Global J. Environ. Sci. Manage.,4(2): 113-126, Spring 2018
DOI: 10.22034/gjesm.2018.04.02.001

ORIGINAL RESEARCH PAPER

Suitability assessment for handling methods of municipal solid waste

***B. Seng*[1,*], *T. Fujiwara*[2], *B. Seng*[3]**

[1]*Graduate School of Environmental and Life Science, Okayama University, 3-1-1 Tsushima, Kita, Okayama 700-8530, Japan*

[2]*Waste Management Research Center, Okayama University, 3-1-1 Tsushima, Kita, Okayama 700-8530, Japan*

[3]*Department of Rural Engineering, Institute of Technologies of Cambodia, Russian Federation Blvd, Phnom Penh, Cambodia*

Received 7 October 2017; revised 23 December 2017; accepted 10 January 2018; available online 1 April 2018

ABSTRACT: Solid waste management is challenging in Phnom Penh city, Capital of Cambodia. The only one formal treatment taken is the final disposal of mixed waste into an open dumpsite. The current study analyses the physical and chemical characteristics of municipal solid waste disposed of in the dumpsite to assess their suitable handling methods. The current study found that the major compositions of waste are food waste (49.18%) and plastic (21.13%), and recyclable waste shares about 17.28% of the total. On average, it contains 60.92% moisture, 35.89% combustible, 3.19% ash, 58.32% carbon and 1.05% nitrogen. High calorific value is 10.03 MJ/kg when the low calorific value is 7.77 MJ/kg. The moisture content is too high to meet the technology demands, especially in the rainy season. It seems workable for incineration without energy recovery. Gasification for melting and incineration with energy recovery are only suitable for the dry season. If the solid waste is well pre-separated, material recovery could be one of the suitable handling methods. Food waste, wood and leave could be digested in the one-stage continuous wet system and co-composted, and plastic is appropriate for refuse-derived fuel generation. The study recommends that the waste pre-separation should be requisite for any handling methods.

KEYWORDS: *Open dumpsite; Pre-separation; Recovery; Solid waste management; Suitable handling method.*

INTRODUCTION

Solid waste in Phnom Penh city, Cambodia is improperly managed. Per capita, solid waste generation was about 0.74 kg/day in 2003 (JICA, 2005) and 0.91 kg/day in 2009 (Sang-Arun *et al.,* 2009) that was also in the range of generation rate, 0.30-1.44 kg/day, in the developing countries (Troschinetz and Mihelcis, 2009). As a center for national economic development, generation rate would grow from 0.89 Gg/day in 2003 (JICA, 2005) to 2.78 Gg/day by 2020 (Seng *et al.,* 2013). Municipal solid waste (MSW) in the city is shared of 62.9% household waste and 37.1% commercial waste (JICA, 2005), and the management system consists only of the collection, transportation, and disposal (Fig. 1). The informal sector plays a key role in recycling (Sothun, 2012; JICA, 2005; Kum *et al.,* 2005), and there are more than 2,000 junk pickers (Sang-Arun *et al.,* 2011) in the city. Such recyclable materials are exported abroad for the recycling markets (Sothun, 2012). However, recyclable materials were openly dumped in the mixed waste at Stung Meanchey dumpsite from 1965 to 2009 and are still dumped at Dangkor Landfill to present (Seng *et al.,* 2010).

*Corresponding Author Email: *bandithseng@gmail.com*
Tel.: +8180 3896 1494 Fax: +8186 251 8994

Note: Discussion period for this manuscript open until July 1, 2018 on GJESM website at the "Show Article".

