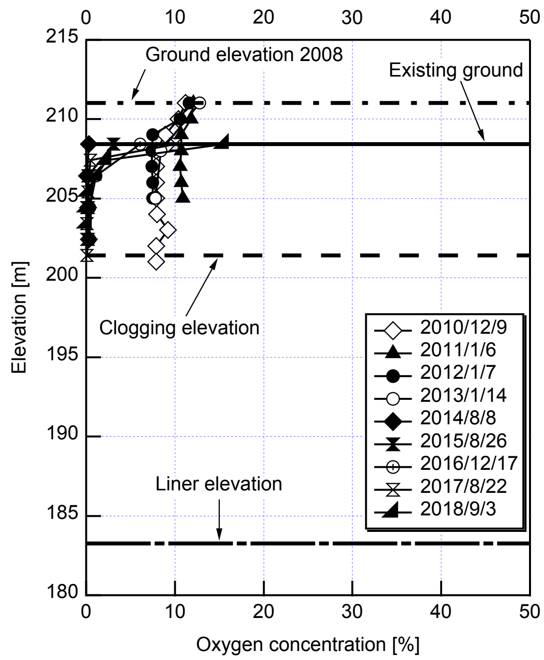

Figure 4 Oxygen concentration distribution of main gas well M2

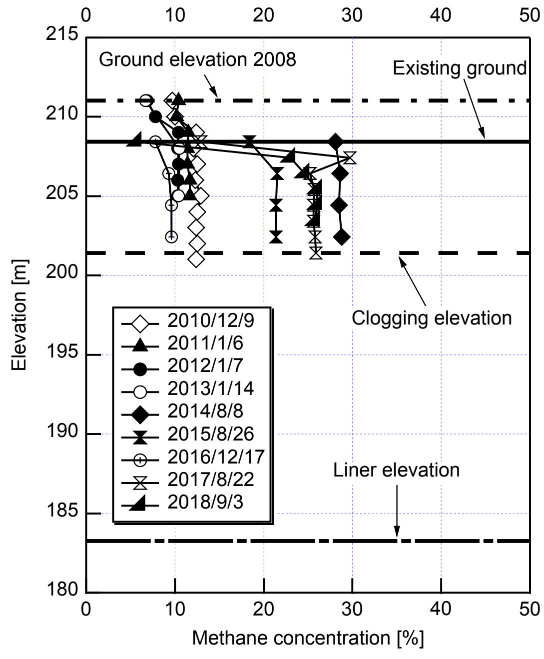

Figure 5 Methane gas concentration distribution of main gas well M2

Oxygen concentration distribution with depth was keep on declining year by year and reached the value less than 5% (even equals 0) from February 2015 to March 2018. This happened after detecting the clogging phenomenon inside the gas well. The decline of oxygen concentration proved that clogging phenomenon was the main reason influencing the performance of the gas well.

An example of variation of gas component for the gas well M2 is shown in Figure 5. It can be seen that methane gas concentration decreases gradually year by year from 15% in January 2010 to 2.8% in February 2014.

Together with the decrease of methane gas concentration, the temperature also decreases from over 55^{o}C in 2011 to 25^{o}C in February 2014. Clearly, during the period of time from 2010 to February 2014, the performance of this semi-aerobic landfill was effective. However, from August 2014, the sudden jump in methane gas concentration had reached nearly 30% from February for 6 months, after immediately detecting the clogging phenomenon. This result showed that the clogging phenomenon significantly governed the production of methane gas. It can be seen the irregular fluctuation of methane gas concentration from that time until now. And it can be realized that anaerobic condition became dominant due to oxygen was not adequately supplied. Because the prevention of oxygen intrusion from the LCPs, the amount of oxygen supplying from the top of venting pipe by diffusion was not enough for consumption of aerobic microorganisms. So far, there have been 26 of 53 gas wells clogged by sludge or waste or deformation of venting pipe. Therefore, if the clogging phenomena are not removed, the semi-aerobic landfill can become the anaerobic landfill.

CONCLUSIONS

The application of semi-aerobic landfill technology obtained much benefit (1) no requirement of mechanical equipment for operation, (2) high landfill temperature can be observed in the landfill. The maximum temperature is over 60^{o}C, (3) aerobic biodegradation happens effectively in semi-aerobic landfill, (4) reduction of emission of methane gas and accelerating the stabilization.

However, in practice, the venting pipes are usually clogged by waste or sludge due to the biodegradation of organic matter. Therefore, the performance of semi-aerobic landfill will be able to significantly decrease.

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NEUTRALIZATION OF HIGH PH LEACHATE ON POND OF OFFSHORE LANDFILL

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ABSTRACT
Many burnable waste is incinerated in Japan and over 70 % of landfill waste is incinerator residue. These residues contain alkali substance. There are some offshore (Sea area) landfill site in Japan. After closure, pH of leachate is higher than wastewater standard (pH9) at many offshore landfill site. On some offshore landfill, there is pond for reserving leachate. In this research, neutralization by atmospheric CO_2 on pond of offshore landfill. After experiment, we estimate pH reduction by CO_2 on pond.

Keywords: Alkali material rich leachate, Basic model of carbon dioxide neutralization

INTRODUCTION
Most of combustible waste is incinerated in Japan. At some area in Japan, incinerator residue recycling for cement raw material. At most areas, Over 70% of landfilled waste is incinerator residue (Ash). Ashes contain much Calcium compounds, thus leachate from MSW landfill is high pH at some case. There are many offshore (sea area) landfills in Japan. This type of landfill has a large volume leachate in that body and these leachate is almost high pH. Some landfill sites has problem of high pH leachate (pH10-12). In Japan, pH regulation of wastewater is 5.0-9.0 at discharging to the sea. Many leachate treatment plants continue pH adjustment (neutralization) for a long time.
Neutralization of high alkaline leachate by atmospheric CO_2 were tried at many our experiments by Miyawaki et.al (2013, 2015, 2016, 2018). Watanabe et. al (2013) showed that CO_2 flux was depend on pH of solution. Sakanakura et.al (2014) showed pH buffer mechanism on seawater.
In this report, part of results from lab scale tests of leachate neutralization on pond surface of offshore landfill were shown.

MATERIALS AND METHODS
Open water tank (pallet, 410x270x60mm) was used for simulate pond of offshore landfill. This tank size was 1/250 scale of real landfill pond (Volume 40,000m^3, depth about 6m). Simulate pond water was made by 1/4 concentration artificial sea water (MARINE ART SF-1). This solution of 2.65L was put in simulate pond. Artificial leachate were prepare 2 type (Artificial sea water and 1/4 conc. Artificial sea water, adjust pH11 by calcium hydro oxide.). Artificial leachate were put in simulate pond by pump for 9.5mL/day. Simulate pond water was sampling same volume every day. Measurement items were pH, EC, Alkalinity (pH8.3), Mg, Ca, K, Na. Also, no air contact condition was include. Experimental condition was showed at table 1 and experimental apparatus was showed at Figure 1 and Photo 1.

Table 1 Experimental conditions

No	Condition	Surface area (mm^2)	Sea water concentration of pond	Air contact
1	Standard (1/4 sea water)	110,700	1/4	Air
2	1/2 Surface area	53,200	1/4	Air
3	No air contact	110,700	1/4	None
4	Sea water	110,700	1	Air

Photo 1 Simulate pond apparatus

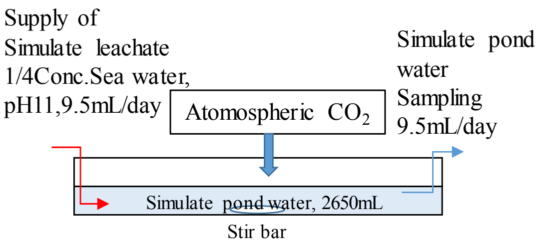

Figure 1 Simulate pond

RESULTS

Figure 2 shows pH variation of effluent by simulate pond at condition No.1,2 and 3. At standard condition (No.1, 1/4 seawater conc.), pH was not increased and showed steady value. At 1/2 surface area condition (No.2), pH variation was same as No.1. At no air contact condition (No.3, dilute only), pH value was increased. Figure 3 shows Electric conductivity (EC) variation. EC was not changed at all condition. Figure 4 shows Ca concentration variation. At standard (No.1) and 1/2 surface condition (No.2), Ca concentration were increased, because additional simulate leachate. Figure 5 shows pH variation of seawater concentration condition (No.4) with compering No.1. At this condition, pH was stayed around 8 and was not increased.

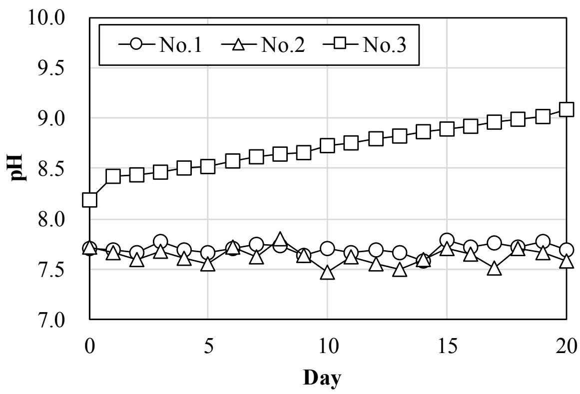

Figure 2 pH variation of simulate pond

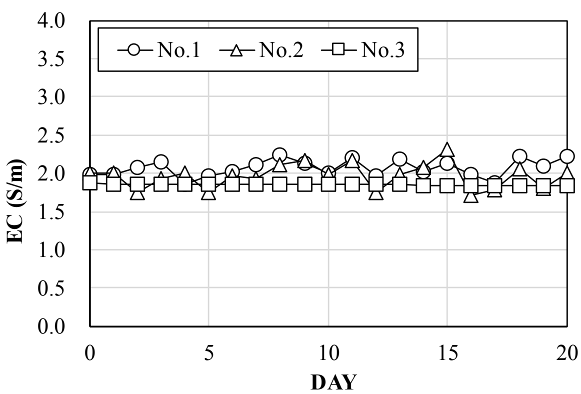

Figure 3 EC variation of simulate pond

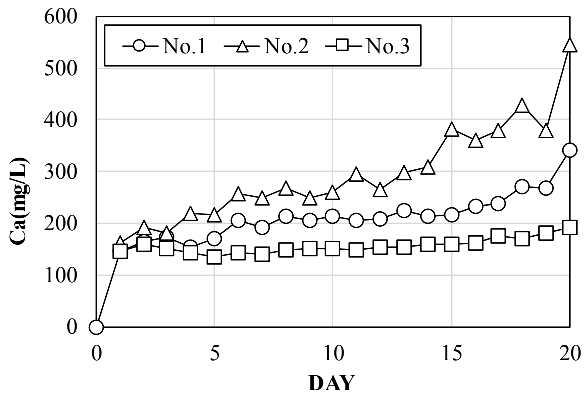

Figure 4 Ca concentration of simulate pond

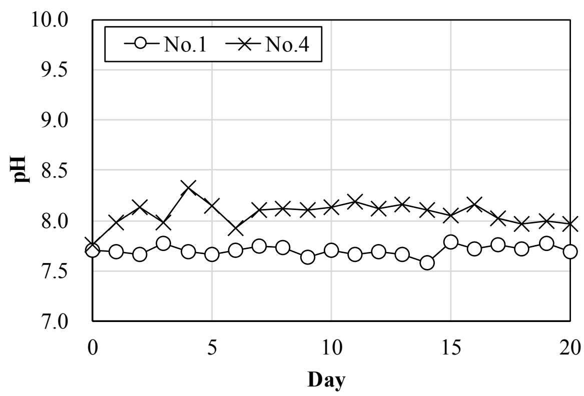

Figure 5 pH variation of seawater condition

DISCUSSION

At the condition of no neutralization by atmospheric CO_2 (No.3 No air contact condition), pH of simulate pond water was increased about 1 while 20 days inflow of artificial leachate. At the condition of neutralization by atmospheric CO_2 (No.1), pH of simulate pond water was not changed around 7.7 and there is a strong possibility that most of inlet alkali material was neutralized by CO_2 (a part of neutralized by buffer of seawater). CO_2 adsorption flux calculated by alkalinity of artificial leachate (0.69mmol/L) was $2.1x10^{-2}$ mol/m^2/min. This value is extremely smaller than data of watanabe (2013)'s experiment and it is certain that CO_2 neutralization was occurred. At small surface condition (No.2 1/2 area), calculated flux was double by standard condition (No.1) and same situation was thought. At seawater condition (No.4), pH was not increased and it was thought that the seawater influence was small.

SIMPLE NUMERICAL MODEL

Figure 6 shows simplified model. Pond pH was calculated by hydroxide ion of inlet leachate and CO2 adsorption flux. CO_2 flux was set for matching of pond pH value to experimental data. In this research, assumption pond parameters were volume 40,000m^3, surface area 6,000m^2 and depth 6.66m. Table 2 shows calculation parameters. Figure 7 shows calculated pH variation of pond. This model was not include buffer effect of seawater. At no CO_2 adsorption, pH value was increased to over 10. On this condition, CO_2 adsorption flux was set to 8.7x10^{-6} mol/m^2/min. This value was an order of magnitude lower than old experimental data. For this reason, there were allowance of CO_2 neutralization on pond surface.

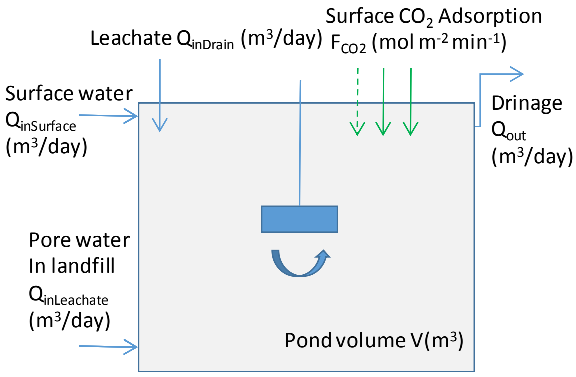

Figure 6 Conceptual diagram

Table 2 Condition and CO_2 Flux on simple model

Pond volume	V (m^3)	40000
Leachate	QinDrain (m^3/day)	150
Surface water	QinSurface (m^3/day)	0
Pore water	QinLeachate (m^3/day)	0
Drainage	Qout (m^3/day)	150
Leachate pH	-	11
Leachate OH$^-$	mol/L	0.001
Surface water pH	-	6
Surface water H$^+$	mol/L	0.0000
Pond initial pH	-	8
Pond initial OH$^-$	mol/L	0.0000
Pore water pH	-	11
Pore water OH$^-$	mol/L	0.001
Surface CO_2 Adsorption	F_{CO2}(mol m^{-2} min$^{-1)}$	8.7E-06
Depth of pond	m	6
Surface area of pond	A (m^2)	6000

CONCLUSIONS

Based on the experiments reported here, there is a good possibility that pond pH increase is prohibited by supply of atmospheric CO2 at pond surface. CO2 adsorption flux which stay pH neutral was smaller than former measurement data, it is probable that real pond pH is prohibited by atmospheric CO2. Simple numerical model showed same possibility. In near future, many case of experiment will do and simple model will improve.

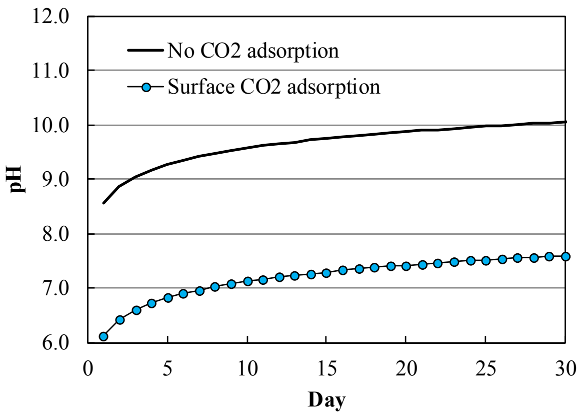

Figure 7 pH variation of pond (Simple model)

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STUDY ON TORREFACTION CHARACTERISTICS OF AGRICULTURAL RESIDUE FOR ENERGY UTILIZATION

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ABSTRACT

Agricultural residues such as rice straw, wheat straw and rice husk have been identified as sources of biomass energy that can contribute to a sustainable society. However, such residues involve many disadvantages due to their inherent characteristics: generation of residues only occurs in the autumn, and they have low bulk density, high moisture content, low grindability, and low heating value compared with wood. Recently, torrefaction has been applied as a pretreatment technique for biomass. Torrefaction is a pyrolysis process at temperature of 200-300°C in inert atmospheres. Torrefaction differs from carbonization that requires higher temperatures. Torrefied products retain a maximum of 90% of their original energy content, while losing a maximum of 30% of their original mass due to a partial loss of the volatile matter and moisture contained in biomass. The torrefaction process can overcome the above disadvantages. This study investigated torrefaction characteristics for some agricultural residues, namely rice straw, rice husk, corn stalk, corn crotch and watermelon stalk. In terms of lower heating value (LHV) and ash content, corn leaves and rice straw gave favorable results, whereas rice husk and watermelon stalks had high ash content and low LHV. The relationships between reduction of volatile matter and grindability were also investigated, and a preferred torrefaction temperature was determined for each of the agricultural residues sampled in this study.

Keywords: agricultural residue, biofuel, torrefaction, fundamental characteristics

INTRODUCTION

Co-combustion of coal and woody biomass at power plants is widely used to reduce greenhouse gas emissions and save fossil fuel. Especially in Japan, the number of large-sized woody biomass power plants has increased since the introduction of a law for a feed-in tariff. However, the available woody biomass may become a limited resource in the future. Agricultural residue, such as rice straw and rice husk, is abundant in Japan. The amount of agricultural residue generation is

13 million tons/year, most of which is not used effectively. The town of Nanporo town, Hokkaido was the first to produce rice straw pellets commercially for a biomass boiler at a public bath and for pellet stoves in the home. In the future, such utilization of local resources for local use will become more important.

In general, a biomass fuel supply chain –that is, the collection and storage of biomass, production of biofuel, and delivery of the biofuel to customers- involves many problems because agricultural residue is spread over large areas, has low density, generates only for a short period just after harvesting. In addition, in many cases, it is difficult to secure sufficient volume of agricultural residue for biofuel. Small amounts of agricultural residue have no scale merit commercially.

The problems in the biomass fuel supply chain, especially using agricultural residue such as rice straw, can be summarized as follows: (1) high costs for transportation and storage due to low bulk density: (2) high water content means that a drying process is needed before the production of biofuel: (3) a large amount of energy is required for shredding due to poor grindability: (4) the resulting low heating value (LHV) is not competitive compared with other biomass fuels such as wood chips and wood pellets: (5) to secure sufficient volumes of agricultural residue, many kinds of agricultural residue with a variety of characteristics need to be converted to biofuel, which results in nonuniform biofuels.

To solve these problems in the supply chain simultaneously, here we introduce the torrefaction process, which is a thermal treatment process in an inert atmosphere and in the low temperature range of 200 - 300°C (van der Stelt et al., 2011). The torrefied product retains a maximum of 90% of its original energy content, while losing a maximum of 30% of its original mass, which is due to a partial loss of the volatile matter and moisture contained in the biomass (Acharya et al., 2015). Thus, torrefaction increases the heating value of agricultural residue based on the weight, and decreases the water content. This process also partially decomposes the hemicellulose in the biomass fiber (Koppejan et al., 2012). As a result, much less energy is required to grind the torrefied biomass (Bridgeman et al., 2008; van der Stelt et al., 2011): thereby the grindability is improved and the bulk density is increased. In addition, the partial loss of the volatile matter renders the various kinds of agricultural residue more homogeneous for use in biofuels.

We investigated torrefaction characteristics for different types of agricultural residue, namely rice straw and rice husk, corn leaf and corn crotch, and watermelon stalk.

MATERIALS AND METHODS

Agricultural residue

Table 1 shows the planting area in Nanporo. This study selected available agricultural residue, including rice straw and rice husk, corn leaf and corn crotch (Figure 1) and watermelon stalk. The share of rice harvesting, corn, and watermelon in Hokkaido is 7.4%, 31.9%, and 3.9%, respectively.

Rice straw and rice husk were sampled and stored at a room temperature of 25°C. Corn leaf and crotch and watermelon stalk were sampled and stored in a refrigerator at a temperature of 4°C. The contents of ash, volatile matter, and water were measured for each residue just after sampling.

Table 1 Planting area in Nanporo town (FY 2016)

Crop	Planting area (ha)
Rice	2,222
Wheat (Autumn)	1,591
Wheat (Spring)	80
Soybean	487
Beet	101
Adsuki bean	67
Long onion	57
Corn	44
Cabbage	42
Broccoli	36
Pumpkin	13
Onion	18
Water melon	6
Others	199

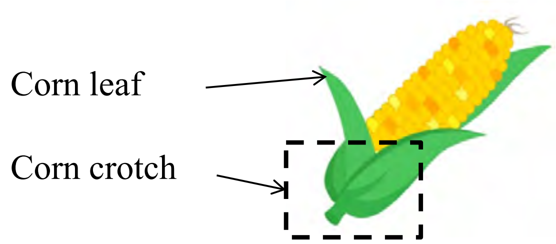

Figure 1 Leaf and crotch of corn

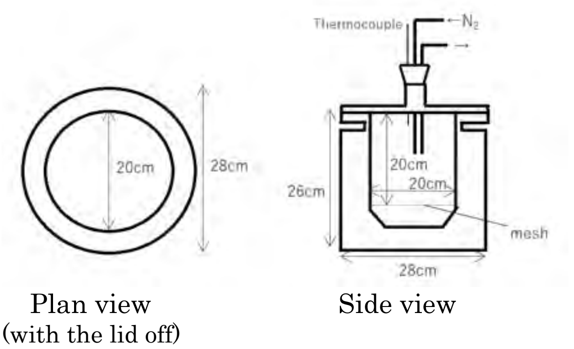

Figure 2 Plan view and side view of reactor

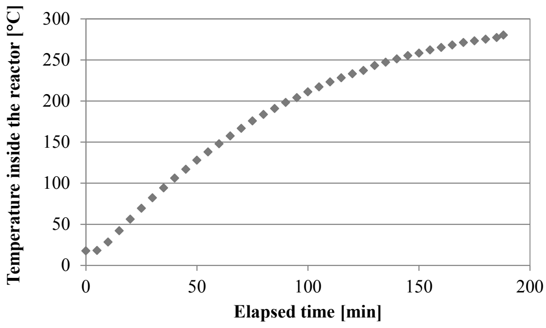

Figure 3 Change in the temperature inside of the reactor (the torrefaction temperature was 280°C)

Torrefaction methods

The rice straw was torrefied in a stainless-steel reactor placed in an electric drying oven. The plan view and side view of the reactor are shown in Figure 2. The raw rice straw was put in the reactor, which was then sealed and placed into the electric drying oven. The reactor was heated to the designated temperature (190-280°C) in a non-oxygen environment obtained from passing nitrogen gas through the reactor. As shown in Figure 3, the temperature inside the reactor was increased by 1°C /min up to 40°C, and by 2°C /min up to 200°C. As the temperature increased further, the temperature rises gradually became slower. After the temperature reached the designated temperature ('the torrefaction temperature'), the temperature was maintained for a designated holding time (0 or 60 min). The reactor was then cooled down naturally to room temperature. The torrefied rice straw was weighed and shredded by continuous mill (IKA MF10 basic). The shredded rice straw was discharged through a 3 mm mesh.

Analysis

Table 2 shows items for analysis before and after torrefaction in this study.

Table 2 Items for analysis

Analysis	Before torrefaction	After torrefaction
Proximate analysis	X	X
Lower heating value	X	X
Energy yield		X
Thermogravimetric analysis	X	
Particle distribution	X	X

In a proximate analysis to determine the water, volatile matter, and ash contents, the samples were dried in an oven at 105 ± 2 °C to a constant weight to determine the water content. The volatile matter was measured by loss on ignition at 600°C, and the remainder was considered as the ash content.

Duplicate samples were milled to determine the heating value by using a bomb calorimeter (IKA C7000), in accordance with Japanese Industrial Standards M 8814 (1993). The LHV was calculated using the moisture content and the hydrogen content.

Torrefaction increases the heating value per weight of agricultural residue. However, the total energy is lost because volatile matter is thermally decomposed. To evaluate the energy loss during torrefaction, the energy yield was calculated from Eq. (1) (Chen et al., 2015).

Energy yield = (LHV for torrefied rice straw × weight of torrefied rice straw) / (LHV for dried rice straw × weight of dried rice straw) (1)

In the thermogravimetric analysis, dried and shredded rice straw was heated to 300°C with a simultaneous thermogravimetric analyzer (HITACHI, STA7300), and the thermal weight and differential heat were measured twice. The heating program was then set to produce the same temperature rise for this experiment, as shown in Figure 3.

The particle size distribution was measured to evaluate the grindability of torrefied samples, by using seven types of test sieves, with mesh sizes of 0.075, 0.125, 0.25, 0.5, 1.0, 2.0 and 5.6 mm, respectively.

RESULTS AND DISCUSSION

Contents of water, volatile matter and ash

Figures 4-7 show the contents of water, volatile matter, and ash before and after torrefaction at temperatures of 190, 220, 250, and 280°C, and for holding time of 0 or 60 min for rice straw, rice husk, watermelon stalk, and corn leaf, respectively.

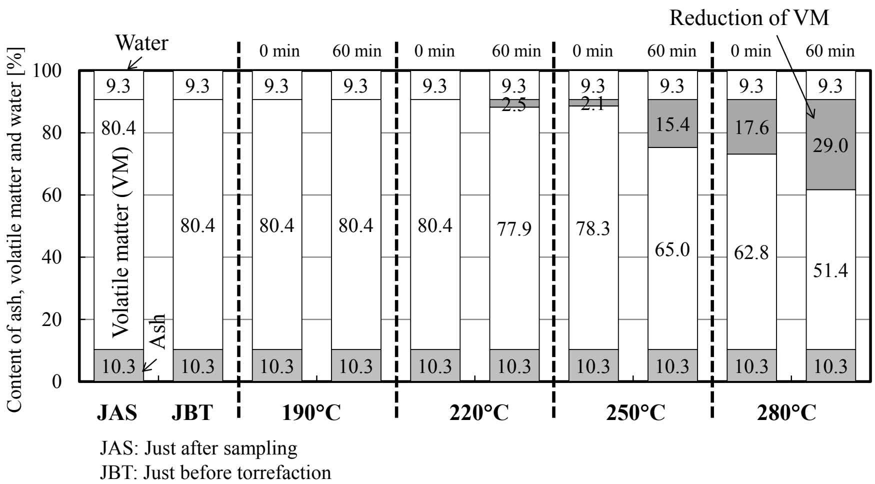

Figure 4 Contents of water, volatile matter, and ash before and after torrefaction for rice straw

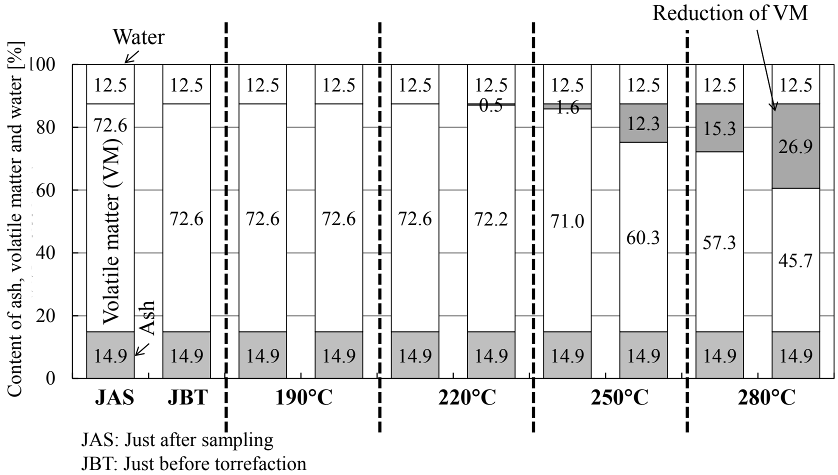

Figure 5 Contents of water, volatile matter, and ash before and after torrefaction for rice husk

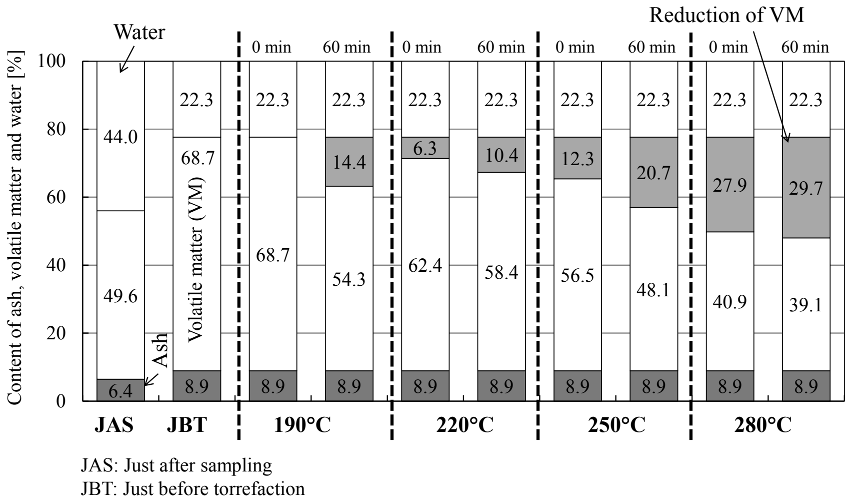

Figure 6 Contents of water, volatile matter, and ash before and after torrefaction for watermelon stalk

Higher torrefaction temperatures and/or higher holding times reduced the amount of volatile matter from the raw samples.

Lower heating value and ash content

In general, biofuel with a high heating value and low ash content is preferred. Figure 8 shows the LHV and ash content. For example, in the case of rice straw, high torrefaction temperatures increased the LHV form about 15 MJ/kg for the dried condition to over 20 MJ/kg at a torrefaction temperature of 280°C. Since the volatile matter was reduced, the ash content increased from about 11% for the dried condition to about 16% at a torrefaction temperature of 280°C. The ash content in rice husk and watermelon stalk was higher for all torrefaction temperatures compared with the other agricultural residues. For corn leaf and crotch, the LHV was relatively higher and the ash content was lower than those for the other agricultural residues. The order of preference of agricultural residue as biofuel is thus

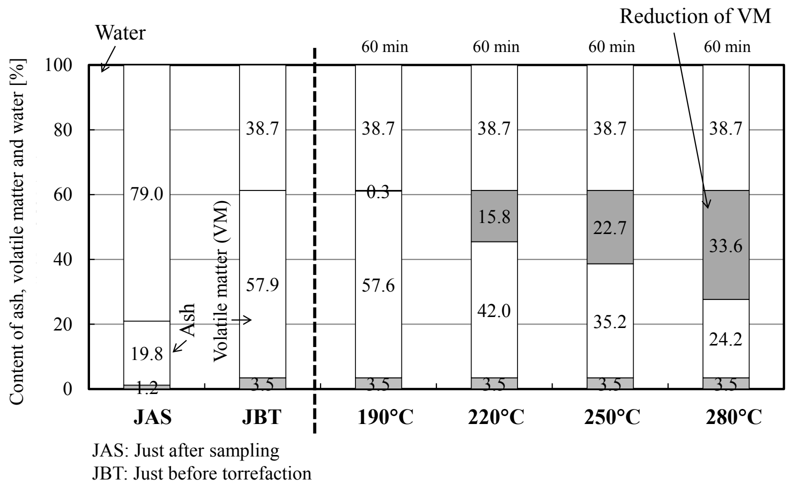

Figure 7 Contents of water, volatile matter, and ash before and after torrefaction for corn leaf

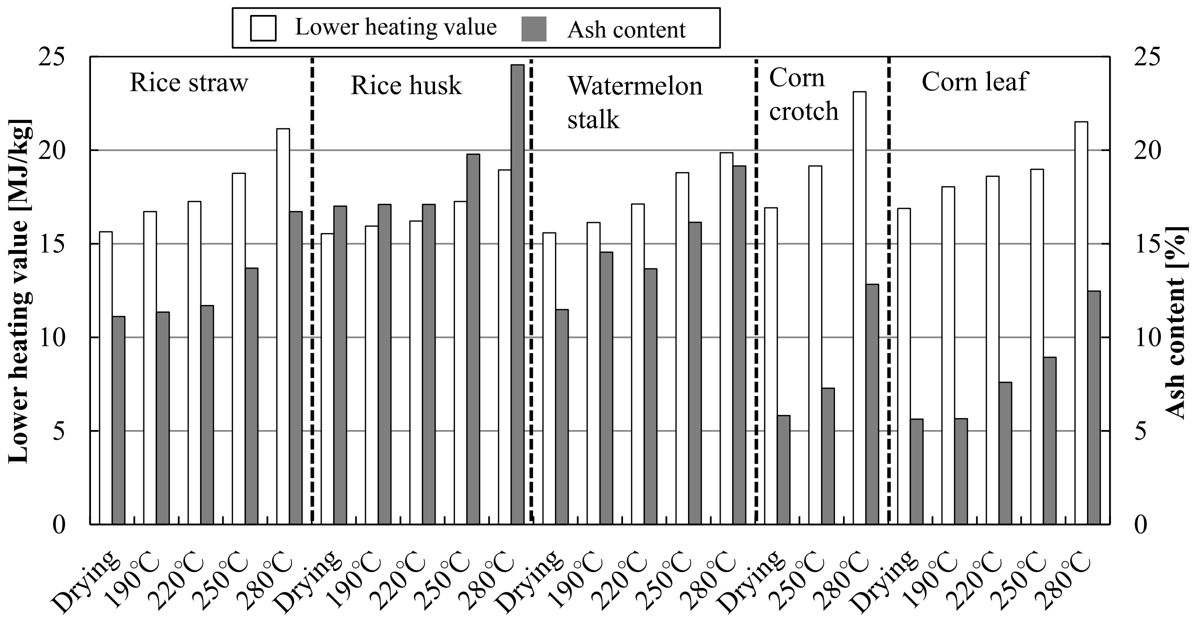

Figure 8 Lower heating value and ash content for each agricultural residue

corn crotch, corn leaf, rice straw, watermelon stalk, and rice husk.

Particle size distribution

Figure 9 shows the particle size distribution for rice straw as the index of grindability. The high torrefaction temperature decreased the particle size, meaning the grindability was improved by torrefaction. Based on a 50% passing ratio (D50), the value of D50 decreased up to the torrefaction temperature of 250°C. Beyond 250°C, the value of D50 did not change significantly. In this case, the preferred torrefaction temperature range

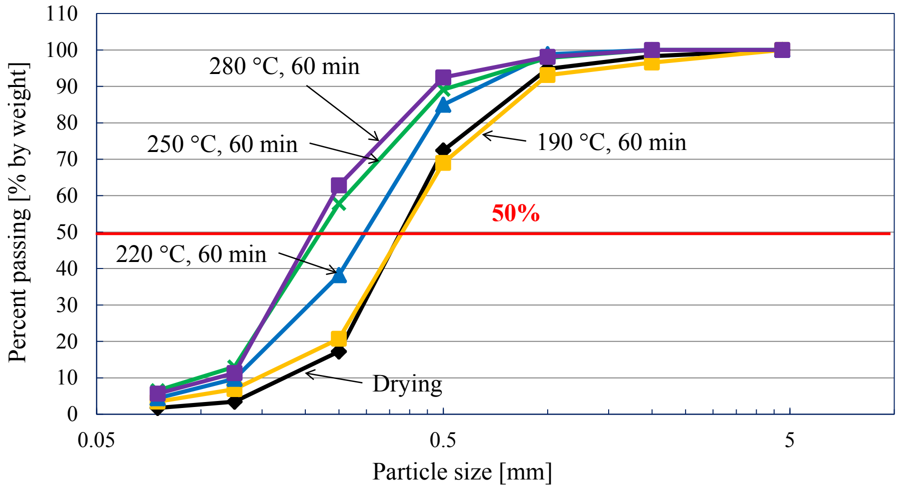

Figure 9 Percentage passing for rice straw

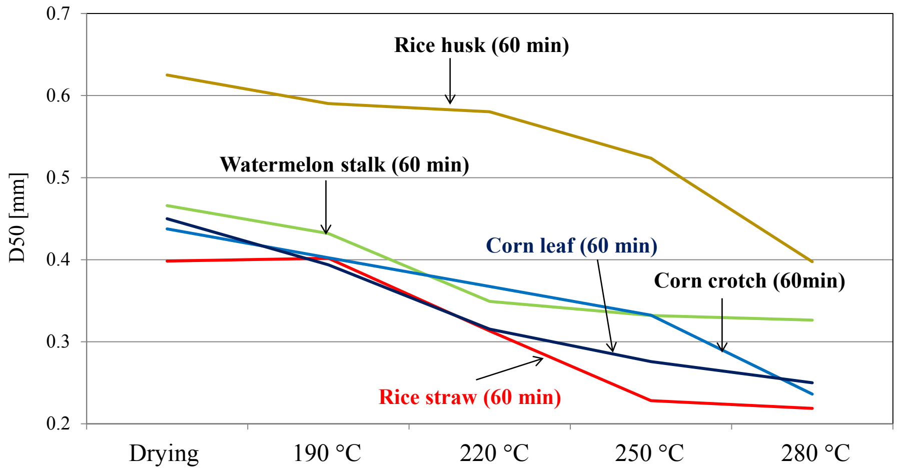

Figure 10 Value of D50

was 220-250°C. Similarly, the preferred torrefaction temperatures for particle size distribution were 250-280°C for rice husk, 190-280°C for corn leaf, 280°C for corn crotch, and 220°C for watermelon stalk (Figure 10).

Energy yield

Figure 11 shows the energy yield. In the case of rice straw, even with the torrefaction temperature at 280°C, 90% of energy was retained. However, the energy potential of corn leaf and crotch was lost significantly by torrefaction.

Considering both energy yield and grindability, the preferred torrefaction temperatures in rice straw, rice husk, corn leaf, corn crotch and watermelon stalk were 220, 250, 190, 280, and 220°C, respectively.

CONCLUSION

This study established that, with regard to LHV and ash content, corn leaf and rice straw gave favorable results,

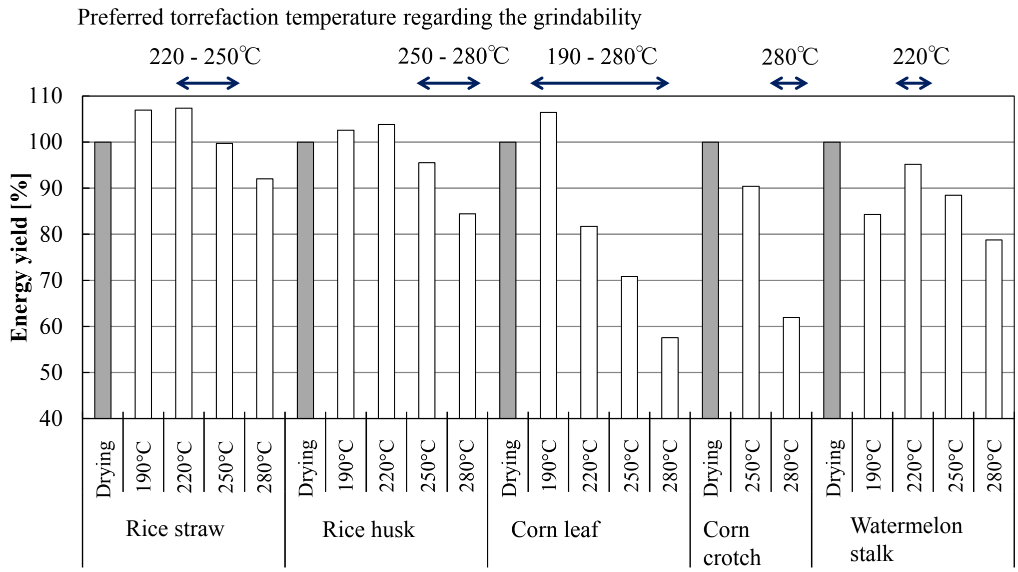

Figure 11 Energy yield and preferred torrefaction temperature regarding grindability

whereas rice husk and watermelon stalk had high ash content and low LHV. In addition, the relationships between the energy yield and the grindability of the residues indicated that a preferred torrefaction temperature can be determined for each agricultural residue.

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We greatly appreciate those responsible in Nanporo for assisting us with sampling the agricultural residues for experiments.

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CHARACTERISTICS OF ENVIRONMENTAL LOAD ON DIESEL ENGINE USING MIXTURE OF GREASE TRAP OIL AND FOSSIL FUEL

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ABSTRACT

Effective utilization of waste bio-oil such as fried oil is important for development of low emission engine. Grease removed from almost restaurant sewage is one of the waste bio-oil. However, that is too dirty and highly viscous for direct application to internal combustion engines. In this work, properties of diesel combustion using mixture of A-type fuel oil (AFO) and trapped grease oil (TGO) were discussed although simply filtration of TGO was carried out. Moreover, environmental burden applying mixture of heavy oil and TGO to commercial diesel generation was investigated.

Fuel supply of the mixture slightly increased with increase in TGO composition. NOx and SOx emission decreased with increase in the composition of TGO. On the contrary, concentration of CO in exhaust gas also decreased. The properties of NOx emission give an indication of reduction in temperature with increase in the composition of TGO but that of CO emission shows improvement of combustion state. On the other hand, the properties of SOx emission were lower than estimation values calculated from sulfur contents of these fuels.

Keywords: Biofuel, Trapped Grease Oil, Diesel Combustion, Environmental Load

INTRODUCTION

In order to reduce 26% CO_2 emissions in Japan until 2030 compared to 2013, nuclear and renewable energy needs to cover around 40% of the primary energy supply due to preliminary calculation by the Ministry of Economy, Trade and Industry. Based on statistical data for energy production and consumption at 2016, renewable energy including hydro-energy has accounted for approximately 10 % of primary energy supply. Due to whether sustaining nuclear power, however, it will be faced with the need of further expansion of renewable energy supply. Biomass is one of these renewable energies and numerous studies have been made on various biomass utilization regardless of its source and type. The art of biomass combustion power generation using wood and/or agricultural waste has practically been introduced for more than 20 years. It has been reported that almost of the power generation efficiencies are close to or above 30% based on lower heating value. (Broek et al., 1996; Evans et al., 2010) Biogas production for power generation and CHP processes due to biochemical technology such as anaerobic digestion has also been placed into commercial use. (Kato et al., 2015) Bioethanol has a long history and the mass production is accelerating since the oil shocks of 1970s. (Wyman ed., 1996) Almost of that is used to automobile and motorcycle as a part of the blend fuel, especially in U.S.A. and Brazil. In recent years, bioethanol production technology has been actively developed from lignocellulose such as rice husk and straw, which do not depend on edible crops. (Limayem and Ricke, 2012) Biodiesel fuel such as fatty acid methyl ester made from vegetable oils and animal fats has been positively used to diesel vehicles in Europe. (Bozbas, 2008) However, the market of diesel vehicle tends to shrink due to shift to electric vehicles and illegal problems for diesel emissions.

In this study, we focus on trapped grease oil (TGO), which is either oil or sludge-like grease and separated from sewage in septic tank. (Kobayashi et al., 2014) TGO has the same heating value as vegetable oils and animal fats. However, the component of TGO is complex, and purification and some chemical treatments such as ester exchange reaction are necessary to apply to vehicle fuel. Moreover, the combustion properties of TGO need to be clarified since it is concerned that the utilization bring other environmental burden.

In view of these points, direct utilization of TGO to diesel power generator without chemical treatment was proposed and behaviors of diesel combustion and emission of pollutants were investigated. Taking into account for practical use, availability of TGO and petroleum fuel mixture was discussed because of high viscosity of TGO.