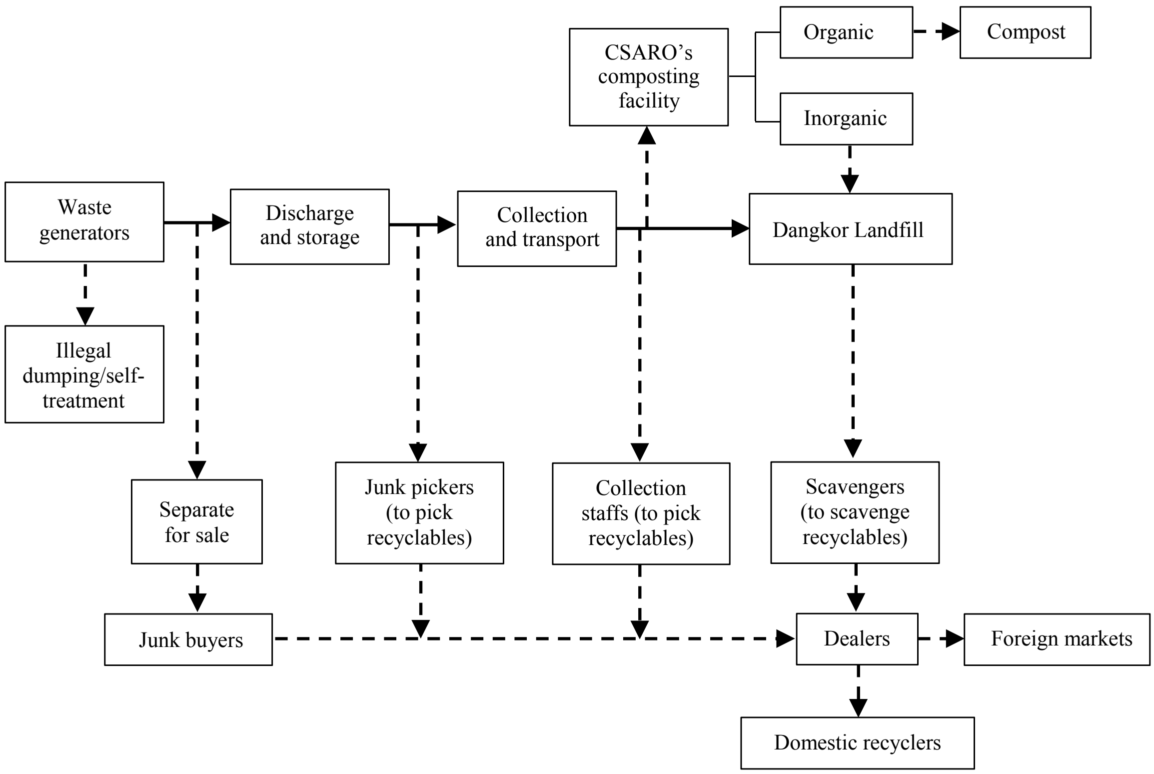

Fig. 1 Municipal solid waste flow in Phnom Penh city
(Seng *et al.*, 2010; Sothun, 2012; CSARO, 2015)

Mongtoeun *et al.* (2014) also indicated that about 61% of commercial waste could be reduced if the recyclable materials and food waste are well-sorted. Phnom Penh has one composting facility, a site run by Community Sanitation and Recycling Organization (CSARO). In 2015, it produced about 35.6 Mg compost (CSARO, 2015). Anaerobic digestion (AD) has also been introduced in Cambodia, especially the rural areas. A total of 20,000 bio-digesters were built between 2006-2012. Yet, there are only household-scale projects (Buysman and Mol, 2013). No commercial scale of biogas digester development was reported. The current management system for the solid waste in Phnom Penh city demonstrate a clear need for improvements. In an ideal scenario, it could be sustainable by enabling efficient resource consumption and pollution controls. By evolving an integrated approach into a new management system, the processes of waste reduction, segregation, transfer, recycling, recovery, and treatments could be consolidated into practices as recommended by United Nations Environment Programme (UNEP, 2013). It requires many multiplex assignments (Costi *et al.*, 2004), including appropriate technologies and sufficient resources (Abu Qdais, 2007; Ngoc and Schnitzer, 2009) and useful information for management planning (Guerrero *et al.*, 2013). However, only limited data on properties of solid waste are available in Phnom Penh at present. This study aims to analyze the physical and chemical characteristics of the solid waste in the Dangkor Landfill of Phnom Penh city to assess the suitability for handling methods. As alternatives to MSW management approach, MSW suitability of material recovery, composting, AD, refuse-derived fuel (RDF) generation, gasification with melting and incineration with and without energy recovery are significantly observed. The results would be basic that can serve for the future planning of the MSW management. The current study carried out the municipal solid waste disposed of into the Dangkor Landfill in Phnom Penh city of Cambodia in 2014-15.

MATERIALS AND METHODS

Study area

Phnom Penh city disposes of collected waste into the Dangkor Landfill, a 31.4-hectare open dumpsite for the final disposal of MSW, slaughterhouse waste and other types, except industrial and medical waste. The MSW refers to waste from residences, commerce and street sweeping. It accounts for about 99.3% of the disposed waste and amounted to 613.94 Gg in 2014 and 677.22 Gg in 2015. The slaughterhouse waste contains mostly organic matters and wastewater. The other types are waste from demolition and construction, sewage and sludge, etc. (Dangkor Landfill Data).

Data collection

The key informants were interviewed from Ministry of Environment (MoE), Phnom Penh City Hall, Dangkor Landfill, Japan International Cooperation Agency (JICA), Cambodian Education and Waste Management Organization (COMPED) and CSARO to discuss MSW management, disposal, challenges and opportunities for handling methods. Such secondary data were also collected including the total amount of MSW disposal, amount of MSW disposed of from each district of the city and the number of landfill scavengers. These secondary data were used for the design of the study, especially waste sampling method and scavenger interview.

Municipal solid waste physical characterization

There are twelve administrative districts (six outskirt and six inskirt districts) in Phnom Penh city. For physical characterization of MSW in the landfill, the city was divided into nine zones for seasonal observation in the rainy season (August 29-September 6, 2014) and the dry season (March 7-15, 2015) (Fig. 2). Six outskirt districts were merged into three zones, as their waste characteristics were presumably indistinguishable, and the other six zones were the six inskirt districts. Mixed MSW is collected by assigned trucks that are well recorded in the Landfill Database. There are various loading capacities of the trucks for collection during daytime and night-