EXPERIMENTAL

Experimental apparatus

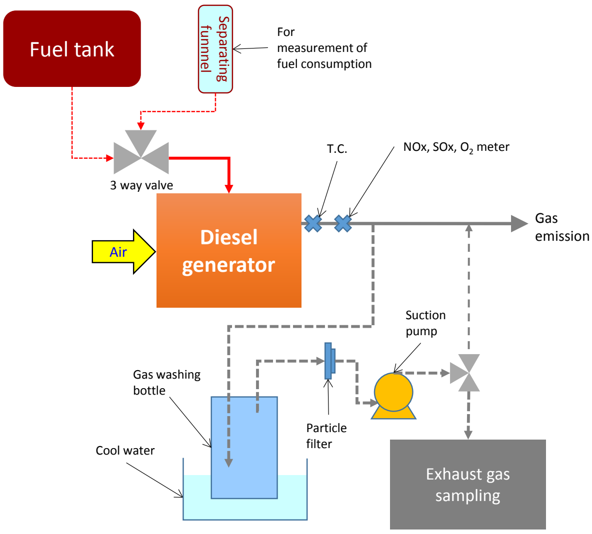

Fig. 1 Schematic diagram of experimental apparatus

A schematic diagram of the experimental equipment used in this study is shown in Fig. 1. This experimental apparatus has a structure in which a fuel supply system of a commercially available compact diesel generator is improved and a gas sampling line for exhaust gas analysis is additionally installed. The specifications and structures of the engine have not been changed, and it has been used in the same state as the commercial use. Fuel supply is branched so that it can be performed not only from the normal fuel tank but also from the separating funnel. When the amount of fuel consumption was measured, fuel was supplied from a separating funnel and fuel consumption per unit time was calculated based on the weight difference.

The basic specifications of the engine and the generator are as shown in Table 1. The engine used in the experiment is a high speed diesel (Sabathe cycle), and DPF for particulate matter removal is not installed.

Table 1 Characteristic of the diesel engine

Engine type	4 stroke diesel
Fuel feeding system	Direct injection
Rotational speed	3000 rpm
Bore×stroke	φ70×57 mm
Displacement	219 cc
Frequency	50 Hz
Electrical voltage	100 V
Max. current	30 A

Experimental materials

Although gas oil is designated as fuel of this engine, AFO of low sulfur composition, which has similar combustion characteristics to gas oil, was used to the experiments as main fuel. Here, TGO using in this study is filtrate after separating solid contents in trapped grease (Kobayashi et al., 2014). The physical properties and a part of elementary compositions are as shown in Table 2. Although the high heating value (HHV) of TGO is about 10% lower than that of AFO, it is found that the amount of sulfur and nitrogen in TGO is extremely small.

Table 2 Characteristics of AFO and TGO

	AFO	TGO
Density [kg/m^3]	860	897.7
HHV [MJ/kg]	45.4	40.2
Sulfur composition [ppm]	< 5000*	51*
Chlorine composition [ppm]	< 500**	39*
Nitrogen composition [ppm]	< 200*	110*

*) Actual measurement value
**) Specification of AFO based on Japan Industrial Standard

Moreover, oleic acid (Kanto Chemical Co.,Inc.; Extra pure) was applied to one of the raw materials of the mixed fuel to compare with TGO.

Experimental procedure

Taking account into solid-liquid equilibrium and high viscosity of TGO, these mixed fuels are prepared at 303 K or more. It was found that high temperature condition more than 330 K was needed to use tristearin and stearic acid (Yui et al., 2017). However, there was almost no immiscible solid phase in TGO more than 300 K. The composition of TGO is determined from 0 to 50 % in weight fraction. These mixed fuels were homogeneous independent on the composition, but it was observed that solid phase precipitated in the mixtures under room temperature. Therefore, temperature of the fuel in the tank or the separation funnel must be kept around 300 K during these experiments.

When temperature of the exhaust gas was almost constant after running the engine, the gas passing through a gas washing bottle and a particle filter was collected. After that, the amount of fuel consumption was measured by means of above mentioned. In order to evaluate under the different engine power conditions, it is necessary to change power generation load using electric heaters, which are commercial one. In that case, these analysis and measurements were performed under steady state in each experimental condition.

TCD gas chromatography (Shimazu, GC2014) was used to analysis of H_2, CO, CO_2 and CH_4 composition in exhaust and detection tubes were applied to measurement of NOx and SOx concentration. Moreover, oxygen detector (testo 327-2) was used to measurement of oxygen concentration.

It has been decided that concentration of TGO in

AFO was varied from 0 to 50 wt% and power generator load was either 0 or 1600 W. The effect of the concentration and the load on exhaust gas composition was discussed in this work.

RESULTS AND DISCUSSION

Fuel consumption

Fig. 2 shows the results summarizing the influence of the TGO composition in the mixed fuel on the fuel supply amount based on these heating values. The value on the vertical axis is obtained by multiplying the average fuel consumption per unit time by the average heating value of the mixed fuel. The average heating value was calculated based on each heating value in Table 2 and composition ratio.

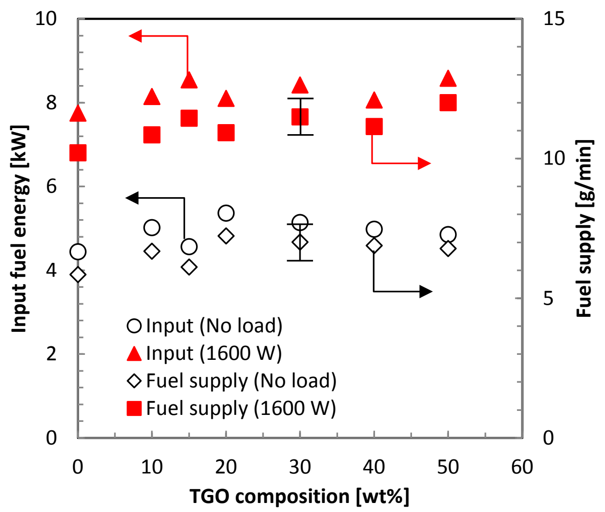

Fig. 2 Effect of TGO concentration on input energy and fuel supply

Fuel supply system of the diesel engine was not improved but standard specification. Therefore, it was predicted that the amount of input energy would be almost independent on the heating value of the mixed fuel and the mass of fuel consumption would slightly increase with increase in TGO composition. As shown in Fig. 2, in fact, the experimental results approximately agreed with the predict values. Moreover, behavior of the engine did not become unstable even if the concentration of TGO increased up to 50 %. From these results, it was found that application of the mixed fuel within 50 % of TGO composition to the diesel power generator was possible.

Combustion behavior

CO and CO_2 concentrations in the exhaust gases using TGO are shown in Figs. 4 and 5, respectively.

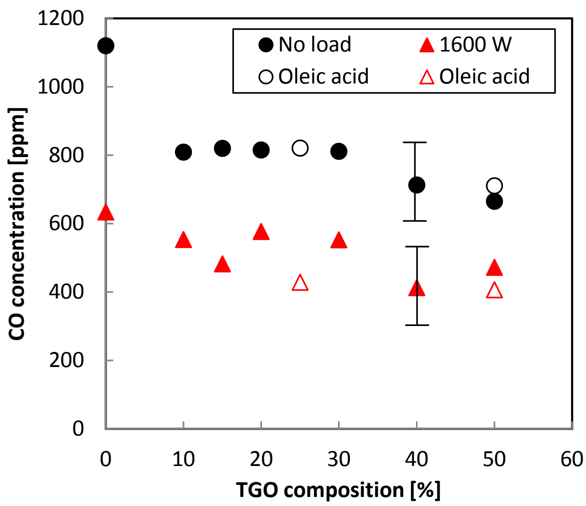

Fig. 3 CO concentration in exhaust gas

From Fig. 2, it was confirmed that the CO concentration in exhaust gas was roughly reduced with increase in TGO composition. Comparing idling conditions with generation operations, the CO concentration with power generation load was lower than that without load. On the other hand, it was found that the influence of TGO composition on CO_2 concentration almost agrees with the behavior of fuel supply, i.e. the concentration slightly increased with increase in TGO composition, as shown in Fig. 4.

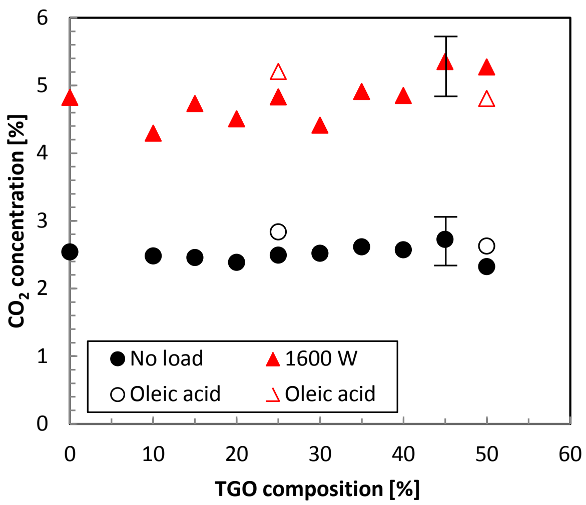

Fig. 4 CO_2 concentration in exhaust gas

Because the amount of fuel supply increased with increase in TGO composition and generated power, it is thought that the concentration of CO_2 also become high. On the other hand, increase in fuel supply certainly leads to high temperature combustion because air ratio in these experiments is more than 2 even high energy consumption condition such as power generation operation. Much higher temperature condition causes thermal dissociation of CO_2, but it is thought that unburnt combustible contents reduce due to improvement of combustion state in this case. In fact, smoke and/or soot was always included in the exhaust gas in spite of fuel lean combustion. Moreover, these fuels containing oxygen, which mainly consists of fatty acid triglycerides, further improved the combustion state and promoted the conversion of CO to CO_2. From these results, it was clarified that the combustion state in the engine was improved using mixture of TGO and AFO.

NOx and SOx emission property

The influence of TGO composition on NOx and SOx emission properties are shown in Figs. 5 and 6, respectively. Here, NOx and SOx concentrations were converted into these at 13% oxygen since oxygen concentration in the exhaust gas varied depending on the presence or absence of the power generation load.

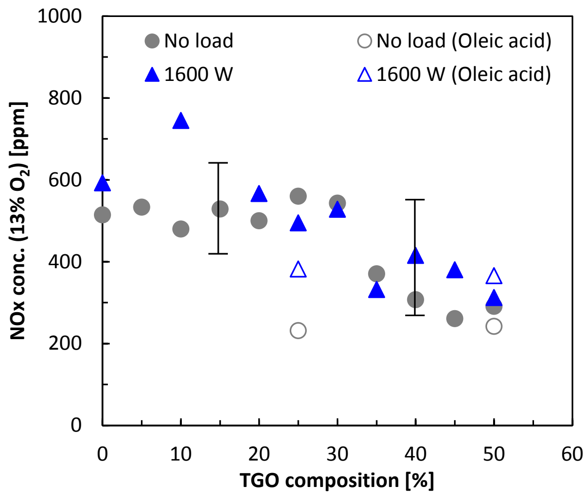

Fig. 5 NOx emission property under various TGO compositions

As shown in Fig. 5, NOx concentration with generation load was almost similar to that without the load. The concentration approximately decreased with increase in TGO composition while the values vary widely. Furthermore, it seems that the NOx concentration is almost constant up to 30% of TGO composition and then gradually decreases over 30% of that. Although reduction of CO concentration leads to increase of combustion temperature, increase of NOx concentration with decrease in CO concentration was not confirmed in this study. Moreover, it was reported that the NOx concentration in exhaust gas increased using fatty acid methyl ester. (Ozsezen and Kanakci, 2011) On the other hand, it was said that the NOx concentration was reduced using directly vegetable oils (Morimune et al., 2000). In this study, the behavior of NOx emission is similar to the latter trend since TGO mainly consists of fatty acid triglyceride.

On the other hand, SOx concentration was lower than that of estimation calculated from the fuel supply and the sulfur composition from Fig. 6. The effect of TGO composition on SOx emission is inexplicit but it seems that SOx concentration is reduced using the mixed fuel. Since the exhaust gases included smoke and soot, sulfur components was probably emitted along them.

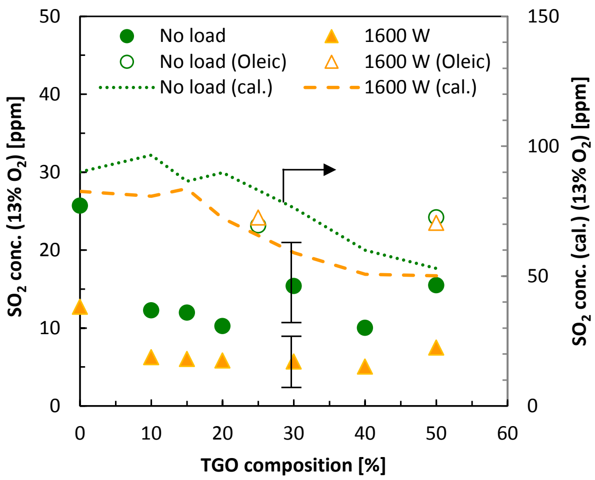

Fig. 6 SO_2 emission property under various TGO compositions

CONCLUSIONS

Using the small diesel power generator, combustion behavior of TGO and AFO mixture was investigated. As a consequence, the following matters were revealed.

1) Input of energy to the diesel engine was almost constant although a negligible amount of fuel supply increased with increase in TGO composition. Moreover, behavior of the engine did not become unstable even if the concentration of TGO increased up to 50 %.

2) CO_2 concentration in exhaust gases slightly increased with increase in TGO composition and the tendency almost agrees with the behavior of fuel supply. On the other hand, CO concentration roughly decreased with increase in TGO composition.

3) NOx concentration with generation load was almost similar to that without the load. The concentration approximately decreased with increase in TGO composition. On the other hand, SOx concentration was lower than that of estimation calculated from the fuel supply and the sulfur composition.

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SEPARATION, COLLECTION AND UTILIZATION OF RECYCLABLE SUBSTANCES CONTAINED IN A BY-PRODUCT OF CRUDE GLYCEROL LEFT AFTER MANUFACTURING BIODIESEL FUEL

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ABSTRACT

Crude glycerol, a by-product resulted from biodiesel fuel, BDF, manufacturing, was treated by neutralization with hydrochloric acid and dilution with water in order to separate hydrophilic glycerol and hydrophobic oil layers and then each layer was collected, respectively. As the top layer was a separated oil containing less amount of water and salts, it was used as a raw material of fuel. On the other hand, as the bottom layer was a glycerol solution containing plenty amount of organic substances and water-soluble neutral salts, it was used as a denitrification reagent in a biological denitrification treatment process. According to the investigations, the higher heating value, HHV, of the separated oil was about 1.5 times higher than that of the crude glycerol and was equivalent to 97% of fresh vegetable oil. Meanwhile, as the glycerol solution was satisfied with both of the denitrification property and the biodegradability as compared with commercially available 50% methanol, it was used as an alternative denitrification reagent in an excreta treatment facility. Through this treatment the crude glycerol was totally recycled as a raw material for a burnable oil and a denitrification reagent of an excreta treatment facility without discharging any by-product.

Keywords: Biodiesel fuel (BDF), Biological denitrification treatment, Crude glycerol, Denitrification reagent, Excreta treatment

INTRODUCTION

Biodiesel fuel, BDF, a renewable fuel made from waste or fresh vegetable oil, is an alternative fuel of the light oil for diesel engines. The BDF has received a lot of attention in recent years as one of the usages of used cooking oil in Japan. A typical manufacturing process of the BDF by wet method is shown in Fig 1. This process is consisted of methyl-esterification and purification. The reactor of generates the BDF, a fatty acid methyl ester, FAME, from the mixture of wasted vegetable oil and methanol by the reaction of alkali catalyzed methyl esterification under gently agitating and mildly heating conditions. After the reaction has completed, the product is kept under standing still for hours to form layers of crude BDF and crude glycerol. Here, the crude BDF is collected and the crude glycerol is separated and discarded as industrial waste. The crude BDF is then introduced into the purifier to remove impurities for obtaining purified BDF. In this treatment process the crude BDF is rinsed with hot water several times. Here, the rinsing water, needed to treat as industrial waste, is discharged. In order to fulfill the BDF manufacturing soundly, appropriate treatments of the crude glycerol and the rinsing water are crucial issues.

There has been considerable research on the recycling of the crude glycerol by microbial conversion and chemical conversion (Aggelis G., 2009, Pagliaro M, Rossi M.,2010). Many of the research were tried to recycle it directly as a raw material, however, it contains a lot of contaminants that makes it hard to recycle.

This article deals with a recycling of crude glycerol discharged from BDF manufacturing and provides a solution for recovering recyclable substances from the crude glycerol and finding their promising usages (Takeshita et al., 2016).

OBJECTIVES

The objective of this research is to recover glycerol and oil separately from the crude glycerol of BDF by-product and to investigate the possibility for using the recovered glycerol and oil for denitrification and fuel, respectively.

MATERIALS AND METHODS

A simple treatment of dilution with water and neutralization with hydrochloric acid, HCl, was taken place in order to separate the crude glycerol into the two liquid layers according to the chemical properties as shown in Fig. 2. The dilution rate of the crude glycerol to water was 1 to 1 in volumetric scale and the pH was adjusted to 6 by adding 35% HCl.

RESULTS AND DISCUSSION

Collection of recyclables from crude glycerol

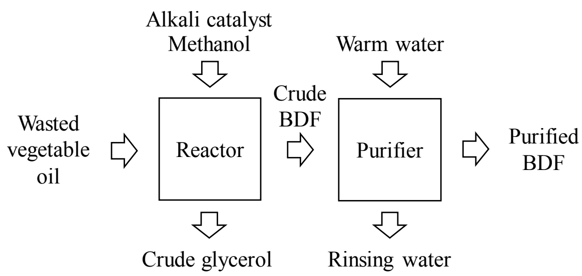

Figure 1 Schematic diagram of a BDF manufacturing using a wet process and discharging consequent by-products

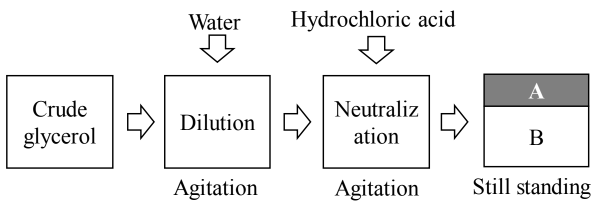

Figure 2 Schematic diagram of the treatment process recovering recyclable materials from the crude glycerol of BDF manufacturing by-product. The top layer A was a separated oil and the bottom layer B was a glycerol solution,

Recyclables were separated from the crude glycerol by the treatment process as shown in Fig. 2. The two layers were appeared as shown in the Photograph. The top layer A was the separated oil containing less

Photograph The top layer was the separated oil and the bottom layer was the glycerol solution appeared in a bottle

amount of water and salts, while the bottom layer B was a glycerol solution containing plenty amount of glycerol, methanol and neutral salts in water. Through this treatment about 30% of the separated oil and 70% of the glycerol solution were obtained in volumetric scale. Each liquid layer was then collected, respectively.

Property of the glycerol solution

According to the investigations, as the obtained glycerol solution contained a high amount of biodegradable organic substances (TOC; 130,000

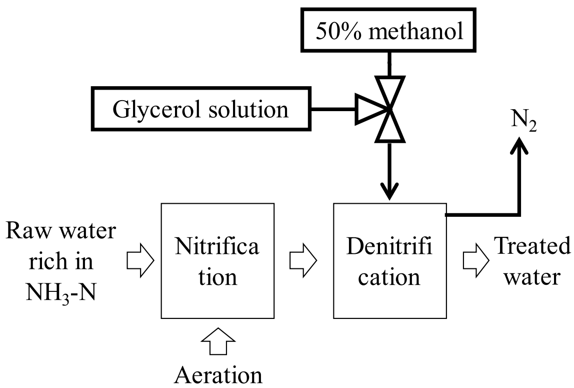

Figure 3 A biological denitrification treatment process using an alternative denitrification reagent of the glycerol solution instead of commercially used 50% methanol

mg/L) as compared to little amount of the total nitrogen (T-N; 19 mg/L), it was used in the biological denitrification process of an excreta treatment facility as an alternative denitrification reagent instead of 50% methanol as shown in Fig. 3. Denitrification

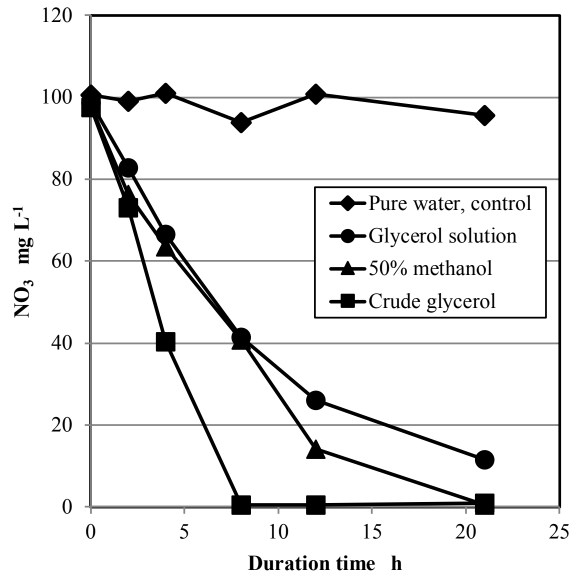

Figure 4 Denitrification efficiency evaluated on different denitrification reagents using activated sludge obtained from an excreta treatment facility

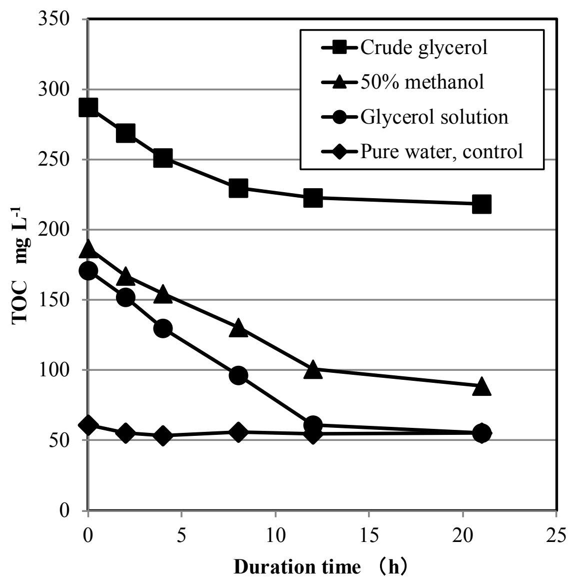

Figure 5 Biodegradability evaluated on the different denitrification reagents by measuring TOC

efficiency was firstly evaluated on the different denitrification reagents such as the glycerol solution, commercially used 50% methanol and BDF by-product of crude glycerol using two-fold diluted activated sludge (MLSS; 6,600 mg/L) obtained from an excreta treatment facility. The experimental data on the denitrification reagents was shown in Fig. 4. The glycerol solution and the 50% methanol represented almost the same denitrification profiles. On the other hand, the crude glycerol showed the highest denitrification efficiency in the three denitrification reagents. Here, as a denitrification reagent is usually added an excess amount to the biological denitrification treatment process in order to remove nitrate completely, the biodegradability on the denitrification reagents was secondly evaluated. The experimental data on the biodegradability was shown in Fig. 5. The glycerol solution showed the highest biodegradability in the three denitrification reagents and that was completely degraded, while the crude glycerol remained plenty amount of biologically undecomposed organic matter. Judging from these results, the glycerol solution was satisfied with the efficiency required for the biological denitrification treatment while the crude glycerol was ill-suited for the treatment because of its weak biodegradability.