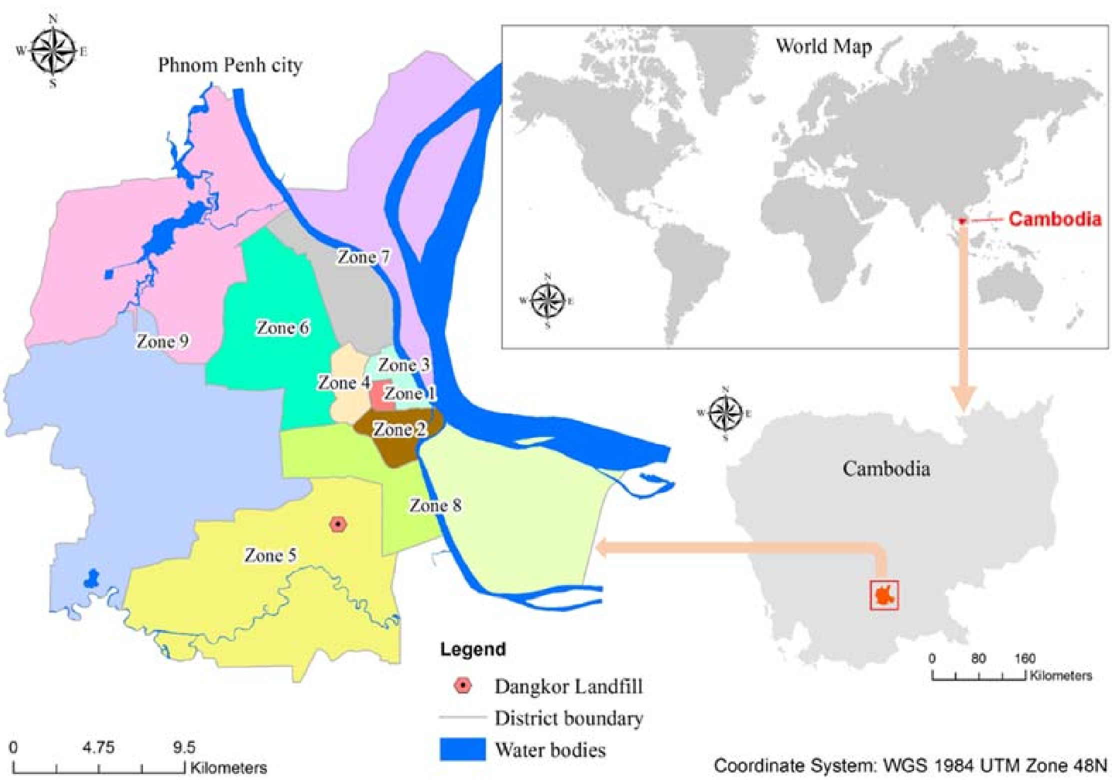

Fig. 2: Location of the study area

time shifts. The large capacity trucks usually collect waste from markets and public spaces from various places across zones to dispose of in the landfill mostly at night (Interview with key informants). But, the study had to collect the waste samples in the morning for the characterization. Waste samples were collected from nine randomly selected 2-Mg and 4-Mg-capacity trucks, each representing one of the nine zones, at a rate of 200-300 kg/truck/season after quartering. Due to a large amount of collected waste, there were 15 labours including university students, landfill staffs and scavengers assisting in this characterization study. In total, about 4,124 kg of waste was manually sorted into twelve waste types (food waste, wood and leaves, paper, textile, nappies, rubber and leather, plastic, glass, metal, stone and ceramic, hazardous waste and others) and 25 sub-compositions. Eq. 1 was used to calculate the MSW sub-compositions. ANOVA was also analysed, as of Pham Phu *et al.* (2018), to identify statistically significant difference (p-value < 0.05) of each waste sub-composition between the nine zones as outskirt and inskirt districts.

$$\mathrm{LMSW_X}\ (\%) = \sum_{i=1}^{9} \left(\mathrm{C_{X_{D_i}}}/\mathrm{M_{Di}}\right)\left(\mathrm{MSW_{D_i}}/\mathrm{LMSW}\right) * 100 \quad (1)$$

where $\mathrm{LMSW_X}$ is percent composition X in MSW disposed of in the landfill; $\mathrm{Cx_{D_i}}$ is the weight of composition X found in zone i (kg); $\mathrm{M_{Di}}$ is the total weight of waste sample collected from zone i (kg); $\mathrm{MSW_{D_i}}$ is the weight of MSW disposed of zone i (kg); LMSW is the weight of MSW disposed of in the landfill (kg) and 9 represents the nine zones.

Analysis of chemical characteristics

After weighing the sorted waste of each day, waste samples were collected for the analysis of chemical properties including moisture (M), combustible (B), ash, carbon (C), hydrogen (H), nitrogen (N) and high calorific value (HCV) content in both seasons. In prior to sampling of organic matters, coning and quartering were needed due to their large homogeneity. The samples were stored in polystyrene screw bottles and kept in cool bags during transportation to the laboratory. The M content was determined by drying a sample at 105 ^{o}C for 24 hours in an oven until the weight was constant. The B content was determined by measuring lost mass after continuous igniting the dry sample in a muffle furnace at 550^{o}C for two hours. The remaining weight was ash. The preparation and analysis procedures were in accordance with the standard methods of ASTM E790 (ASTM International, 2004a), E830 (ASTM International, 2004b) and E897 (ASTM International, 2004c) and Guermoud *et al.* (2009) and calculated by Eqs. 2, 3 and 4.

$$\mathrm{M}\ (\%) = (\mathrm{W_i} - \mathrm{W_f})/\mathrm{W_i} * 100 \quad (2)$$

$$\mathrm{B}\ (\%) = (\mathrm{W_i} - \mathrm{W_f})/\mathrm{W_i} * 100 \quad (3)$$

$$\mathrm{Ash}\ (\%) = 100 - (\mathrm{M} + \mathrm{B}) \quad (4)$$

Where $\mathrm{W_i}$ = the weight before drying or igniting (g); and $\mathrm{W_{f}}$ = the weight after drying or igniting (g).

The C, H and N content of the dry samples were analysed in a PerkinElmer 2400 Series II CHNS/O Analyzer with triple analyses after confirming that the analyzer attained the standard values for acid acetanilide in blank and K Factor for calibration according to the instruction manual. Eq. 5 was used to quantify the H content of wet basis ($\mathrm{H_W}$) from the dry mass.

$$\mathrm{H_W}\ (\%) = \mathrm{H} * [(100 - \mathrm{M})/100] \quad (5)$$

HCV was thrice measured by a Digital Calorimeter Model DCS-196 in accordance with ASTM E711 standards (ASTM International, 2004d) and compared to the value calculated by fractions of organic (OMW), paper (PW) and plastic (PLW) (Eq. 6). The low calorific value (LCV) is one of the criteria for showing self-combustibility of solid waste or the need for supportive fuel for thermal treatments (World Bank, 1999). LCV in kcal/kg was calculated from HCV based on Guermoud *et al.* (2009) and converted to kJ at a conversion rate of 1 kcal is 4.18 kJ in Eq. 7.

$$\text{Calculated HCV (MJ/kg)} = 0.051(\mathrm{OMW} + 3.6\mathrm{PW}) + 0.352\mathrm{PLW} \quad (6)$$

$$\mathrm{LCV\ (kJ/kg)} = \mathrm{HCV} - [6(\mathrm{M} + 9\mathrm{H_W})] * 4.18 \quad (7)$$

Suitability assessment for treatments

This assessment identifies whether the MSW is suitable for direct landfilling, composting, AD, RDF generation, gasification with melting or incineration with or without energy recovery (Table 1). Composting requires organic matter with a moisture content of 50-70% (Siti Norbaizura and Fujiwara, 2013) and carbon-to-nitrogen (C/N) ratio of 20-35 (Guermoud *et al.,* 2009). AD requires the same C/N ratio as composting with a total feedstock solid exceeding 15-20% for a one-stage continuous dry system or less than 15% for a wet system (Naik *et al.,* 2013). To generate RDF from waste directly, without dewatering, a moisture content of less than 20% ensures a necessary LCV above 12.55 MJ/kg. Gasification with melting works with an LCV above 7.11 MJ/kg when the incineration prefers 6.28 MJ/kg for technology with energy recovery and 3.35 MJ/kg for technology without energy recovery (Siti Norbaizura and Fujiwara, 2013).

Material recovery

Material recovery is considered one of handling methods for MSW management that is promoted worldwide (Matter *et al.,* 2013; Linzner and Salhofer, 2014; Hotta and Aoki-Suzuki, 2014). This study performed the suitability evaluation of material recovery by observing ongoing activities of informal recycling in the landfill. There were 300 landfill scavengers scavenging recyclables for making their living (Interview with landfill officer). The landfill scavengers were interviewed, as also performed by Sasaki and Araki (2014), by using a structured questionnaire. The main questions were about types, quantities market price, and economic benefits of materials that were usually scavenged. A total of 75 scavengers were interviewed to meet a sample adequate to assure statistical significance, as calculated by the formula of Yamane (1967) cited from Singh and Masuku (2014) with a 10% error level in Eq. 8. In remarks, the waste pickers and junk buyers outside of the landfill were not included.

$$n = N/(1 + N(e)^2) = 75 \tag{8}$$

Where, n = total sample of scavengers; N = total number of scavengers and e = error level (10%).