Property of the separated oil

The higher heating value, HHV, of the separated oil and the crude glycerol is shown in Fig. 6. The HHV of the separated oil was about 1.5 times higher than that of the crude glycerol, 37.3 kJ/g in average, and that was equivalent to 97% of fresh vegetable oil, and also to 83% of the A-type heavy fuel oil or the refined lubricant oil. So, the separated oil could be used in an industrial furnace as a burner fuel without any treatment or mixed with refined lubricant oil.

The HHV of the given proportion of the separated oil to the refined lubricant oil was shown in Fig. 7. The separated oil could be miscible in all proportions with the refined lubricant oil and the HHV of the

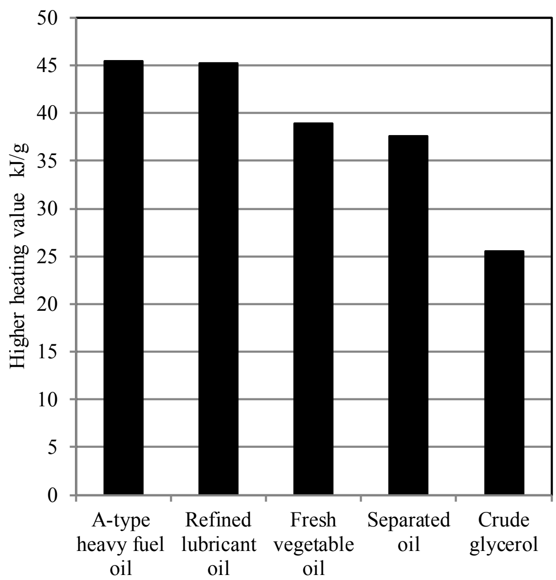

Figure 6 Comparison of the higher heating value of the burnable oils with separated oil and crude glycerol

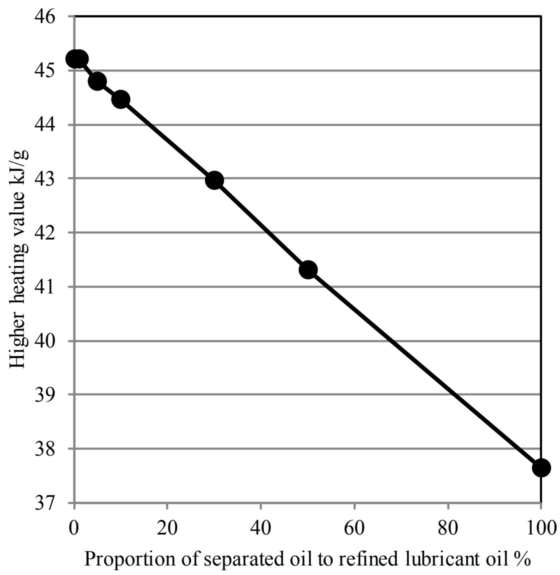

Figure 7 Changes of the higher heating value in the given proportion of separated oil to the refined lubricant oil.

obtained mixture was changed linearly with increasing the proportion of the separated oil to the refined lubricant oil.

CONCLUSION

Through this treatment, the crude glycerol of BDF by-product could be completely recycled without discharging any by-product. Moreover, it was considered that the rinsing water, which was arisen from the purification of crude BDF with hot water in the BDF manufacturing by wet method shown in Fig. 1, could be also recycled by using it on behalf of dilution water in this treatment process.

Now the glycerol solution is adopted as an alternative denitrification reagent in several excreta treatment facilities in Japan and the number is growing. The present issues in the practical applications are to stabilize the producing quality and to improve the conveying efficiency of the glycerol solution.

ACKNOWLEDGMENT

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ENERGY POTENTIAL FROM OIL PALM BIOMASS RESIDUES AND MUNICIPAL SOLID WASTE FOR SOLID FUEL PRODUCTION BY HYDROTHERMAL TREATMENT IN MALAYSIA

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ABSTRACT

This paper investigates the availability and energy potential from oil palm biomass residues and MSW for production of hydrocar by HTT which properties resembles coal. The potential renewable energy generated from oil palm biomass residue in Malaysia was increased by 10.58% from 2016 (803.37 PJ in total) to 2017 (888.33 PJ). The potential energy of OPF was the highest among all biomass type, with 361.43 PJ (44.99 % of total energy potential) in 2016 and 367.71 PJ (41.39%) in 2017. This was followed by MF, EFB and PKS and OPT. POME showed the least energy potential, with 48.86 PJ (6.08%) in 2016 and 57.50 PJ (6.47%) in 2017. The average electricity generated in 2016 is estimated to be 80.81 TWh while in 2017, it is estimated to be 89.36 TWh, resulting in an increase of 10.58% in the electricity generation. Meanwhile, the average amount of MSW generated in Malaysia is about 1.1 kg/day. About 26500 tonnes of solid waste is disposed daily through 166 operating landfills in the country. Therefore, the total annual solid wastes generated is estimated to be 9.67 million tonnes. The LHV of MSW was determined as 9 GJ/ton (2500kWh/ton) which approximately generate 8.76TWh energy per year.

Keywords: Biomass, Municipal Solid Waste, Hydrothermal Treatment, Energy Potential

INTRODUCTION

Malaysia with the total area of 330,345 km^2 in 2016 is separated by South China Sea into western coast Peninsular Malaysia with area of 131,990 km^2 and eastern coast of Sarawak and Sabah with area of 124,451 km^2 and 73,904 km^2 respectively. From 31.63 million populations, 79% located in Peninsular Malaysia followed by 12% and 9% in Sabah and Sarawak. Due to Malaysia's strategic geographical location, precious natural resources such as petroleum, natural gas and coal as well as sources of renewables such as hydro, solar, biomass and wind are readily available for exploitation. To reduce the dependency level on fossil fuels and minimise the negative environmental impacts, Malaysia is now concentrated on the development of renewable energy as an alternative. Under Malaysian Fifth Fuel Policy, renewables are recognised as the country's fifth fuel after oil, coal, natural gas and hydro.

Malaysia is known as the world's leading exporter of palm oil and the world's second largest producer of crude palm oil after Indonesia. According to Malaysia Palm Oil Board (MPOB) statistics, the total oil palm planted area in 2017 reached 5.81 million hectares, an increase of 1.3% as against 5.74 million hectares in the previous year . In 2017, the total oil palm planted area in Peninsular Malaysia was 2.70 million hectares (46.6% of the total) followed by Sarawak with 1.56 million hectares (26.8% of the total Malaysian oil palm planted area), and Sabah with 1.55 million hectares (26.6% of the total). There were 453 operating mills in Malaysia where 245 mills were located in Peninsular whereas 208 in Sabah and Sarawak.

With population of 32.3 million in 2017, the daily Municipal Solid Waste (MSW) generation in Malaysia is estimated at 49,670 tonnes at a rate of 0.5% per year with economic growth and population increase (Ministry of Energy Green Technology and Water Malaysia, 2017). Many developing countries including Malaysia disposed the most of the solid waste through landfill whilst the remaining is diverted into resource recovery and composted activities.

The oil palm biomass residue is generated from the plantation and mill sites. However, most of the biomass is left in the plantations. About 75% of the solid waste is made up of oil palm fronds (OPF) and oil palm trunks (OPT) which are readily available in the plantation sites while empty fruit bunch (EFB), mesocarp fibre (MF), palm kernel shell (PKS) and palm oil mill effluent (POME) that account for the remaining 25% which are usually available at the mill sites.

It was obvious that oil palm fronds and trunks occupy the largest portion of the overall biomass residue generated from the oil palm plantations. Trunks from oil-palm trees are available upon replanting, on average, every 25 years while fronds are a by-product of the cultivation of oil palm trees. Not all of the oil palm fronds are left unutilised, but part of them are used in the field to conserve the soil, act as soil conditioner and prevent erosion. Another abundantly available solid waste obtained from the Crude palm oil (CPO) production is known as the EFB. It exists as a fibrous material and can be utilised to produce bioalcohol, solid fuel, pulp and many other value-added products. PKS is one of the by-products from Fresh Fruit Bunch (FFB) processed. Its complex pore structure and fibre matrix make it a good feedstock for premium activated carbon production. MF is another by-product of oil palm FFB after the extraction process. It is wildly used as biomass fuel for steam boiler due to its porous nature. On the other hand, POME is the waste water that discharged during processing of palm oil. This highly polluted liquid effluent can pose significant environmental issues if it is not treated properly. POME has great potential for biogas production, which can then be used to generate power through gas turbines or gas fired engines

In our past study, there were many research focus on empty fruit bunch residues from palm oil mills due to it's high availability. The hydrochar product produced from via HTT at 180°C is found to be most favorable for large-scale production of solid fuel from EFB. Moreover, the calorific value of the hydrochar is equal to low-grade sub-bituminous coal. The combination of HTT and washing co-treatment was proven to achieve 92% potassium removal, lowered the ash and the chlorine content of EFB to 0.9% and 0.19%, respectively (Novianti, 2016). This finding shows positive results in the term of the deposition tendency, thus clarified that the removal of potassium may lead to lower deposition tendency.

In this study we will estimate the availability and energy potential of oil palm biomass residues and MSW in Malaysia for the potential of thermal treatment by hydrothermal treatment (HTT) process taking advantage that the system is suitable for treatment high moisture content into uniform value-added dry powder solid fuel.

Table 1: FFB yield and processed by mills in Malaysia from 2014 to 2017 (Malaysia Palm Oil Board (MPOB), 2018)

Year	2014	2015	2016	2017
FFB Yield (Tonnes/hectare)	18.63	18.48	15.91	17.89
FFB Processed by Mill (Tonnes)	95,380,438	97,566,393	85,836,769	101,022,441

Table 2: Oil palm biomass availability based on standard biomass to FFB extraction rate (Loh, 2017)

Type of oil palm biomass	Availability
Empty fruit bunches (EFB)	EFB (wet basis) = 22% of FFB EFB (dry weight) = 35% of EFB (wet basis)
Palm shell (PS)	PS (wet basis) = 5.5% of FFB PS (dry weight) = 85% of PS (wet basis)
Mesocarp fibres (MF)	MF (wet basis) = 13.5% of FFB MF (dry weight) = 60% of MF (wet basis)
Palm oil mill effluent (POME)	POME (wet basis) = 67% of FFB or 0.65 $m^3\ t^{-1}$ FFB [15]
Oil palm trunks (OPT)	OPT (replanting, dry weight) = 74.48 t ha^{-1}, an average of 142 OPT is available from a ha of oil palm, and only 50% can be removed from the plantation
Oil palm fronds (OPF)	OPF (pruned, dry weight) = 10.40 t ha^{-1}, 75% of oil palm trees aged 7 years are due for pruning, and only 50% can be removed from the plantation OPF (replanting, dry weight) = 14.47 t ha^{-1}, and only 50% can be removed from the plantation

MATERIALS AND METHODS

The method of determining the availability of oil palm biomass residues has been studied previously by a few scholars. In 2017, the fresh fruit bunch (FFB) yield showed a significant increase by 12.4% to 17.89 tonnes per hectare as against 15.91 tonnes per hectare in 2016. This is mainly due to the increase of oil palm planted area by 1.3% in 2017 (5.81 million hectares) as compared to the previous year (5.74 million hectares).

Availability of each biomass type is calculated based on the standard biomass to FFB extraction rate (Table 2). The availability of crop residues generated was calculated using the formula:

Availability = FFB Processed x Extraction rate of biomass type (dry weight)

Moreover, energy potential of each biomass type has been determined. It is obtained based on the gross calorific value in Table 3.

Energy potential = Availability x Gross calorific value

Table 3: Combustion characteristics of various forms of oil palm biomass as a fuel for thermal processes (Loh, 2017)

Sample	Moisture content (wt.%)[a]	Ash content (wt.%)[a]	Volatile matter content (wt.%)[a]	Gross calorific value (MJ kg^{-1})[a]	Hexane-extractable content (wt.%)[a]
Empty fruit bunches	67.00 ± 1.41	4.60 ± 0.50	87.04 ± 0.42	18.88 ± 0.74	11.25 ± 2.43
Mesocarp fibre	37.09 ± 2.06	6.10 ± 0.94	84.91 ± 0.62	19.06 ± 0.32	7.60 ± 0.76
Nuts	12.67 ± 0.12	4.05 ± 0.08	84.0 ± 0.71	24.48 ± 0.40	4.4 ± 0.42
Palm shell	12.00 ± 1.08	3.00 ± 1.27	83.45 ± 0.68	20.09 ± 0.43	3.26 ± 0.31
Kernel	6.31 ± 4.09	1.49 ± 0.94	78.2 ± 5.59	38.03 ± 0.10	95.5 ± 0.92
Palm kernel cake	0.28 ± 0.01	3.94 ± 0.08	88.5 ± 1.41	18.89 ± 0.01	3.9 ± 0.16
EFB juice (dried)	88.75 ± 0.28	11.63 ± 0.06	78.5 ± 0.71	20.75 ± 0.17	3.85 ± 0.02
Palm oil mill effluent	93.00 ± 1.67	15.20 ± 2.22	77.09 ± 1.64	16.99 ± 0.58	12.55 ± 1.71
Sludge (separator, decanter)	90.69 ± 1.67	12.02 ± 4.27	21.84 ± 5.98	16.13 ± 3.73	9.81 ± 5.85
Sterilizer condensate	93.53 ± 2.60	15.20 ± 2.22	20.60 ± 11.99	22.07 ± 14.34	4.20 ± 2.07
Crude palm oil	0.07 ± 0.03	0.91 ± 0.12	75.45 ± 0.67	39.36 ± 0.03	95.84 ± 0.71
Palm kernel oil	0.07 ± 0.09	0.79 ± 0.01	74.27 ± 0.28	37.98 ± 0.07	95.06 ± 0.92
Core	70.23 ± 7.00	7.59 ± 4.72	17.39 ± 1.50	17.68 ± 2.89	11.83 ± 11.88
Spikelets	56.52 ± 4.36	3.48 ± 1.04	18.61 ± 2.20	19.79 ± 1.19	12.64 ± 6.87
Ash	20.87 ± 7.07	71.52 ± 26.97	89.13 ± 7.40	6.03 ± 6.01	–
Oil palm fronds	70.60 ± 5.58	3.37 ± 0.45	85.10 ± 1.23	15.72 ± 0.26	0.62 ± 0.29
Oil palm leaflets	46.30 ± 2.08	15.46 ± 0.88	73.76 ± 0.57	15.72 ± 0.26	4.06 ± 0.59
Oil palm trunks	75.60 ± 6.16	3.35 ± 0.37	86.70 ± 1.03	17.47 ± 0.35	0.81 ± 0.34
Roots	36.00 ± 12.02	5.92 ± 1.03	86.30 ± 0.85	15.55 ± 0.20	0.20 ± 0.08
Bagasse	50.00 ± 7.07	3.5	–	19.4	–
Cereal straw	6.00	–	79.0	17.3	–
Bituminuous	11.00 ± 2.83	8.7	46	28.3	–
Lignite coal	39.00 ± 21.21	10.7	29	2.8	–

[a] Moisture free or oven-dry biomass samples were used for the analysis except for moisture content. Means ± standard deviations, n = 5.

The available electricity generated from the oil palm biomass residues obtained is calculated based on the energy potential value for each biomass type, assuming that the average thermal efficiency of all coal-firing power plants in Peninsular Malaysia is about 36.21% (Malaysia Energy Commission, 2018) and 1 MJ is equivalent to 0.2775 kWh.

Electricity generated = Energy potential (in Wh) x Thermal efficiency of coal-firing power plant in Malaysia

As for MSW the potential energy generated is calculated using this formula:

Energy generated per year = Annual average MSW amount x LHV value of mixed MSW x Thermal efficiency of power plant

Apart from that, emission of methane from waste disposal sites can be determined by referring to the method proposed by the Intergovernmental Panel on Climate Change (IPCC) (Fazeli, Bakhtvar, Jahanshaloo, Che Sidik, & Bayat, 2016):

$$Q = (MSW_T \times MSW_F \times MCF \times DOC \times DOC_F \times F \times 16/12 - R)(1 - OX)$$

where Q = Total methane emissions (Gg/year)

MSW_T = Total solid waste generated (Gg/year)

MSW_F = Fraction of solid waste disposed to landfill = 0.8 (80% of the total MSW generated in Malaysia is sent to the landfill)

MCF = Methane correction factor (fraction) = 0.6 (for uncategorised SWDS)

DOC = Degradable organic carbon (fraction) = 0.14

DOC_F = Dissimilated organic fraction (i.e., fraction converted to LFG) = 0.77

F = Fraction of CH4 in landfill gas = 0.55

R = Recovered CH4 (Gg/year) = 0

16/12 = Molecular weight ratio of methane and carbon

OX = Oxidation factor (fraction) = 0

Table 4: Availability and energy potential of various biomass type in Malaysia in 2016 and 2017

Biomass Type	OPF		EFB		PKS		MF		POME		OPT	
Year	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Availability (Mt)	22.99	23.39	6.61	7.78	4.01	4.72	6.95	8.18	2.88	3.38	3.16	3.74
Energy Potential (PJ)	361.43	367.71	124.79	146.86	80.62	94.88	132.52	155.96	48.86	57.50	55.15	65.42
Equivalent Electricity Generation (TWh)	36.36	36.99	12.55	14.77	8.11	9.54	13.33	15.68	4.91	5.78	5.55	6.58

Table 5: Availability and energy value of MSW in Malaysia

Daily Average Waste Amount (ton/day)	49,670
Annual Average Waste Amount (ton/year)	18,129,550
LHV of Mixed MSW (kWh/ton)	2319.57
Energy Generated (TWh/year)	15.22

Table 6: Equivalent electricity generation resulted by emission of methane from MSW

Total MSW Generated (tonnes)	Methane Emission (tonnes)	Volume of Methane ($x10^6$ m^3)	Calorific Value ($x10^9$ MJ)	Equivalent Electricity Generation (TWh)
18,129,550	687,937	1031.89	17.53	1.76

RESULTS AND DISCUSSION

Availability and Energy Potential of Oil Palm Biomass Residues

The availability and energy potential from oil palm biomass residues is shown in Table 4. Overall, the potential renewable energy generated from oil palm biomass residue in Malaysia was increased by 10.58% from 2016 (803.37 PJ in total) to 2017 (888.33 PJ). The potential energy of OPF was the highest among all biomass type, with 361.43 PJ (44.99 % of total energy potential) in 2016 and 367.71 PJ (41.39%) in 2017. This was followed by MF, EFB and PKS and OPT. POME showed the least energy potential, with 48.86 PJ (6.08%) in 2016 and 57.50 PJ (6.47%) in 2017.

Energy Recovery from MSW in Malaysia

The availability and energy potential from MSW are shown in Table 5. The average per capita of waste generated from household, commercial, industrial and institution was 1.17 kg per day in 2012 (Jabatan Pengurusan Sisa Pepejal Negara, 2013). About 49,670 tonnes at a rate of 0.5% per year of solid waste is disposed daily. Therefore, the total annual solid wastes generated is estimated to be 18.13 million tonnes. The average calorific value of Malaysian MSW was determined as of 2319.57kWh/tonnes (Kathirvale, Muhd Yunus, Sopian, & Samsuddin, 2004). Considering that the average thermal efficiency of coal-firing power stations in Peninsular Malaysia is 36.21%, approximate 15.22 TWh energy is generated per year from the MSW.

By applying the method and equation mentioned above, the total methane emission is obtained as 687,937 tonnes. Methane is the main source of energy obtained from the combustion of biomass residues. Processing of MSW will produce landfill gases (LFG) which comprises of 55% of methane with a density of 0.667 kg/m3 at 30°C and LFG calorific value of 17 MJ/m (Noor, Yusuf, Abba, Abu Hassan, & Mohd Din, 2013). Hence, 1031.89 $x10^6m^3$ of methane with a calorific value of 17.53 $x10^9$ MJ is obtained and this is equivalent to an electricity generation of about 1.76 TWh per year.

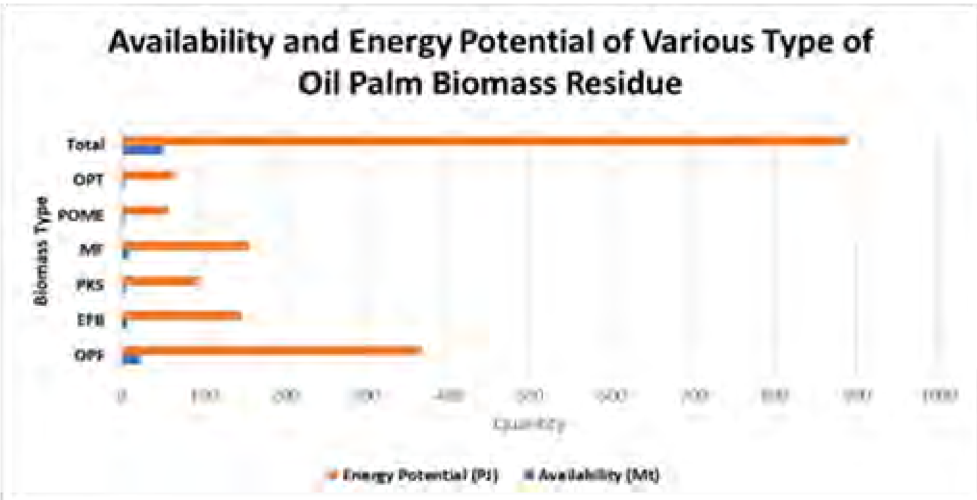

Figure 1: Potential renewable energy from oil palm biomass residues based on 101.02 million tonnes of fresh fruit bunches processed in 2017

CONCLUSION AND RECOMMENDATIONS

Based on the findings reported here, the estimated energy potential from oil palm biomass residues from OPF was the highest among all biomass type followed by MF, EFB and PKS and OPT. However, POME showed the least energy potential. Therefore, it can be concluded that OPF, MF, EFB, PKS and OPT are more suitable for HTT of solid fuel production which have energy potential of 830.83 PJ and generate electricity at 83.57 TWh electricity generated. Meanwhile energy from POME only contribute 57.5 PJ with 5.784 TWh electricity generated which make it more suitable for biogas energy from methane.