Results of this scavenger survey were used to compare with the data of physical characterization as it is assumed that the general MSW contains the recyclable materials (TR_X) and unrecyclable materials. The amount of materials that the landfill scavengers could scavenge is defined as the number of recovered materials (RM). Thus, the total amount of the recyclables was the sum of the weight of the recovered and unrecovered materials. The recovered amount of material X (RM_X) equalled to the sum of the amount recovered by all scavengers (Eq. 9). Eqs. 10 and 11 were used to calculate the percent amount of the recovered material X ($\%RM_X$) and the recyclability (Re_X). As the amount of RM_X and its market price obtained, Eq. 12 calculated the total benefits of recovered material X (RR_X).

$$RM_X\ (\text{kg}) = \left(\left(\sum_{n=1}^{75} X_n\right)\Big/ n\right) * N \tag{9}$$

$$RM_X\ (\%) = (RM_X/MSW_X) * 100 \tag{10}$$

$$Re_X\ (\%) = (RM_X/TR_X) * 100 \tag{11}$$

$$RR_X\ (\text{USD/kg}) = RM_X * MPx \tag{12}$$

Where, X = the recovered material (paper, plastic, metal, …), RM_X = recovered amount of material X (kg), MSW_X = the amount of material X in total MSW (kg), Re_X = percent recoverability of material X (%), TR_X = total recyclable amount of material

Table 1: Criteria for suitability assessment

Treatment types	Criteria
Direct landfilling	M < 85%; B * (100 - M) < 0.1
Composting	50% < M < 70%; 40B * 0.5 > 6M; C/N ratio = 20 to 35
AD	C/N ratio = 20 to 35; Total solid < 15% (one stage wet system) Total solid > 15 to 20% (one stage dry system)
RDF	M < 20%; LCV (MJ/kg) = 0.418 * 50B > 12.55
Gasification with melting	LCV (MJ/kg) = 0.418 * (50B - 6M) > 7.11
Incineration without energy recovery	LCV (MJ/kg) = 0.418 * (50B - 6M) > 3.35
Incineration with energy recovery	LCV (MJ/kg) = 0.418 * (50B - 6M) > 6.28

Source: Guermoud *et al.,* 2009; Naik *et al.,* 2013; Siti Norbaizura and Fujiwara, 2013

X in total recyclables (kg), RR_X = the revenue of recovered material X (USD/kg), and MP_X = market price of material X (USD/kg).

RESULTS AND DISCUSSION

Physical characteristics of municipal solid waste

On average, food waste makes up the largest proportion of total disposed MSW in Phnom Penh city, 49.18%, followed by plastic, 21.13%. The proportion of food waste is smaller in Bangkok, Thailand, where it is about 35.89%. The plastic proportion of both cities is essentially the same as of 20.76% in Bangkok (Inazumi *et al.,* 2011). The other categories break down as follows: textile, 8.01%; wood and leaves, 6.69%; mixed paper, 5.70%; nappies, 2.91%; stone and ceramic, 1.54%; glass, 1.42%; metal, 1.05%; rubber and leather, 0.87%; cardboard, 0.84%; batteries, 0.07%; medical waste, 0.10%; residues, 0.49%. According to MoE and COMPED (2006), batteries and medical waste are hazardous. Medical waste, which includes both sharp implements and infectious materials, is separately collected from health care centers and hospitals and conveyed to an incinerator nearby the Dangkor Landfill (Interview with MoE official). Some portions of medical waste, however, remain mixed within the disposed of MSW as no service has been set up for separate medical waste collection in residential areas. As of this writing, no such landfill for hazardous waste has been constructed in the county. The batteries and medical waste are still dumped in the landfill. To minimize leakage of heavy metals into the environment, MoE and COMPED (2006) recommended disposal of batteries into a separate landfill for hazardous waste. Among the twelve waste types, the proportions of food waste and wood and leaves differ significantly between the inskirt and outskirt zones of the city ($p\text{-value} < 0.05$). The inskirts seem to dispose of food waste less than the outskirts, while the inskirts dispose of far more of wood and leaves. It is reasonable since wood and leaves are mostly from green spaces and home gardens in central areas when these kinds of waste are generally self-treated in the outskirts (Interview with key informants). Between the rainy and dry seasons, there are significant changes in the portions of food waste, wood and leaves, mixed paper, textile, nappies, plastic bags and stone and ceramic discarded. Fig. 3 compares seasonal variations of 25 MSW sub-compositions.