As for MSW, it is estimated that 15.22 TWh energy generated per year. The equivalent energy from methane gas to an electricity generation approximated at 1.76 TWh per year.

Therefore, solid fuel production from hydrothermal treatment has significant impact for electricity generation in Malaysia hence feasibility on techno economic analysis should be conducted to increase knowledge on this subject.

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A STUDY ON KINETIC CHARACTERISTICS OF CO_2 METHANATION REACTION TARGETING CO_2 OF BIOGAS

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ABSTRACT

As sea dumping of organic waste has been banned and the disposal expense has increased, there is a need for efficient countermeasures. Among them, anaerobic digestion is receiving attention as it could reduce organic matters and generate useful biogas. Generally, the major components of biogas are CH_4 (50-60%), CO_2 (30-50%), H_2S, NH_3 etc, and when purifying, CO_2 is unusable and disposed. If the disposed CO_2 is reused, it could generate additional new renewable energy. CO_2 methanation reaction, one of the way to reuse CO_2 generates CH_4 by mixing CO_2 and H_2 in 1:4 molar ratio. However, as CO_2 is thermodynamically stable, it requires external energy to obtain new material using CO_2 as reactants. Even if proper energy is supplied, the conversion could be limited due to thermodynamic balance, therefore requires catalyst. Catalysts used in CO_2 methanation reaction generally put Ni, Al, Ti as supporters and mainly are promoter, additive and metals for coating. Previous researches mainly focused on improvement of catalysts activation. However, this study made disk type catalysts with Ni with excellent price competitiveness and active ability for efficient biogas purification. Also, to evaluate kinetic characteristics, the molar ratio of CO_2 and H_2 was controlled to carry out the experiment on each pressure. Based on each conversion ratio, kinetic characteristics of CO_2 methanation were evaluated to figure out the response dependence regarding CO_2 and H_2.,

Keywords: CO_2 methanation, Biogas, pressure, kinetic

INTRODUCTION

Recently, due to the 'London Dumping Convention', the dumping of wastes in the ocean is prohibited, so many organic wastes that had been dumped in the ocean have been converted to land treatment, such that a preparation of efficient plan is urgently needed(Hwang et al., 2016). In addition, recently the limitations of landfilling and incineration of organic wastes were revealed, and a need for technology to replace such treatment technology is required. Now, there has been a growing interest in treatment technologies for treating organic wastes and utilizing them as resources. Currently, the recycling treatment of organic wastes is expanding, and many researches have been reported due to the diversification of resources technology due to the development of technology and industry. Currently, organic wastes can be recycled as composting, feed conversion, landfill materials, solid fuels and anaerobic digestion methods. Anaerobic digestion is a process by which organic matter is degraded under anaerobic conditions and biogas, one of the useful fuels, can be obtained. Biogas generally consists of 50-60% CH_4, 30-50% CO_2, H_2S and NH_3(Lim et al., 2012). The use of biogas requires a purification process to improve the purity of CH_4. Studies on solidification purification for CH_4 use are being actively carried out, but research on the use of CO_2 to be discarded in CH_4 solidification purification is insufficient. Therefore, there is a need for technology that can utilize the CO_2 being discarded. The way to utilize CO_2 can be divided into direct use technology and energy or fuel conversion technology. At this time, the technology to convert to energy or fuel can treat large amounts of CO_2, reduce the environmental burden caused by organic wastes, and contribute to sustainable development in an environment friendly way. The CO_2 methanation reaction, one of the ways to convert CO_2 to energy or fuel, is shown below. (Hong et al., 2012)

$$CO_2\ (g) + 4H_2\ (g) \leftrightarrow CH_4\ (g) + 2H_2O\ (g),$$

$$\Delta H^0 = -39.6 \text{ kcal mol-1}$$

The CO_2 methanation reaction is an exothermic reaction in which one mole of CO_2 and four moles of H_2 react to form one mole of CH_4 and two moles of H_2O. However, since CO_2 is a thermodynamically very stable material, an external energy source is needed when converting to CH_4. Therefore, a catalyst is required for proper reaction rate and CH_4 selectivity(Xiaobin et al., 2012, Wie et al., 2011). In general, Ni, Ti, Fe, Co and so on are mainly used for the CO_2 methanation reaction, and studies using precious metals such as Ru and Pd are also reported, but they are very disadvantageous from the economical point of view(Kristian et al., 2018, Grava et al., 2014, Park et al., 2011). In this study, Ni - based catalysts were prepared considering price, catalytic activity, stability and durability, and YSZ was added to prevent sintering. In addition, studies on the catalytic activity have been carried out in diverse, but studies on the mechanism of reaction in the conversion of CH_4 to CO_2 on the Ni catalyst still insufficient.

Therefore, in this study, the reaction rate of the CO_2 methanation reaction and the dependence on the influent are derived using the power law kinetic model and the Langmuir-Hinshelwood rate equation using the kinetic data(Yang et al., 2003, Seong et al., 2013).

METHOD

Ni(Sigma Aldrich Co), TiO_2(Ishihara Sangyo Kaisha Ltd), CeO_2(Sigma Aldrich Co), YSZ(Sigma Aldrich Co) and $RuCl_3$(Sigma Aldrich Co) were used as reagents, and Ti, Ce and YSZ were mixed with distilled water using Ni as a supporter. After stirring, the water was completely evaporated at 65 °C on a Rotary evaporator(N-1100, EYELA). In order to homogenize the powder particles, total amount of 3 g was filtered with a 40 mesh sieve and molded into a disk shape using an injection mold. The prepared catalyst was maintained at 950 °C for 2 hours at a room temperature. A 0.07 M RuCl3 aqueous solution was prepared and seeded on the surface of the finished catalyst. After the seeding, it was dried in an oven at 105 °C, and then reduced to a hydrogen atmosphere at 350 °C. The inlet gas was mixed with H_2, CO_2, and N_2 at a ratio of 4: 1: 1, respectively. In the experiment, the reaction temperature was set to 280 °C, 300 °C and 350 °C for each catalyst. For the analysis of the properties of the effluent gas, 6500G/C(YL instrument) was used.

RESULT

The positive reaction rate of the chemical reaction depends on the concentration of the reactants, and the reaction rate can be expressed as $d[A] / dt = -k [A]^a X[B]^b$. Reaction orders are not predictable by chemical equations and are determined experimentally. The overall reaction order can be expressed as (a + b), where a and b are the a-order reaction for A and the b-order reaction for B. The degree of dependence of the influent can be assessed through each reaction order.

In order to investigate the dependence of the reaction on the partial pressures of CO_2 and H_2, an experiment was carried out with varying partial pressures of CO_2 and H_2, and the total gas flow rate was fixed at 240 mL. The conversion rates from CO_2 to CH_4 for each partial pressure are shown in Fig. 1.

Ni-Ti-Ce-YSZ, Ru / Ni-Ti-Ce-YSZ and Ni-YSZ catalysts were prepared under the conditions of 280 °C, 300 °C and 350 °C respectively.

The conversion rate was appeared to be highest when the rate between CO_2 and H_2 was 1:16 and the catalysts of Ni-Ti-Ce-YSZ, Ru/Ni-Ti-Ce-YSZ and Ni-YSZ were 87%, 60% and 35% respectively. The lower the partial pressure of H_2 was, the lower the conversion from CO_2 to CH_4 was. In all three catalysts, it was confirmed that the conversion ratio from CO_2 to CH_4 was decreased as the partial pressure of H_2 was lowered through the slope of each graph based on the portion of 1: 4 ratio of the static pressure of CO_2 and H_2. It was also found that when the partial pressure of H_2 was increased exceeding a certain rate, the conversion rate did not depend on the partial pressure, and it was confirmed that the conversion rate did not depend on the partial pressure of H_2 when the partial pressure of H_2 was decreased to below a certain rate.

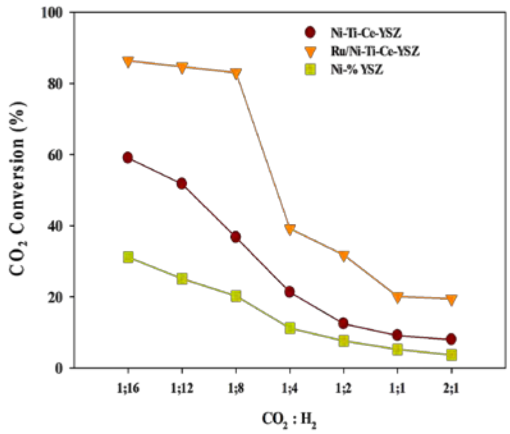

Fig.1. Activity tests of methanation under different atmosphere

The reaction rate according to the partial pressures of CO_2 and H_2 was diagramed in Fig. 2 using differential equations based on the conversion rate evaluation result of each catalyst. As the partial pressure of CO_2 increased, the reaction rate decreased. However, as the partial pressure of H_2 increased, the reaction rate increased with partial pressure of each catalyst. However, it was found that the reaction rate did not depend on the partial pressure when a certain level of partial pressure was increased. In this study, because the flow rate is fixed, the reaction rate is increased because the partial pressure of H_2 is increased and the H_2 is supplied excessively, comparing to the 1: 4 condition of CO_2 and H_2.

Reaction rate dependence of CO_2 partial pressure and H_2 partial pressure was derived according to power law. The reaction equation can be expressed as $r_0 = k\ (P^0{}_{CO2})^a\ (P^0{}_{H2})^b$ where r_0, k, a and b represent the initial reaction rate, (mol CO_2 h^{-1} $gcat^{-1}$) reaction rate constant (mol CO_2 h^{-1} $gcat^{-1(a+b)}$) and reaction orders according to partial pressures of CO_2 and H_2, respectively.

The kinetic constant k was derived from the above experimental results. That is, the k value was derived as 0.9972. a and b were 0.1367 and 0.9223 respectively, and a + b = 1.059. Therefore, it can be understood that the reaction degree of CO_2 methanation is more dependent on the partial pressure of H_2 because the reaction degree of H_2 is larger than the reaction degree of CO_2.

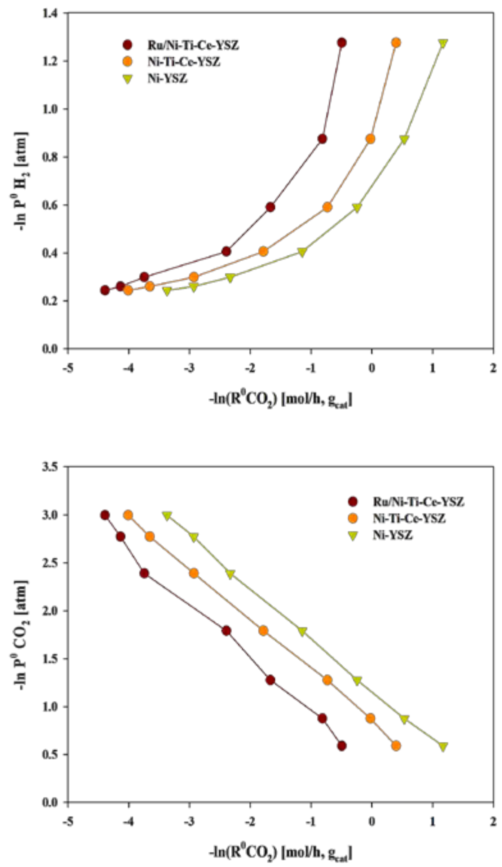

Fig.2. Dependence of the methanation reaction upon partial pressure of CO_2, H_2, respectively

CONCLUSION

The CO_2 methanation reaction was selected to treat and recycle CO_2 in the biogas. Experiments were conducted to derive the dependence of partial pressures of H_2 and CO_2 in the CO_2 methanation reaction.

1) The degree of reaction was 0.1367 and 0.9223 for CO_2 and H_2 respectively when assessed the dependence through the conversion rate.

$$Rxn=0.997*CO_2^{0.137}*H_2^{0.922}$$

2) The CO2 methanation reaction was more affected by the H_2 partial pressure than the CO_2 partial pressure.

ACKNOWLEDGMENT

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Optimization of operating condition of Disk type catalyst for CO_2 methanation reaction

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ABSTRACT

Bio gas commonly generated from anaerobic digestion are consist of methane(CH_4), carbon dioxide(CO_2), hydrogen sulfide(H_2S), ammonia(NH_3) and other various components. In the process of purifying bio gas, most of the CO_2 are disposed to the air and cause global warming. Thus, there is a need for technology to reduce and use disposed CO_2. CCU(Carbon Capture & Utilization) technology generates reusable energy by converting sampled highly concentrated CO_2 into substance with high added value. Among various CCU technologies, CO_2 methantion is a process of converting CO_2 and hydrogen into methane. The reaction formula is $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$, and it is an exothermic reaction generally occurs between 200 °C ~ 450 °C in accordance with catalyst and experiment condition. In this study, the Ni-Ce-Ti-YSZ catalyst used a CO_2 methanation reaction. As for the making of catalyst, through physical stirring, powder is made, shaped in to disk type using mold and processed in 950 °C. The chemical and physical characteristics of catalyst were verified through SEM, EDS and XRD. To improve activation of CO_2 methanation, the pressure, space velocity and H_2:CO_2 ratio was controlled for operation condition. This study has confirmed that the increase of pressure and ratio of H_2:CO_2 in operating CO_2 methanation of Ni-Ce-Ti-YSZ catalyst, and decrease of space velocity led to higher CO_2 conversion.

key word: Bio gas , CCU technology, CO_2 methanation, Disk type, CO_2 conversion

INTRODUCTION

Biogas is a gas produced by anaerobic digestion of organic matter such as household waste or industrial waste such as manure, fertilizer and wastewater. Although there is no accurate statistics on biogas production globally, production of biogas in EU is estimated to be around 69 tons in 2007 (Anneli P. et al., 2009). Biogas, which is mainly generated in anaerobic digestion, consists of various components including methane (CH_4), carbon dioxide (CO_2), hydrogen sulfide (H_2S), ammonia (NH_3) (Ghinwa M. N. et al., 2011). These gases can be used as an energy source, such as city gas by purifying to increase the purity of methane. Therefore, a technology that can reduce and utilize the waste carbon dioxide is needed. Carbon capture and storage (CCS) technology is the most commonly studied technology, which can safely capture, store and transport large volumes of carbon dioxide safely in the rock bed. However, it has potential risks and disadvantages that require large-scale treatment facilities, high costs, compression and cooling of large quantities of carbon dioxide during transportation and storage, which can cause serious damage if released into the atmosphere (Gabman C., 2014). CCU technologies are being studied to overcome the shortcomings of CCS technology. Carbon Capture & Utilization (CCU) technology is a technology that captures carbon dioxide and converts it to high value-added materials to generate high-efficiency energy. Of the various CCU technologies, CO_2 methanation is the process of converting carbon dioxide and hydrogen into methane. The reaction formula is $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$, which is an exothermic reaction generally occurring at 200℃ to 450℃ depending on the catalyst and experimental conditions (Patrizia F. et al., 2017). However, this reaction has limitations in reaching thermodynamic equilibrium. Therefore, the CO_2 methanation requires a catalyst to reach high conversion and reaction velocity. Powder type catalysts for CO_2 methanation reaction has been studied but has many barriers to be commercialized. The disk type catalyst is excellent in mechanical strength and in thermal stability and is more effective for commercialization. In this study, CO_2 methanation was carried out using Ni-Ce-Ti-YSZ catalyst in disk form. In the case of manufacturing method, powder was prepared by physical stirring and compressed into disk type using a mold. In order to enhance the activity of the reaction, the operating conditions were carried out by adjusting the ratio of H_2:CO_2, the space velocity (GHSV) and the pressure of the inflow gas. Physical and chemical properties of the catalysts were identified by SEM, EDS and XRD.

EXPERIMENTAL

Catalyst preparation

Ni, TiO_2, CeO_2 and YSZ were used as reagents for preparing the catalyst. All reagents were put in a round flask with distilled water and stirred for 1 hour. After stirring, the mixture was connected to a Rotary evaporator(N-1100, EYELA) and dried at 65 °C until the water completely evaporate. A 40 mesh sieve was used to make the obtained powder into uniform size. The powder was put into a mold and compressed to 10,000 bar to form a disk type. After that, the Ni-Ce-Ti-YSZ Disk catalyst was obtained by heat treatment at 950 °C.

Catalytic activity test

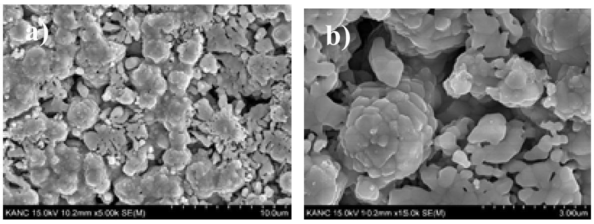
All CO_2 methanation was conducted in a quartz tubular fixed-bed reactor placed in a furnace under atmospheric pressure. The flow rate of the inflow gas was 120 ml, and the ratio of H_2: CO_2: N_2 = 4: 1: 1 was set. The temperature of the reactor was lowered by 20 °C at 200 °C - 350 °C, and the reaction product was measured by GC (6500GC, YL instrument, TCD) at each temperature condition. After the CO_2 conversion was evaluated under the mentioned above conditions, the operating conditions were controlled by adjusting the pressure, space velocity, and H_2: CO_2 ratio of the input gas.

The other operating conditions were constant and the inlet gas pressure was adjusted to 1 - 5 bar and the space velocity was adjusted to 3600 hr^{-1}, 7200 hr^{-1}, 10800 hr^{-1}, and 14400 hr^{-1},and CO_2: H_2 ratio was adjusted to 1: 4, 1: 5, and 1: 6. The optimum operating conditions were evaluated by comparing each CO_2 conversion.

RESULTS AND DISCUSSION

Characterization

The structure and elemental distribution of the catalyst surface were observed through Fe-SEM and EDS. The SEM magnification was set to × 5000 and × 15000, and the elemental distributions of Ni, Ce, Ti, Zr and O on the catalyst surface were confirmed. SEM and EDS analysis results are shown in Figure 1. As a result of the EDS analysis, the Ni-Ce-Ti-YSZ disk catalyst had a high proportion of O element on the surface. As a result of SEM analysis, Ni particle size was small and many pores existed..



Element	Weight(%)	Atomic(%)
O	19.19	47.04
Ti	6.00	4.91
Ni	68.17	45.54
Zr	4.33	1.86
Ce	2.32	0.65
Totals	100.0	100.0

Figure 1 SEM image and EDS anlaysis of the Ni-Ce-Ti-YSZ Disk catalyst (a = ×5,000, b = ×15,000)

The crystallite of the catalyst surface was obtained by XRD analysis and the analysis results are shown in Figure 2. As a result of XRD analysis, Ni on the surface of the Ni-Ce-Ti-YSZ disk catalyst was present in the form of NiO. When Ni on the surface exists in the form of NiO, sintering of Ni due to oxygen is suppressed. (Daehyun M. et al., 2018).

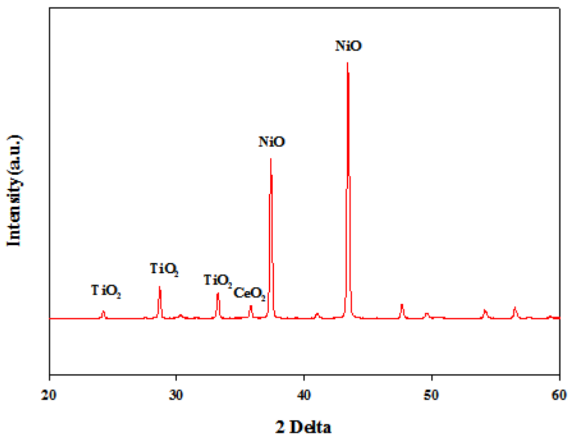


Figure 2 XRD pattern of the Ni-Ce-Ti-YSZ Disk catalyst

Catalyst activity test

The Ni-Ce-Ti-YSZ disk catalyst was evaluated in different operating conditions and the result is shown in Figure 3-5. In the operating conditions, GHSV and pressure of the inflow gas were fixed to 14,400 hr^{-1} and 1 bar, respectively. It was conducted by adjusting H_2: CO_2 ratio of the input gas in Figure 3. As a result of the reaction, the CO_2 conversion was high in the order of 6:1> 5:1> 4:1, and was highest in the ratio of 6: 1. It can be concluded that the higher the ratio of hydrogen, the greater the CO_2 conversion.

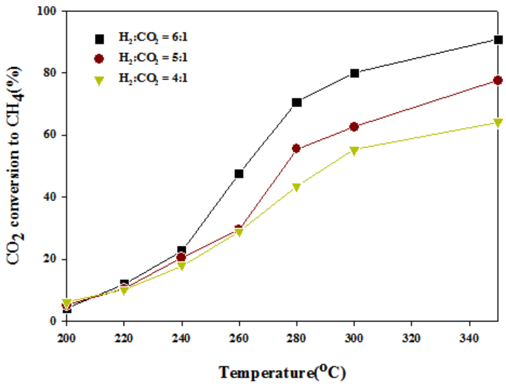


Figure 3 CO_2 conversion to CH_4 of the Ni-Ce-Ti-YSZ Disk catalyst with different CO_2:H_2 ratio, GHSV= 14,400 hr^{-1}, P = 1 bar

In the operating conditions, H_2: CO_2 ratio of the input gas and pressure of the inflow gas were fixed to 4:1 and 1 bar respectively. It was conducted by adjusting GHSV in Figure 4. As a result of the reaction, the CO_2 conversion was high in the order of 3600hr^{-1}>7200 hr^{-1}>10,800 hr^{-1}>14,400 hr^{-1} and was highest at 3600 hr^{-1}. It is considered that the lower the GHSV, the greater the CO_2 conversion. It is expected that higher CO_2 conversion will be obtained by carrying out a study to maintain the shape of the catalyst and to reduce the volume.

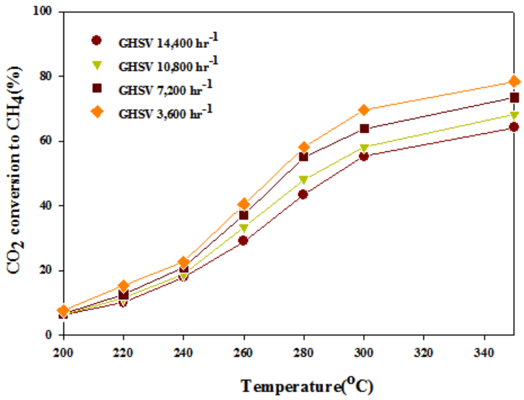


Figure 4 CO_2 conversion to CH_4 of the Ni-Ce-Ti-YSZ Disk catalyst with different space velocities, CO_2:N_2:H_2 = 1:1:4, P = 1bar

In the operating conditions, H_2: CO_2 ratio of the input gas and GHSV were fixed to 4:1 and 14400hr^{-1} respectively. It was conducted by adjusting pressure of the inflow gas in Figure 5. As a result of the reaction, the CO_2 conversion was high in the order of 5 bar> 4 bar> 3 bar> 2 bar> 1 bar and it was highest at 5 bar. It can be concluded that the higher the pressure of the incoming gas, the greater the CO_2 conversion.

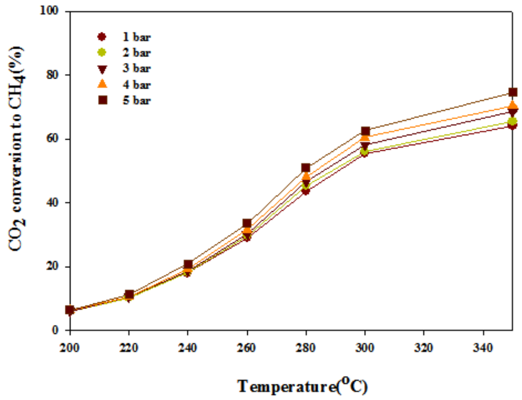


Figure 5 CO_2 conversion to CH_4 of the Ni-Ce-Ti-YSZ Disk catalyst with different inflow pressure, CO_2:N_2:H_2 = 1:1:4, GHSV= 14,400 hr^{-1}

CONCLUSION

In this study, we have studied how to reduce and utilize carbon dioxide that is discarded when refining biogas. Among the various CCU technologies, the CO_2 methanation was selected and evaluated using Ni-Ce-Ti-YSZ disk catalysts. The activity of the catalyst was evaluated by CO_2 conversion, and the reaction conditions were adjusted to improve the activity.

1) The SEM, EDS and XRD results show that the Ni particle size on the catalyst surface is small, the number of pores is large, and Ni on the surface exists in the form of NiO to suppress the sintering of Ni due to oxygen,

2) As a result of the CO_2 methanation, the catalyst activity was the best when the ratio of H_2: CO_2 = 6: 1. The GHSV was adjusted to be the best when 3,600 hr^{-1}. The pressure of the inflow gas was controlled to be the best when 5 bar.

3) The activity of the catalyst was improved by controlling the operating conditions of the CO_2 methanation. In order to enhance the activity of the CO_2 methanation in the future, it is necessary to carry out the reaction by adjusting the pretreatment temperature, pressure, and gas influence during the catalyst production in addition to the reaction operating conditions.

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CURRENT CONDITION AND ISSUES OF MUNICIPAL SOLID WASTE MANAGEMENT IN VIENTIANE CAPITAL, LUANG PRABANG DISTRICT AND XAYABOURI DISTRICT IN LAOS PEOPLE'S DEMOCRATIC REPUBLIC

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ABSTRACT

The presentation describes the current condition, issues and challenges of Solid Waste Management (SWM) in Laos People's Democratic Republic (Lao PDR) based on the recent studies conducted in three local authorities; Vientiane Capital (VTE) as large scale urban area, Luang Prabang District (LPB) as middle scale town area and Xayabouri District (XYB) as mall scale rural area. The national level legislation, regulation and policy related to SWM in Lao PDR are described, while the waste generation, waste collection, waste composition, finance, intermediate treatment system and landfill site in three local authorities are discussed in this study. The waste collection amount in three local authorities increased after the Japanese Government grant aid project in 2016, such as the distribution of waste collection vehicles and the construction of waste transfer station. Although the activities of intermediate treatment was not so common in Lao PDR before, the pilot project of composting system was introduced in three local authorities by Japan International Cooperation Agency (JICA) since 2011 to 2015. There is no sanitary landfill sites in three local authorities due to lack of budget, technical knowledge and human resource, and those often cause environmental issues. The results obtained for these projects suggest that there are some requirement for constitution applicable engineered landfill.

Keywords: Waste Management, Laos, Waste composition, Composting, Final disposal site

INTRODUCTION

The Lao People's Democratic Republic (Lao PDR) is an inland country in Indochina surrounded by Vietnam, Cambodia, Thailand, Myanmar and China, which area is approximately 236,8000 km^2 with population of around 6.5 million [UNDP Lao PDR, 2018]. Strong economic growth has enabled Lao PDR to move from the ranks of low-income economies to a lower middle-income country from 2010 and Lao PDR aims to graduate from Least Developed Country (LDC) status by 2020 [United Nations in Lao PDR, 2018]. Administration of Lao PDR has 3 levels, which are provinces, districts and villages. There are 18 provinces,148 districts and 8464 villages [Lao Statistics Bureau, 2018].

Table 1 Background Information on Lao PDR

Year	1995	2000	2005	2010	2015
Population	4,851,923	5,329,304	5,754,026	6,246,274	6,663,967
Pop. Density (people/ sq. km)	21	23	25	27	29
Pop.growth (annual %)	2.3	1.7	1.6	1.5	1.3
Life expectancy at birth (years)	56.2	58.9	61.8	64.4	66.3
GDP per capita growth(annual %)	4.6	4.1	5.4	6.9	5.9
GDP per capita (current US$)	363	325	475	1,141	2,159

Source [The World Bank, 2018]

In spite of rapid economic growth as shown in Table 1, significant issues remain with regard to poverty, income disparity, social inequality and environmental issues. One of environmental issues is the poor solid waste management (SWM). Vientiane Capital (VTE), for example, generates 655t/day of waste, but just 209t/day of them is collected and carried into the dumping site in 2011. Others are self-disposed or recycled by uncontrolled manner [JICA, Ministry of Natural Resources and Environment, Ministry of Public Works and Transport Lao PDR, 2015].

METHODOLOGY

The research method consists of the literature reviews, questionnaires and observations. The objective of literature review method is to recognize the current condition of SWM in Lao PDR from central and local government documents, donor-oriented project documents, and past Researches, etc. The objectives of questionnaires and observations are to collect data on SWM from selected Provinces and Districts offices to understand opinion from stakeholders surrounding SWM and to identify the social issues.

DEFINITION OF MUNICIPAL SOLID WASTE

Municipality solid waste in Lao PDR includes commercial and domestic wastes generated in municipal or notified areas in either solid or semi-solid form excluding industrial hazardous wastes but including treated bio-medical wastes are generally categorized into "accepted waste" and "non accepted waste" in municipal landfills. The sources and components of solid waste are:

- Residential is single and multifamily dwellings (Food wastes, paper, cardboard, plastics, textiles, glass, metals, ashes, special wastes (bulky items, consumer electronics, batteries, oil, tires) and household hazardous wastes;
- Commercials are stores, hotels, restaurants, markets, office buildings (Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes);
- Institutional are schools, government center, hospitals, etc., (Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes);
- Municipal waste collection from Street sweepings, landscape and tree trimmings, general wastes from parks, and other recreational areas.

The waste from building construction, public engineering works, such as road, bridge and so on are defined as the construction wastes while the waste from factory is defined as industrial waste (Hazardous waste are excluded). None accepted waste consists of the scheduled or hazardous waste defined as follows;

- Explosive;
- Flammable Liquid;
- Flammable Solid;
- Self-igniting Compounds;
- Oxidizing Compounds;
- Toxic Compounds;

- Infectious and Disguising Acting Compounds;
- Corrosives;
- Mixtures of Miscellaneous, Dangerous Compounds

ACTS, REGULATIONS, STRATEGIES AND OFFICIAL DOCUMENTS RELATED TO SWM IN LAO PDR

Among the overall policy and legislation at the national level, there are different Acts and regulations. Environmental Protection Law (EPL) No 29/NA, date 18 December 2012 was issued to cover the general MSW management, treatment, recycling, and resource recovery. Some regulations were issued to cover other aspects such as on source reduction, segregation of waste at source, collection, transportation, landfills, incinerators, as well as industrial waste, healthcare waste and others management. National government is responsible to propose and promulgate the law, where are provided the specifications for the local government and for the private sector about the provision of Municipal Solid Waste (MSW) management service, in terms of collection, transportation, disposal and recycling. Likewise, local authority and private sector will manage Industrial waste. Currently, the Pollution Control Department, Ministry of Natural Resource and Environment (MONRE) is drafting the ministerial decision regarding the Law and legislation related to SWM management. Table 2 shows the acts, regulations, strategies and official documents related to SWM in Lao PDR.

Table 2 Acts, regulations, strategies and official documents related to SWM in Lao PDR

Year	Law/Regulation	Article
1999	Urban Planning Law (UPL) No, 3-99/NA, date April 3, 1999	-Article 21: Allocation of Specific Land within Cities Allocation of any specific land within a city is the allocation of specific and in areas which have limited land in the urban plan for the purpose of constructing and expanding public infrastructure and utilities, and other socioeconomic activities. An urban plan may have one or more specific land allocation plans, as necessary.
2004	Decree on Waste Management from Health Care Facilities (No 1706 /MOH, 2/7/2004).	-Article 8: Separation into 3 fractions: Infectious, Sharp and General Waste. -Article 9: Collection & Storage -Article 10: Handling & Internal Transfer -Article 12-13: Communal Storage & Duration
1994	Industrial Waste Discharge Regulation No. 180/MOIC, date 3/11/1994	-Article 8: Any industry having its own waste treatment system shall respond to the standards fixed by this regulation.
2010	Decree on Environment Impact Assessment. No.112/PM, date 16/2/2010	-Article 13: Environmental management and monitoring plans -Article 14: Social management and monitoring plans -Article 15: Examine the report on the environmental impact assessment, the environmental management and monitoring plan, and the social management and monitoring plan
2012	Law on Environment Protection. No 29/ NA, dated December 18, 2012.	-Article 38: Waste Disposal -Article 39: Management of Toxic and Hazardous Waste -Article 40: Obligations of Operators Involved with Toxic Chemicals and Wastes
2013	Industry Processing Law	-Article 19: Factory Waste Disposal Areas
2017	The technical assistances required to take projects forward are as follows:	-Development of the national strategy for municipal solid waste management -Formulation of the provincials strategy for municipal solid waste management -Issuance of the law on municipal solid waste management -Draft of the regulation on municipal solid waste management -Development of economic instrument for municipal solid waste management -Development of methods for data collection and analysis -Development of methods for assessing the solid waste management of town/city -Development of methods for determining gaps in the municipal solid waste management -Development of methods for developing action plan for municipal solid waste management together with activities, outputs and timeline -Development of methods for making documents required for awareness raising on SLCPs and on general municipal solid waste management -Development of methods for making spots for advertising on SLCPs -Development of methods for municipal solid waste management to reduce SLCPs -Determination of a potential pilot project for waste recycling - -Determination of a pilot project for waste segregation at sources

SOLID WASTE MANAGEMENT IN SOME LOCAL AUTHORITIES IN LAO PDR

Municipal budget and SWM cost

Table 3 shows the municipal budget, SWM revenue and expenditure for VTE, LPB and XYB from 2010 to 2012. The SWM revenue for each local authority ranged in between 0.09% and 23.2% of total municipal budget. It seems to give heavy burden to LPB's and XYB's finance, while quite light burden to VTE's. The majority of SWM expenditure of VTE and LPB was attributed to waste collection, ranging from 42.2 % to 59.5% of total SWM cost, while XYB was administration. The expenditure of landfill site operation was quite low ranging from 1.0% to 8.2%.

Table 3 Municipal budget and SWM costs of VTE, LPB and XYB from 2010 to 2012 ('000Kip)

Local Authority	VTE			LBP			XYB		
Year	2010	2011	2012	2010	2011	2012	2010	2011	2012
Municipal budget	-	-	10,938,000,000	-	-	10,700,000	-	-	4,700,00
SWM revenue									
Subsidy CG[1)]	-	100,000	100,000	443,000	435,000	435,000	-	-	-
Self-budget	3,943,054	5,943,153	3,500,000	137,142	151,883	100,000	170,510	-	-
Income SWM	5,294,343	5,606,448	6,365,016	655,455	604,394	1,201,857	532,829	866,206	1,091,292
Subsidy others	-	-	-	300,000	200,000	237,574	113,230	-	-
Total	9,237,397	11,649,601	9,965,016	1,535,597	1,391,277	1,974,431	816,569	866,206	1,091,292
(% of municipal budget)	-	-	(0.09%)	-	-	(18.5%)	-	-	(23.2%)
SWM Expenditure									
Collection	4,876,225	5,462,404	5,343,109	630,666	474,225	677,809	551,361	301,249	314,262
	(47.3%)	(42.2%)	(52.1%)	(59.5%)	(59.0%)	(36.8%)	(67.6%)	(28.8%)	(35.4%)
Street cleaning	3,943,054	5,943,153	3,500,000	106,941	121,651	364,973	5,773	54,000	74,000
	(38.3%)	(46.0%)	(34.2%)	(10.1%)	(15.1%)	(19.7%)	(0.7%)	(5.2%)	(8.3%)
Landfill site	850,000	876,000	652,376	21,765	8,000	85,800	47,200	36,000	23,181
	(8.2%)	(6.8%)	(6.4%)	(2.1%)	(1.0%)	(4.6%)	(5.8%)	(3.5%)	(2.6%)
Administration	638,738	646,454	750,000	300,000	200,000	720,000	211,364	652,138	477,058
	(6.2%)	(5.0%)	(7.3%)	(28.3%)	(24.9%)	(38.9%)	(25.9%)	(62.5%)	(53.7%)
Total	10,308,017	12,928,011	10,245,485	1,059,372	803,876	1,848,582	815,698	1,043,387	888,501
	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)

1) CG: Central Government

Source: JICA "The preparatory survey on the project for improvement of solid waste management in environmental sustainable cities in Loa People's Democratic Republic"(2014)

Waste composition and waste stream

Table 4 shows the physical composition of waste for three local authorities in 2012. The waste composition of municipal waste in Lao PRD seems to compose of approximately 70% of bio-degradable waste, approximately 15-20% of recyclable waste such as plastic, paper and metal. Introducing the compost for kitchen waste, and the grass and wood is effective as intermediate treatment to reduce the discharge amount of waste and mitigate the environmental issue at the final disposal site in VTE, LPB and XYB.

Table 4 Composition of waste in wet base in 2012

Physical composition	Unit	VTE	LPB and XYB
Kitchen waste	%	34	39
Grass & wood	%	30	30
Paper	%	7	6
Plastic	%	12	8
Glass	%	7	2
Textile	%	5	4
Metal	%	1	1
Leather & rubber	%	3	1
Inert (sand & sand)	%	1	4
Others	%	0	5
Total	%	100	100
Applicability			
Compostable	%	64	69
In-organic recyclables	%	36	30

Source: 1) JICA" Laos Pilot Program for Narrowing the Development Gap towards ASEAN Integration Environmental Management Component Project Completion Report Supplement Book" (2015)

Waste stream shows the waste amount and ratio of generation, collection, recycling, and disposal.

Figure 1 and Table 5 exemplified the result of waste stream in VTE, LPB and XYB in 2012. Base on the results from waste stream investigation in VTE, LPB and XYB, the rate of waste collection ranged from 31.9 % to 76.6 of waste generation. On-site recycling ranged from 5.2% in VTE, 1.4% in LPB and 0% in XYB, while off-site recycling ranged from 2.9% to 3.5%. The waste self-disposal ranged from 31.4% to 61.9%, while final disposal ranged from 29.8% to 64.3%.

The waste collection amount in three local authorities increased after the Japanese Government grant aid project in 2016, such as the distribution of waste collection vehicles and the construction of waste transfer station. The project granted 47 waste collection vehicles to VTE, 8 collection vehicles to LPB and 4 collection vehicles to XYB in 2016. Expected increased waste collection amount from 2015 to 2020 is 190.4 ton/day in VTE, 33.8 ton/day in LPB and 19.9 ton/day in XYB respectively. The planned waste amount of transferring at constructed transfer station is approximately 50 ton/day in 2020.

INTERMEDIATE TREATMENT AND FINAL DISPOSAL

Since the majority of waste composition in VTE, LPB and XYB is bio-degradable waste, the most suitable intermediate treatment system is on-site and off-site compost plant to reduce the discharge amount of bio-degradable waste and to mitigate environmental issue at the disposal site. Although the activities of intermediate treatment was not so common in Lao PDR before, the pilot project of composting system was introduced in three local authorities by Japan International Cooperation Agency (JICA) technical cooperation project since 2011 to 2015. The composting system consists of on-site composting (home compost barrel) in three local authorities and off-site composting (windrow compost) in LPB.

There was no engineered landfill site in three local authorities due to lack of budget, technical knowledge and human resource, and those often cause environmental issues before the rehabilitation pilot project by above mentioned JICA technical cooperation project and the procurement of heavy machinery granted by Japanese Government in 2016.

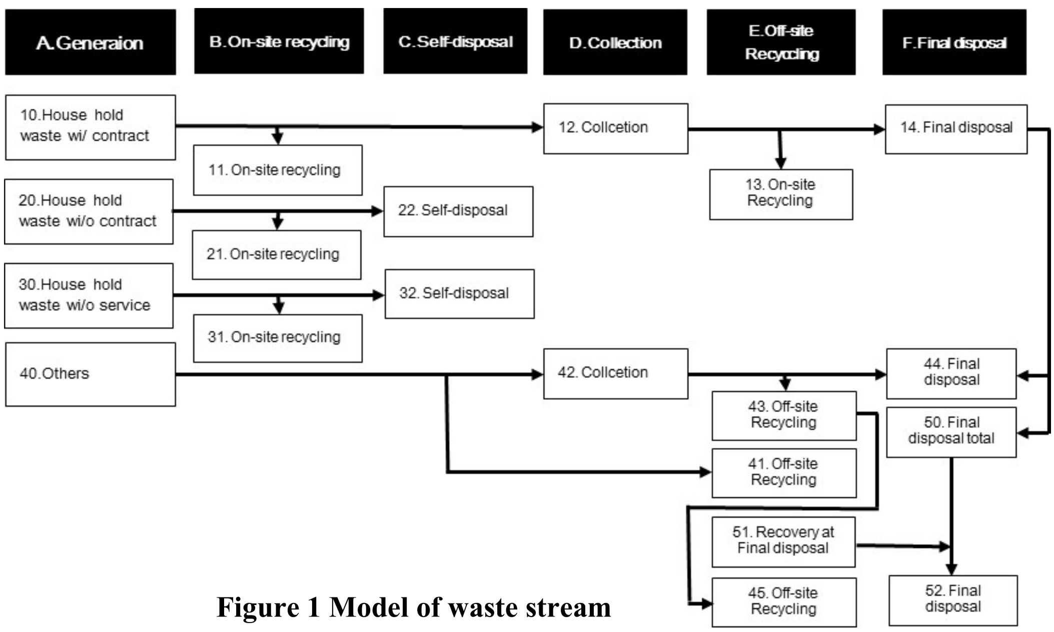

Figure 1 Model of waste stream

Table 5 Detail of waste stream and waste generation rate in wet base in 2011

Items	VTE		LPB		XYB	
Detail of waste stream (ton/day)						
A. Generation	655	(100%)	70	(100%)	38	(100%)
10.Household waste w/ contract	94		30		11	
20.Household waste w/o contract	155		2		1	
30.Household waste w/o service	276		20		21	
40.Others	130		18		5	
B. On-site recycling	34	(5.2%)	1	(1.4%)	0	(0%)
11.On-site recycling of "10.Houehold waste w/ contract"	6		1		0	
21.On-site recycling of "20.Houehold waste w/ contract"	10		0		0	
31.On-site recycling of "30.Houehold waste w/ contract"	18		0		0	
C. Self-disposal	403	(61.6%)	22	(31.4%)	22	(59.8%)
22.Self-disposal of "20.Houehold waste w/o contract"	145		2		1	
32.Self-disposal of "30.Houehold waste w/o service"	258		20		21	
D. Collection	209	(31.9%)	46	(76.6%)	16	(42.1%)
12.Collection of "10.Houehold waste w/ contract"	88		29		11	
42.Collection of "40.Others"	121		17		5	
E. Off-site Recycling	23	(3.5%)	3	(4.3%)	1	(2.6%)
13.Off-site recycling of "10.Houehold waste w/ contract"	4		0		1	
41.Off-site recycling before collection of "Others"	8		1		0	
43.Off-site recycling after collection of "Others"	9		1		0	
51.Recovery at final disposal	2		0		0	
F. Final Disposal	195	(29.8%)	45	(64.3%)	15	(39.5%)
14.Final disposal of "10.Houehold waste w/ contract"	84		29		10	
44.Final disposal of "Others"	113		16		5	
50.Final disposal total	197		45		15	
51.Recovery at final disposal	-2		0		0	
Waste generation rate (g/capita/day)						
Urban area	686		569		398	
Suburban area	695		766		536	
Weighted average	691		654		477	

Source: 1) JICA" Laos Pilot Program for Narrowing the Development Gap towards ASEAN Integration Environmental Management Component Project Completion Report Supplement Book" (2015)

The results obtained for these projects suggest that there are some requirement for constitution applicable engineered landfill. In order to improve and upgrade open dumps, taking into account the technical, economic, social and institutional aspects of local authorities are required in Lao PDR (e.g., Zurbrugg, 2003). Especially for developing structural standards of engineered landfills, there are some requirement; 1) use of local available material, topography, natural condition and public acceptance as "Site specific" 2) less construction cost and less O&M cost as "Low cost", 3) simple structure, easy maintain and operation as "Sustainable", and 4)less pollution and easy mitigation system as "Environmental friendly".

CONCLUSIONS

In spite of the acts, regulations and strategies related to SWM, and technical and financial supports through donor-oriented projects, there are still many issues of SWM in Lao PDR such as high SWM cost, illegal dumping, inadequate waste collection, low recycling rate, difficulties in landfill sitting, poor technical capacity on landfill operation and so on. Due to population growth and economic growth, the amount of waste generation will increase continuously, causing serious sanitary, environmental and social problems. In order to solve existing and future issues, proper policy decision, affordable and applicable technology for waste collection and final disposal site, proper financial, and awareness program should be more encouraged.