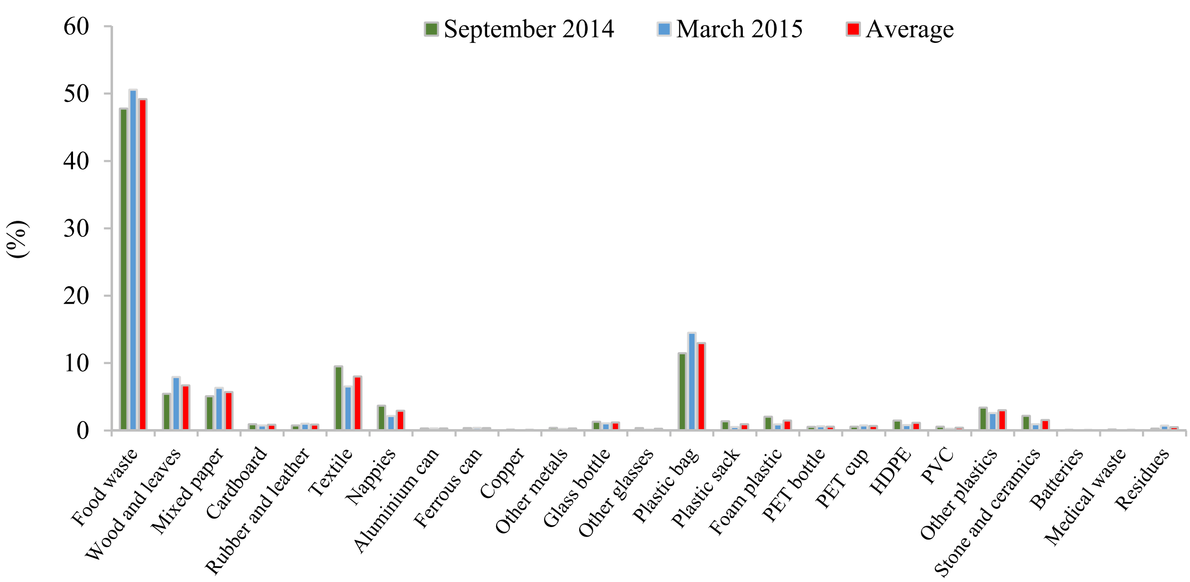

Fig. 3: Sub-compositions of municipal solid waste (% of wet basis)

Table 2 presents the variation of the MSW compositions. In MSW disposed at Dangkor Landfill, the food waste portion was increased from 47.77% in 2014 to 50.58% in 2015. However, it was less than its portion found in 2009 (Sang-Arun *et al.,* 2011). In MSW generated in Phnom Penh city before disposal to the landfill, food waste shared of 87% in 1999 (MoE, 2004 cited from Seng *et al.,* 2010), 65% in 2002 (Kum *et al.,* 2005) and 63.3% in 2003 (JICA, 2005). It shows that the food waste portion of this study is likely to decrease, in comparison to the previous investigations. The portion of plastic disposed of into the landfill was 20.90% in 2015, comparable to 21.36% in 2014. It was steadily increased from 6% in 1999 (MoE, 2004 cited from Seng *et al.,* 2010) to 13.2% in 2002 (Kum *et al.,* 2005) and 15.5% in 2003 (JICA, 2005), even though it dropped to only 6% in 2009 (Sang-Arun *et al.,* 2011). If compared to the overall MSW in the city, there is a remarkable decrease of food waste and an increase of plastic. The portion of plastic has a tendency to increase in opposite to decreasing of food waste. The proportion of wood and leaves, paper, textile, glass, metal, and stone and ceramic are fluctuated from one investigation to another, unlike rubber and leather proportion that seems to increase significantly. This study presents significant change in the relative volumes of nappies and hazardous waste discarded because there is no remark of these kinds of waste in the previous studies (MoE, 2004 cited from Seng *et al.,* 2010; JICA, 2005; Kum *et al.,* 2005; Sang-Arun *et al.,* 2011).