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PERFORMANCE EVALUATION OF A LABORATORY SCALE LEACHATE TREATMENT BIOREACTOR WITH A BIOFILTER LINER SYSTEM BY APPLICATION OF MICHAELIS-MENTEN KINETICS

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ABSTRACT
A laboratory scale leachate treatment bioreactor (LTB) with a bio-filter liner was tested for 61 days. It was operated as a semi-batch set-up with re-circulation of leachate once a day until the reactor was stabilized and triple superphosphate (0.04g/L) was introduced on the 13th day. From 21st day onwards diluted leachate was fed daily for 40 days. The bio-reactor performances are dependent on inter-relationships with media, environmental factors, and microbial activities with enzyme secretions controlling the reaction rate v. We can relate it to pH, temperature, and ionic strength. The latter is governed by the mineralization process and we could assume it to be proportional to total fixed solids (TFS) content. Therefore, v can be deduced from changes in TFS. And the initial enzyme concentration and subsequent secretions are governed by "time and rate perspectives" with initial conditions being zero and the rate of change of substrate as volatile solids content/day. We are then able to determine Michaelis-Menten kinetic parameters by using the Lineweaver Burk plot. The phase changes can be identified in obtaining kinetic parameters. They were dependent on the interventions and the rate of feeding. These results indicate that the rate of feeding can be increased because at half saturation, K_m value is less in the 2nd phase. It is an effective treatment system and the estimated time for replacement of media is 10 years.

KEYWORDS: Leachate treatment bioreactor, Mineralization, Michaelis-Menten kinetics

INTRODUCTION

Landfill leachate, especially old landfill leachate is very difficult to treat using conventional biological processes. Therefore, leachate management is one of the major challenges in the rehabilitation efforts of municipal solid waste dumpsites. As a part of rehabilitation of the Gohogoda dumpsite, Kandy and establish an integrated solid waste management system, an integrated leachate treatment system (LTS) was designed and established by combining landfill bioreactor technology with clay-polyethylene-clay biofilter liner system developed by University of Peradeniya which can reduce its strength to manageable level (Ariyawansha et al., 2013). The LTS consisting of leachate collection tanks, a leachate treatment bioreactor (LTB) followed by an algae pond, a floating wetland, two sub-surface constructed wetlands, and two charcoal filter-beds. The LTS was operated for more than three years. The LTB was designed to have an estimated hydraulic retention time (HRT) of one day and solid retention time (SRT) of 14 days under anaerobic conditions. The LTB consisted of two reactors each having a design capacity of 825 m^3 was operated alternatively, between active and passive modes. In other words, in the active mode, leachate from dumpsite was fed while recirculation of it until the reactor was full and then sent to second one for passive treatment within it by recirculation the leachate while the effluent sent to the algal pond. The LTB was filled with shredded coconut combs, coconut husks, and old municipal solid waste. Two LTBs were operated batch-wise (Priyashantha et al., 2015). Towards the later part, the performance reduced and overloading of the system took place. Therefore, we needed to develop a robust LTB that can decrease the pollution level by reducing the volatile solids (VS) content and at the same time mineralize the inorganic contents.

It is necessary to know the varieties of biochemical transformation processes that occur during the growth of microbes in bioreactors. In most of these biochemical transformations, diverse groups of micro-organisms interact with substrate and enzymes. It results in the degradation and stabilization of the substrate within bioreactors. The chemical engineering kinetic aspects of bioreactors need more investigation in order to complete the phenomena and to develop relationships useful for designing biological reactors (Bailey and Ollis, 1986). Kinetic studies permit better scientific judgment in predicting the biochemical transformation kinetics of reactors, processes, and ascertain mathematical relationships to make comparisons between different reactors and such studies can be used to optimize process conditions and reactor configurations (Basnayake et al., 2006). Like all biochemical processes, anaerobic digestion is catalyzed by extracellular and intracellular enzymes. Disintegration and depolymerization of the solid organic particles are extracellular processes, mainly catalyzed by enzymes excreted from the hydrolytic and fermentative bacteria, whereas the subsequent digestion of the soluble materials by the microbial consortia is an intracellular process resulting in the growth of the microorganisms and production of liquid and gaseous metabolites (Panico et al., 2014). Therefore, a laboratory scale LTB was designed with degraded municipal solid waste with coconut husks and rubberized materials was used as the media and tested for 61 days.

Michaelis-Menten (MM) kinetics (Michaelis and Menten, 1913) is a basic enzyme kinetics scheme, used extensively in chemistry and biology for the study of enzymatic catalysis. The rate of an enzyme-catalyzed reaction is proportional to the concentration of enzyme-substrate complex predicted by the Michaelis-Menten equation (Johnson, and Goody, 2011). The bio-reactor performances are very much dependent on inter-relationships with media, environmental factors, and microbial activities with enzyme secretions controlling the overall rate of reaction *v*. We can relate it to pH, temperature, and ionic strength. The latter, this study was conducted to evaluate the performance of the laboratory scale LTB by application of Michaelis-Menten kinetics. It enabled us to determine actual loading per day and the lifespan of the media before it will need replacement.

MATERIALS AND METHODS

The Experimental Setup

The LTB was constructed in layers of a 5 cm gravel, a 5 cm sand, a 15 cm bio-filter liner, 60 cm of media, 20 cm cover with same bio-filter liner and vegetation cap (turf). And a gas collection system, a leachate collection and a recirculation system, and sampling ports were incorporated as shown in **Figure 1**. The main body of the reactor was fabricated by using a 100 cm long PVC pipe of 11 cm diameter and an end cap for the bottom. A permeate collecting port of 2 cm diameter was placed on the middle of the end cap. An iron frame was used to erect the main reactor. Partially decomposed coconut husks, pieces of rubberized materials and partially decomposed municipal solid waste that were collected from Gohogoda solid waste dumpsite were used as filling media of the LTB. Coconut husks were chopped into small pieces of about 1.5 cm size and put into a water bath for 18 hours to remove the tannin. Rubberized materials shredded into small pieces of about 1 cm and washed thoroughly to remove impurities. Firstly, pre-processed coconut husks were filled into the reactor to occupy 5 cm thickness, followed by 15 cm layer of partially decomposed municipal solid waste, 5 cm layer of pre-processed pieces of rubberized materials, once again, 15 cm layer of partially decomposed municipal solid waste, 3 cm layer of pre-processed pieces of rubberized materials, 5 cm layer of pre-processed coconut husk pieces, 2 cm layer of pre-processed pieces of rubberized materials and 5 cm layer of pre-processed coconut husk pieces as shown in **Figure 1**. While filling the materials, a gas collection pipe of 1 cm diameter was placed at the middle of the reactor as shown in **Figure 1** and leachate inlet pipe and recirculation pipe were connected to the reactor. After filling the materials, on top of that, the clay-polyethylene-clay biofilter liner and a turf were placed as the cover. Leachate collected from Gohagoda dumpsite was used to feed the LTB. Leachate was fed through a 2 cm diameter pipe with a valve in to the reactor from a storage tank (Gnanakaran et al., 2017). The LTB was operated as a semi-batch set-up with re-circulation of leachate once a day until the reactor was stabilized. On the 13th day of operation, triple supperphosphate was introduced at a rate of 0.04 g/L. From 21st day of operation onwards, fresh leachate (60 mL/day) and freshwater (30 mL/day) were fed daily for 40 days with recirculation of effluent. VS and total fixed solid (TFS)/ash content of the effluent was measured daily by using APHA method 2540-G.

Application of Michaelis-Menten kinetics

The bioreactor performances are very much dependent on interrelationships with media, environmental factors, and microbial activities with enzyme secretions controlling the overall reaction rate *v*. We can relate it to pH, temperature, and ionic strength. The latter is governed by the mineralization process and we could assume it to be proportional to TFS content. Therefore, *v* can be deduced from changes in TFS. And the initial enzyme concentration and subsequent secretions are governed by both "time" and "rate" perspectives with initial conditions being zero and rate of change of substrate as VS content/day. The daily value is a differential and they secrete microbial enzymes from the beginning of the reactions stated as zero and it is the reactant. Rubinow and Segel, 1991 has clearly stated the importance to consider $t = 0$ in enzyme reactions as the starting point. The overall rate of reaction v is defined by Michaelis and Menten, 1913.

$$v = \frac{v_m[S]}{K_m + [S]} \quad (1)$$

Where; v_m = maximum overall rate of reaction, K_m = Michaelis-Menten constant and $[S]$ = substrate concentration. v is dependent on the reactant and it can be postulated that the rate of change of v is proportional to TFS content, where;

$$v = \sum_1^n \frac{[TFS_1]}{t_1} + \frac{[TFS_2]}{t_2} + ... \frac{[TFS_n]}{t_n} \quad (2)$$

The VS content is altered by the actions of the microbes making it available substrate, S in the course of reactions in transforming solids to liquids and then to gases. Therefore, cumulative values of VS, where dS=VS should correspond to mineralization. Then, we can write;

$$S = \sum_1^n [VS_1] + [VS_2] .... [VS_n] \quad (3)$$

The Lineveawer Burk plot (LBP) of $1/v$ vs $1/S$ was used to give v_m and K_m values (Johnson, 2013). The phase changes can be distinctively identified in obtaining the kinetic parameters. When we obtained the LBP for the total time of experimentation, there are two different slopes. The slope K_m/v_m of LBP was used to demarcate the growth phase and for each of these growth phases v_m and K_m values were obtained.

The overall reaction rate v of the 2nd phase from 15th to 61th day was used to predict the performance of the LTB, in which cumulative vt against cumulative TFS and cumulative VS, substrate S was regressed to obtain power functions. The numerical values of the products (P) from the reactions were obtained by considering the daily input of 12 g/L to give;

$$P_i = 12 - S_i \quad (4)$$

Where; P_i and S_i are products and substrate for the ith term. It was also regressed to find the relationship between P and vt. The mineralization process was determined by considering the differential of Michaelis-Menten equation, where;

$$\frac{dv}{dS} = \frac{v_m K_m}{(K_m + S)^2} \quad (5)$$

It was compared with experimental values. Since it is a diminishing term, the substrate S was deduced when; $\frac{dv}{dS} \to o$. Therefore, considering the fourth decimal;

$$S = \sqrt{\left[\frac{v_m K_m}{\frac{dv}{dS}} \times 1000\right]} - K_m \quad (6)$$

The overall reaction rate v was found by using Eq.1. In the latter part (2nd phase from 15th to 61th day), the substrate S was regressed to obtain a straight line relationship with vt. Therefore, time t was deduced to find the replacement year of the media.

RESULTS AND DISCUSSION

pH of inlet leachate before being fed into the LTB was 6.9, electrical conductivity was 8.7 mS indicating high content of dissolved salts. Salinity was 6.3 ‰. Dissolved oxygen concentration was 0.29 mg/L, total dissolved solid content was 6,230 mg/L, biochemical oxygen demand was 29,700 mg/L, total solids (TS) content was 26 g/L and VS content was 12 g/L. Average pH value of the permeate was 7.84±0.3, salinity was 0.26±0.05 ‰, electrical conductivity was 0.51±0.1 mS, total dissolved solid content was 256.7±65.7 mg/L, and dissolved oxygen concentration was 5.95±0.37mg/L. Biochemical oxygen demand value did reduce from 29,700 mg/L to 3,000 mg/L during the experimental period (Gnanakaran et al., 2017). Total TFS (ash) content of the effluent reduced from 14 g/L to 4.42 g/L and VS content reduced from 12 g/L to 2.55 g/L during the experimental period as shown in **Figure 2**. In fact, 9.59 g/L of TFS can be removed from the reactor. Cumulative TFS and VS content variations with time during the experimental period are shown in **Figure 3**. The LBP for the total time of experimentation is shown in **Figure 4(a)**. Based on the slope of this graph, two growth phases was distinctively identified and the time duration for the 1st growth phase is 1st 14 days of the experimental period and the second growth phase was 15th - 61st day of the experimental period. The LBP of each growth phase is shown in **Figure 4**. v_m for the first phase was 68.02 while K_m was 117.97. v_m for the second phase was 56.82 and K_m was 72.49 as given in **Table 1** and they were dependent on the interventions and the rate of feeding. These results indicate that the rate of feeding can be increased because at half saturation, K_m value is less in the 2nd phase, thus it is an effective treatment system.

Table 1 Kinetic parameters

Duration	K_m/v_m	v_m	K_m
Total experimental period (61 days)	1.72	64.94	111.37
1st 14 days	1.73	68.03	117.97
15th - 61st day	1.28	56.82	72.49

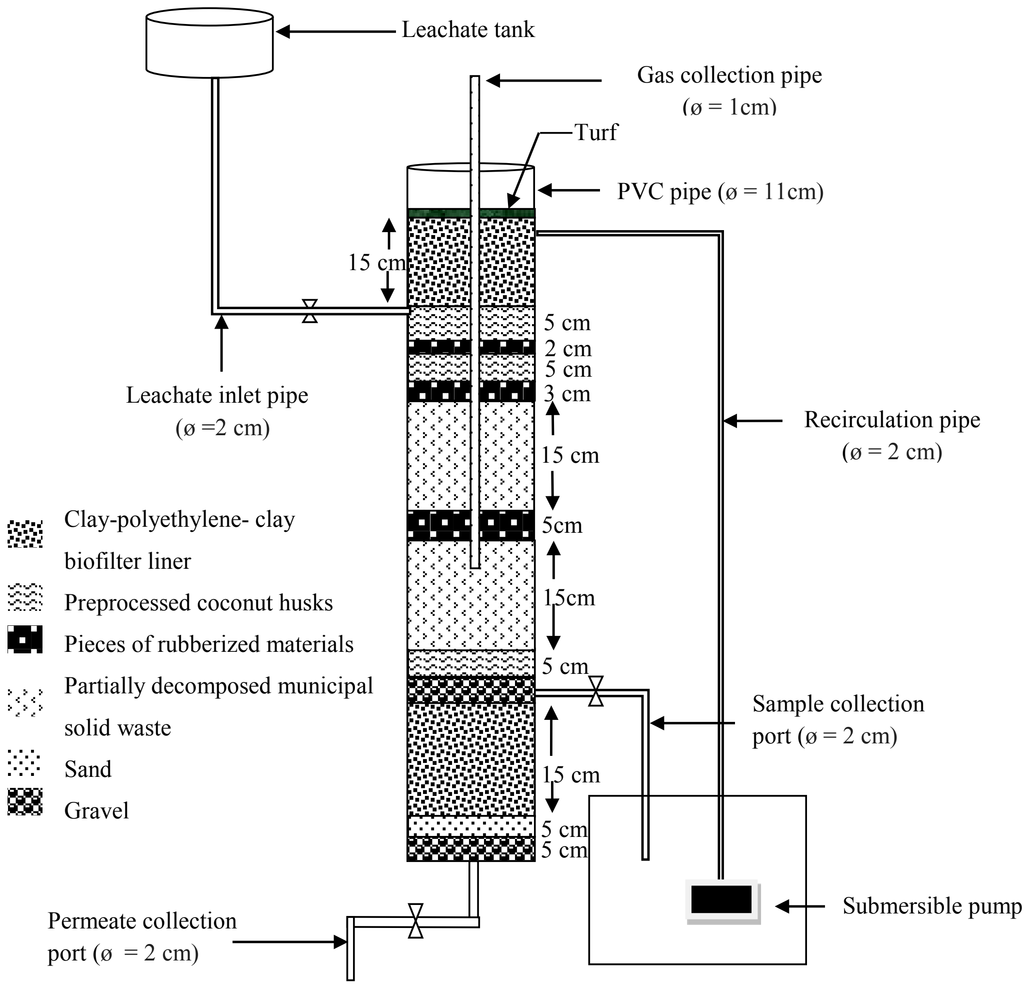

Figure 1 A schematic diagram of the laboratory scale LTB (Gnanakaran et al., 2017)

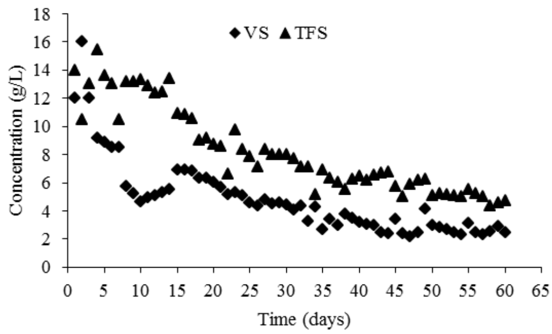

Figure 2 VS and TFS concentration of the laboratory scale LTB with time

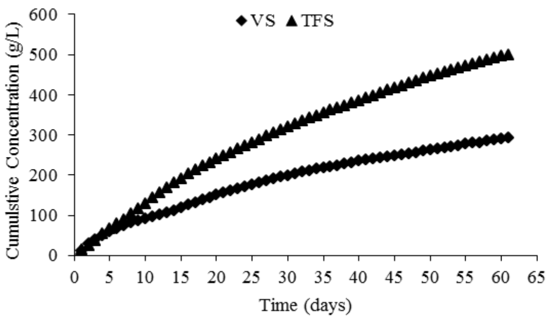

Figure 3 Cumulative VS and TFS concentration variations with time

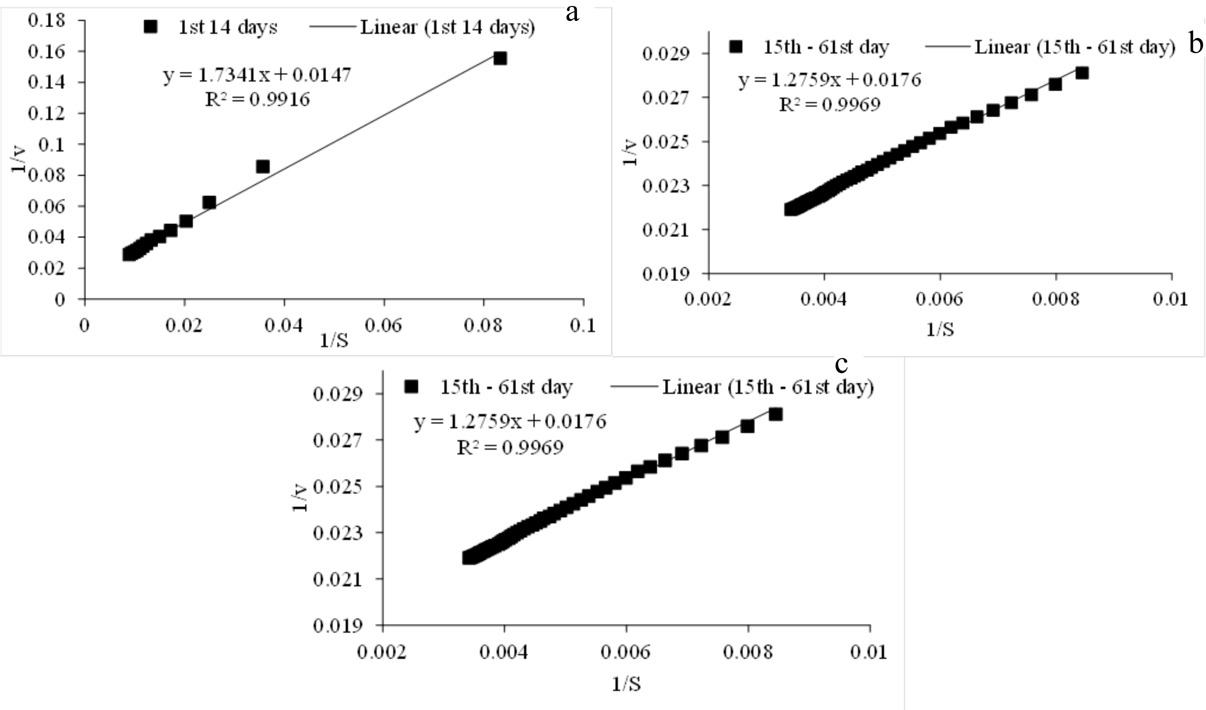

Figure 4 Lineveawer Burk plot (LBP) (a.) total experimental period (b.) 1st 14 days (c.) 15th -61st day

In reality, there is always variable loading and thus having a margin of safety is better in the design and operation of full-scale LTBs. It is important to maintain the ratio of 2:1 between leachate being fed and addition of freshwater every day. The influence of freshwater rather than relying only on recirculation of leachate seems to be one of the major factors in promoting mineralization. It is then imperative to adjust this ratio, depending on the readings of electrical conductivity and salinity. The introduction of an online automated system of monitoring and dilution of leachate with freshwater can be the best practice to prolong the useful life of media. The media was characterized by the relationships obtained between *vt* and cumulative TFS and VS as shown in **Figure 5**. The accuracy is better in the case of mineralization function of $cum.TFS = 5.235(vt)^{0.576}$ (7)

than cumulative VS. The products also gave a very accurate relationship of

$$P = 0.026(vt)^{1.224} \quad (8)$$

see **Figure 6**. The relationship of the experimental and predicted values given in **Figure 7** of the differential, $\frac{dv}{dS}$ clearly show the mineralization process. The Eq. 1, Eq. 7 and Eq. 8 were used to find the replacement time of the media and it indicates a value of more than 10 years. It was a reasonable prediction. Therefore, the large-scale LTB was rehabilitated with the tested media and the performance was better than the laboratory scale LTB.

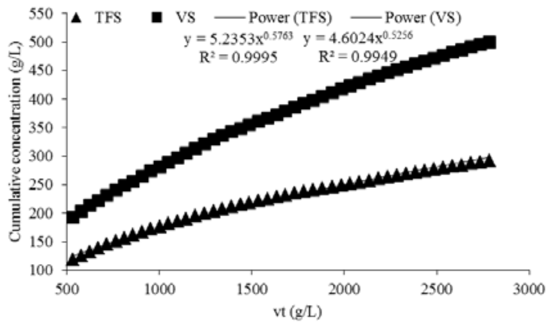

Figure 5 The relationships obtained between *vt* and cumulative TFS and VS

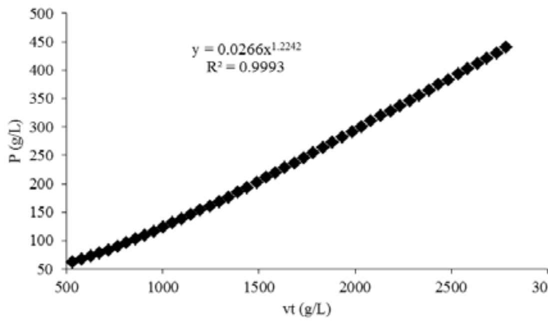

Figure 6 Relationship obtained between *vt* and products (*P*)

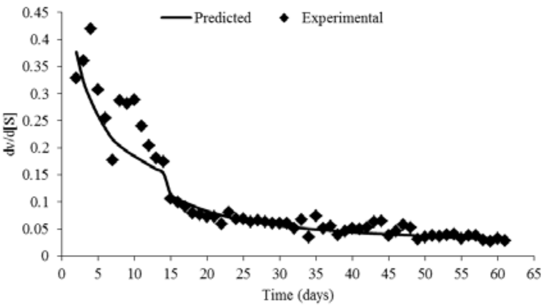

Figure 7 Experimental and predicted dv/d[S] variations with time

CONCLUSIONS

In applying Michaelis-Menten kinetics, we were able to find out that the feeding rate can be increased. Such increase can be accommodated because at half saturation, K_m value is less in the 2nd phase, indicating positive corporativity. Therefore, it can buffer variable loading and effective in mineralizing inorganic substances. It is an effective treatment system, because LTB can be operated for more than ten years before the media needs replacement. Based on these findings the large-scale LTB was rehabilitated with the tested media and the performance was better than the laboratory scale LTB.

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EXPERIMENTAL STUDY ON TORRE-PYROLYSIS PROCESS TO CONVERT MIXED MUNICIPAL SOLID WASTE INTO SOLID AND LIQUID FUEL

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ABSTRACT

Study on the waste composition in the landfill showed an increasing plastic content in older landfill, hindering the usage of biological process in the landfill. A combination of wet torrefaction (a.k.a. hydrothermal) and pyrolysis processes, namely torre-pyrolysis process, has been developed in Indonesia to treat the mixed waste into solid and liquid fuel. A mixture of organic waste, polypropylene and aluminum-laminated plastic waste was torrefied in a 2.5 L reactor using saturated steam in the temperature range of 150 to 200 °C. Afterwards, the plastic part of the products were pyrolyzed in the temperature of 500 °C to produce oil, while the organic parts were prepared for briquetting. While the volatile parts of organics were devolatilized and having higher fixed carbon content after the wet torrefaction process, it was observed from thermogravimetric and SEM analysis that the plastic parts were not decomposed. The plastic part, however, was showing increasing density due to agglomeration during the torrefaction, and after underwent pyrolysis process was converted into oil-like liquid, showing the properties similar to gas oil. It can be concluded that the torre-pyrolysis process can be a revolutionary solution to treat mixed MSW without any separation required to produce usable solid and liquid fuel.

Keywords: Mixed waste, Hydrothermal, Wet torrefaction, Pyrolysis, Waste-to-fuel

INTRODUCTION

Many major cities in Indonesia are struggling to handle their Municipal Solid Waste (MSW) due to limited landfill area. Unfortunately, the waste management carried out by the government is still using “the end of pipe” solution (Chaerul et al., 2007), omitting the waste generation prevention and focus only on the generated waste. The MSW treatment procedure is also practicing the conventional way of collecting, transporting, and disposal of waste to a landfill as the final disposal site. Compared to Europe, the legislation has adopted that landfilling of all recyclable waste shall be prevented by 2025, and European states should virtually eliminate landfill by 2030 (European Economic and Social Comm., 2017).

On the other hand, the shortage of fossil fuels in the world has already affected the economic growth of many countries, and ever since many governments were starting to develop alternative energies to reduce their dependency on the non-renewable fuels (BP Report, 2014). Recently, though, the oil and coal prices were steadily decreased, but still the alternative energies are needed to prevent similar fuel shortage in the future. One of the fuel source can be supplied from the treated MSW, so in this way the waste problem can be solved at the same time. The challenge is to treat the mixed waste into a uniform fuel, especially in developing countries where waste separation is still in progress.

This paper discusses the processing of plastics and organics in the mixed MSW by employing the combination of wet torrefaction (a.k.a. hydrothermal) and pyrolysis process to produce solid and liquid fuel. The wet torrefaction experiments were conducted in the temperature of lower than 200 °C, while the pyrolysis experiments were conducted in the temperature of lower than 500 °C. These conditions are different compared to the typical hydrothermal processing temperature of 250 °C in subcritical water condition (Yoshikawa et al., 2014).

The hydrothermally treated products have been reported to be utilized as solid fuel (Prawisudha et al., 2013), fertilizer (Jambaldorj et al. 2007), livestock feed, and diesel oil (Fröling et al., 2005) depends on its raw input. The method has been conducted for producing chlorine-free solid fuel from plastic waste at working temperature of 225 °C (Prawisudha et al., 2011). Similar method, but conducted in higher temperature, has shown the ability to separate the aluminum from plastic in the laminated aluminum used in snack packaging (Mu'min et al., 2017).

The wet torrefaction process in the lower temperature, however, was able to produce separated organic and plastic waste (Prawisudha et al., 2015). This separated plastic has very high potential as the raw material of pyrolysis process, converting the plastic waste into liquid fuel.

EXPERIMENTS

Mixed Waste Characteristics

The study started with a field survey to the final landfilling site of Bandung municipality. It has about 250 hectare area and located in Sarimukti Village, West Bandung Regency. It received about 1,200 – 1,800 ton waste generated from Bandung City, Cimahi City, and West Bandung Regency daily. The methods to measure and calculate the waste composition were adopted from SNI 19-3964-1994 for Sampling and Measurement Method of Municipal Solid Waste and ASTM D 5231 Standard Test Method for Determination of Unprocessed Municipal Solid Waste. Waste sample was sorted into several categories provided by the standard (organic, paper, glass, metal, plastic, and etc) and weighed to obtain the fraction of each category, as shown in Figure 1. Two graphs are shown: the new waste at the top and older waste (2 – 3 months old) at the bottom.

It can be seen from the figure that in older landfill site the waste composition has changed, especially in the reduction of organic wastes. The plastic portion was consequently increased due to this reduction, but the similar fate did not occurred for metals and others, since probably they were collected by scavengers during the landfilling period.

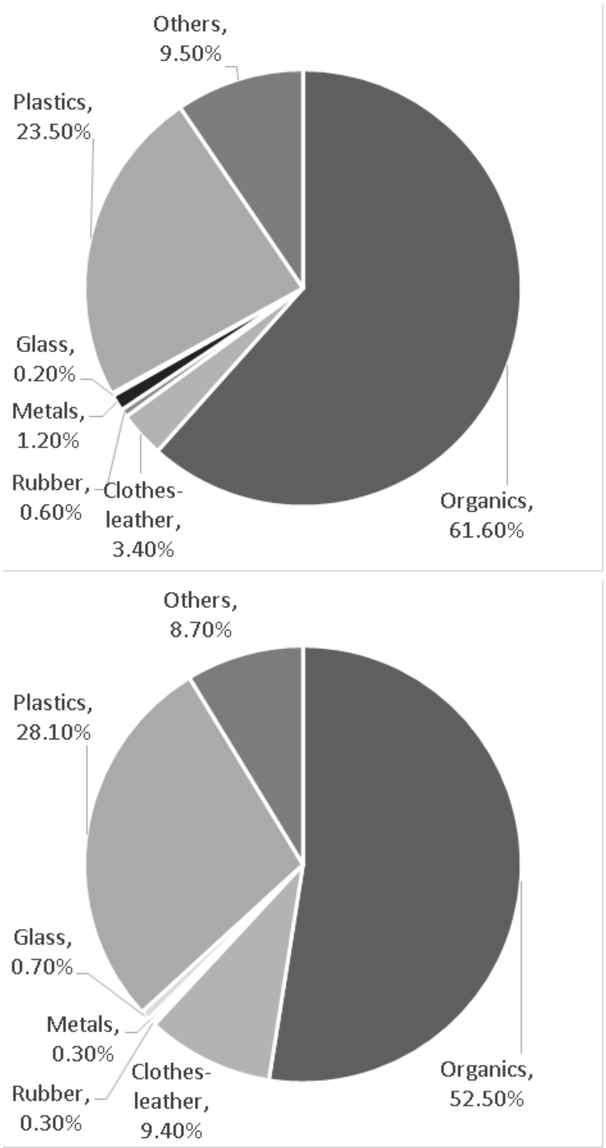


Figure 1 Waste composition in new landfill site (top) and older landfill site (bottom).

Wet Torrefaction Experiments

The survey results indicated the amount and composition of waste as the raw sample in the experiment. Only non-recyclable plastic and organic waste were used in the raw sample, and its ratio was set to be 1:5 as that of survey result. A 300 g mixture of banana leaves, rice, cassava stem and leaves (as representative of organic waste) and instant noodle plastic and snack packaging (as representative of plastic waste) was added with 750 mL demineralized water and inserted into a 2.5 L reactor. An integrated 2000 W band heater was used to heat the reactor with the schematic diagram shown in Figure 2.

The process started after the samples and water were locked inside the reactor cylinder and subsequently the heater was turned on, increasing the temperature of the mixture until reaching the set operating temperature of 150, 175 and 200 °C. The temperature was then held constant for 30 min, and subsequently the treated product was taken from the reactor and the solids were separated from the liquids by using 2 mm mesh net before being dried.

Pyrolysis Experiments

The plastic products after wet torrefaction process was separated by wet gravitation and visual inspection. Usually the plastics would float in the water, while the organic products would sink. The color of plastics would tend to be greyish, while the color of organics would tend to be dark brown. The separated plastics were then inserted into a 3 L pyrolysis reactor with setting temperature of 500 °C and heating rate of 20 °C/min. Condensation in the reactor was conducted by using water at 6 °C as the coolant, and the condensed gases were collected while the non-condensable gases were carried into an activated carbon bed.

Product Analysis

Gallenkamp adiabatic bomb calorimeter was used to obtain the higher heating value with reference to ASTM D 5865 "Standard Test Method for Gross Calorific Value of Coal and Coke". The physical composition

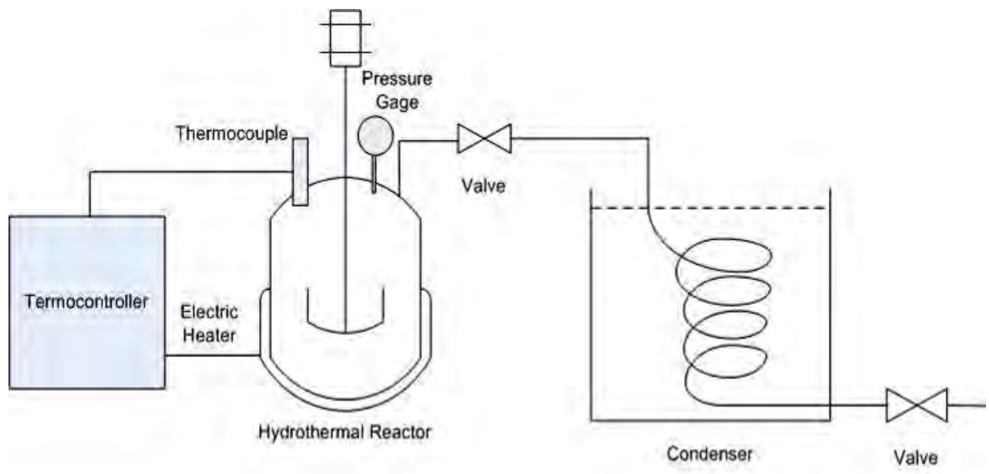


Figure 2 Schematic diagram of hydrothermal experiment.

analysis was conducted using LECO TGA-601 analyzer at Mineral and Geothermal Resources Center Laboratory, according to ASTM D 7582 “Standard Test Method for Proximate Analysis of Coal and Coke by Macro Thermogravimetric Analysis”. The results obtained were in air dried basis (adb) condition, therefore a conversion to dry base (db) was required using ASTM D 3180 “Calculating Coal and Coke Analyses from As-Determined to Different Bases” standard. The analyzed products were only of organics, and the plastics were assumed to retain their composition as shown in other paper (Mu’min et al., 2017). The liquid product from pyrolysis process was analyzed in GC-FID for its carbon number, and its cetane index was measured using ASTM D 4737 “Test Method for Calculated Cetane Index by Four Variable Equation” standard.

RESULTS AND DISCUSSIONS

Physical Appearance of Torrefied Products

Two forms of solid product were obtained; one part was soft material from organics and the other was hard plastic as shown in Figure 3. Below 175 °C, the organic parts were still fibrous, dominated by the hard organics, but in the higher processing temperature, uniform powdery materials were observed. The organic parts was also becoming darker after processing in higher temperature.

For the plastic parts, however, significant difference can be observed at lower temperature products. At 150 °C, the plastics were still large and apparently not yet melted. It can be concluded that for organic parts, increasing temperature will produce smaller particle size, due to more hydrolyzed particles producing shorter chemical chain (Robbiani, 2013). The plastics, however, would not melt and degrade below 161 °C (for polypropylene) and the separation phenomenon may not occurred at 150 °C processing temperature.

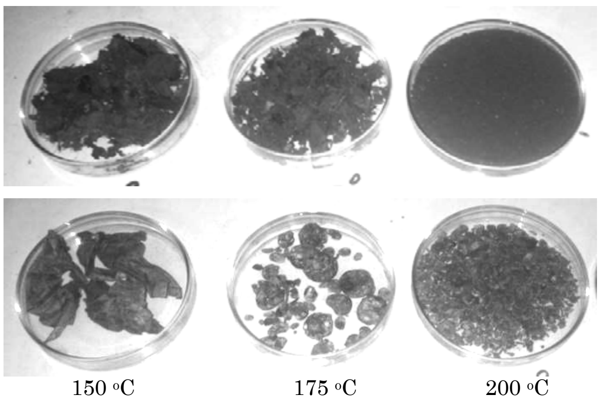
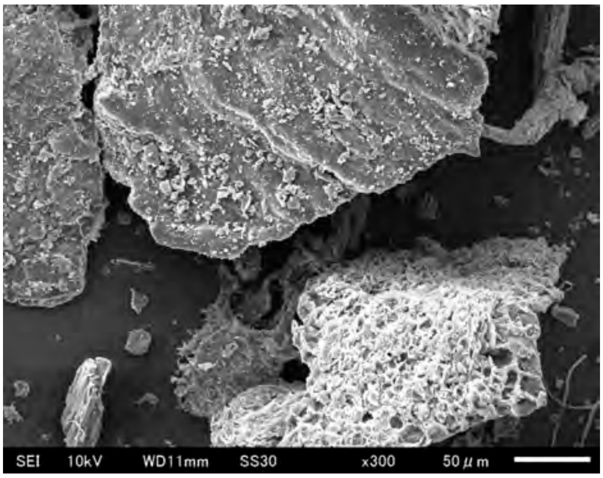


Figure 3 Organic parts (top) and plastic parts (bottom) products at various temperatures.

Scanning Electron Microscope results showed that after wet torrefaction process, some degraded organics would stick on the plastic part, but no reaction between the plastics and organics as shown in Figure 4 below.



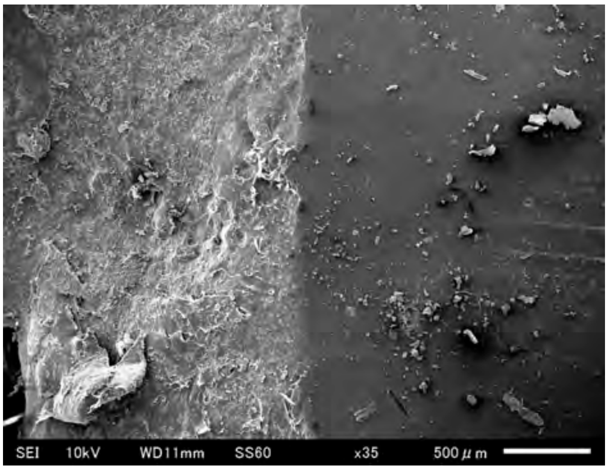


Figure 4 (Top) Organic parts sticking on the surface of plastic bulk and (bottom) the cutaway image of plastic parts showing no organic impurities.

Physical Composition and Heating Value

The thermogravimetry analysis result of the organic products shown in Figure 5 suggests that the volatile matter content was reduced as the processing temperature increased. This is related to the dilution of volatile organics into the water part, resulted in some increase in the fixed carbon content (Yoshikawa et al., 2014). The increase of the carbon content will further improve the calorific value of the organic fraction product near to that of subbituminous coal (5500 kcal/kg), as shown in Figure 6.

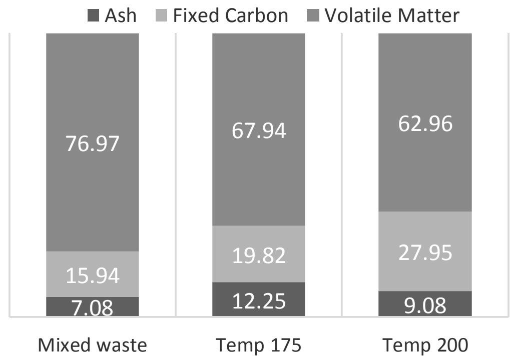


Figure 5 Physical composition of organic products in various torrefaction temperatures.

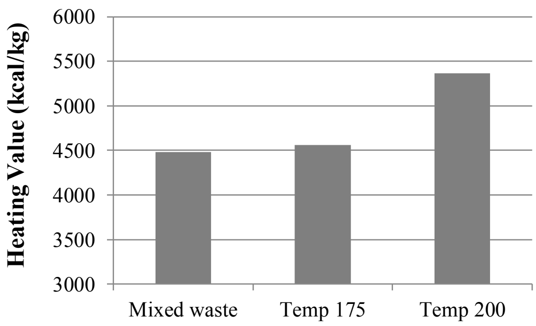


Figure 6 Heating value of organic products in various torrefaction temperatures.

Post-torrefied Pyrolyzed Plastic Characteristics

The bulky plastic after wet torrefaction process was then further pyrolyzed to obtain the liquid part. From 200 g torrefied plastic inserted into the reactor, an average of 120 mL pyrolytic oil was obtained, indicating a converting efficiency of 0,6 L/kg plastic.

The combustion of the pyrolytic oil in a small oil stove showed adequate result. The flame color was near to blue, and visually similar to the typical kerosene. The chemical characteristics results, however, still far from the standard for diesel oil, since the pyrolytic oil showed Cetane index of 25 (lower than standard of 45 in Indonesia). The chemical composition obtained from GC-FID shown in Figure 7 also indicated similar result: the carbon compounds constituted the pyrolytic oil was lighter than diesel oil.

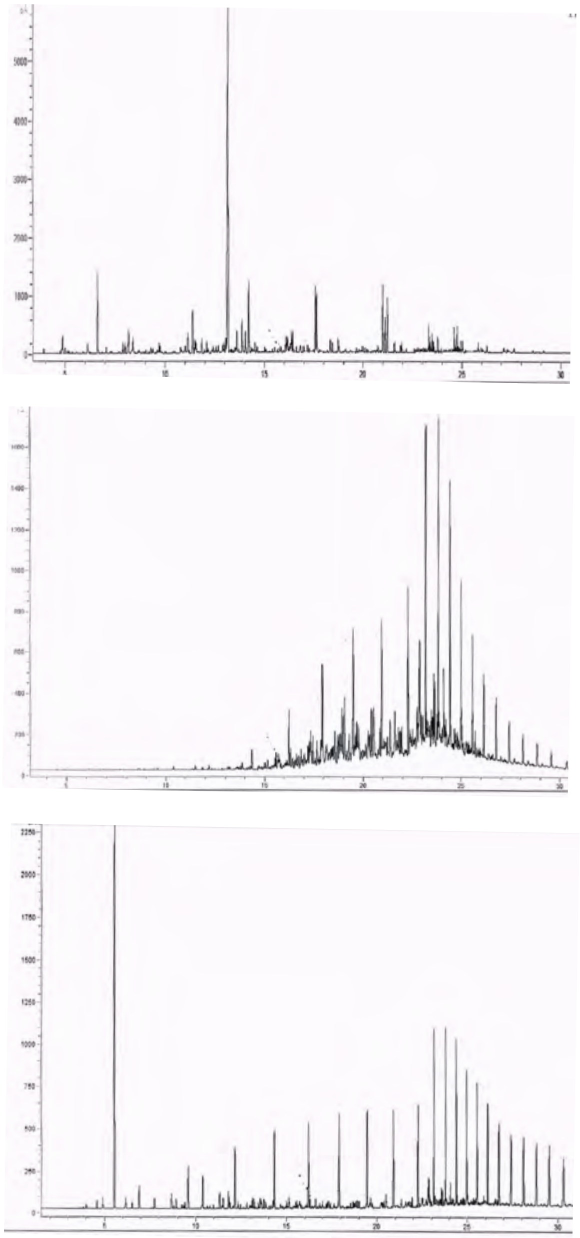


Figure 7 GC-FID results of pyrolytic oil (top), diesel oil (middle), and crude oil (bottom).

CONCLUSIONS

A combination of wet torrefaction and pyrolysis processes, namely torre-pyrolysis process, has been developed to treat the mixed (municipal solid) waste into solid and liquid fuel. Experimental results showed that wet torrefaction can improve the characteristics of mixed MSW at the wet torrefaction temperature of 200 ^{o}C and residence time of 30 min to produce higher heating value of the organic part product near to that of subbituminous coal.

The plastic parts after wet torrefaction were easily separated without altered chemical characteristics, and became agglomerated and bulkier so that their bulk density were increased and easier to enter the pyrolysis reactor. The produced oil was at 0.6 L/kg process efficiency; however, the Cetane index of the oil was still at low number of 25, with majority of hydrocarbon constituents were in light hydrocarbons, lower than that of diesel oil.

The results suggest that by employing wet torrefaction, the organic fibers in the mixed waste can be easily separated from plastics while at the same time became carbonized and suitable as solid fuel. The plastics will also be separable and denser, suitable for pyrolysis application. Therefore, the torre-pyrolysis process can be a revolutionary solution to treat mixed waste without any separation required to produce high calorific solid and liquid fuel.

Further pyrolysis research to obtain optimum results for plastic waste and packaging, however, are still needed, especially if the pyrolytic oil target is to replace the diesel oil. For typical stove, however, the pyrolytic oil showed similar result as kerosene, and further field experiments will be conducted to confirm the result.

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