Recyclables make up about 17.28% of disposed MSW on average, and 18.73% in the rainy season and 15.82% in the dry season. Recyclables are materials with values for the recycling market including food waste, paper, glass bottles, metal, plastic, textile and rubber, and leather, indifferently to the result of Mongtoeun *et al.* (2014). More than 50% of plastic is recyclable, and 0.55% of cooked rice residue, food waste, can be recycled for animal feed as same as in the Philippines (Paul *et al.,* 2012). Some of the discarded paper, glass bottles, and foam plastic are uncounted because they are moistened, smashed and no longer marketable.

Material recovery and economic revenues

In general, landfill scavengers pick the materials they seek as soon as the collection trucks dump the waste into a designated area. The dumped waste piles up, which prevents the scavengers from collecting some of the recyclables. The scavengers recover about 2.02 Mg/scavenger/month on average and 607.07 Mg/month in total that equates to only 1.128% of the total recyclables discarded. Similarly, the total recovery amount in the Stung Meanchey dumpsite in 2003 was about 549 Mg/month (JICA, 2005). The most common recovered material is plastic (0.87%), mainly plastic bags (0.389%). Compared to the total volume of dumped plastic, the recovered plastic is relatively small. Overloading of the mixed waste makes the numerous recyclables (16.15%) seen valueless, especially none of paper and foam plastic have been recovered. In Bangkok, the scavengers also recover about 50-150 kg/scavenger/day, but metal and paper recoverability is rather low (Chiemchaisri

Table 2: Variation of municipal solid waste compositions

Compositions / Year	% of MSW in Phnom Penh city			% of disposed MSW at Dangkor Landfill		
	1999[a]	2002[b]	2003[c]	2009[d]	2014 (Rainy season)	2015 (Dry season)
Food waste	87	65.0	63.3	70	47.77	50.58
Plastic	6	13.2	15.5	6	21.36	20.90
Wood and leaves	-	-	6.8	6	5.45	7.93
Paper	3	3.8	6.4	5	6.00	7.08
Textile	-	-	2.5	3	9.51	6.52
Nappies	-	-	-	-	3.67	2.15
Glass	1	4.9	1.2	2	1.64	1.19
Rubber and leather	-	0.6	0.1	-	0.73	1.00
Metal	1	1.0	0.6	2	1.15	0.95
Stone and ceramic	-	-	1.5	-	2.18	0.91
Hazardous waste	-	-	-	-	0.25	0.09
Others	2	11.5	2.1	6	0.28	0.70

Source: [a] MoE, 2004 cited from Seng *et al.,* 2010; [b] Kum *et al.,* 2005; [c] JICA, 2005; [d] Sang-Arun *et al.,* 2011 *et al.,* 2007). The plastic recovery in a dumpsite in the Philippines also experiences indifferent case (Paul *et al.,* 2012). Buyers and dealers determine the price of recyclables so that it differs from one buyer to another. Copper wire costs 4.18 USD/kg, the most expensive when food waste is only 0.02 USD/kg, the cheapest recyclable). On average, a scavenger earns about 8.33 USD/scavenger/day. The total revenue of recovered materials, therefore, is about 75,010 USD/month. It is about 3.5 times the level in Jordan, where recycling generates about 21,149 USD/month (Abu Qdais, 2007). The relatively high revenue generated in Phnom Penh is worthy of notice (Table 3). Yet, if all the recyclables could be recovered, the revenue would be even more.

Municipal solid waste chemical characteristics

The moisture content of food waste reaches 88.41% in the rainy season and average 78.77%. Apart from food waste, the analysis demonstrates high moisture content in the mixed paper (63.61%),

Table 3: Recyclables, recoverability and economic revenues

Recyclables	TR (%)	RM (%)	Re (%)	Price (USD/kg)	RR (USD/month)
Food waste	0.55	0.094	16.95	0.02	930
Paper	0.14	-	-	0.10	-
Cardboard	0.05	0.046	87.97	0.09	2,132
Rubber and leather	0.19	0.003	1.69	0.18	308
Textile	0.19	0.001	0.57	0.18	106
Aluminium can	0.31	0.021	6.65	1.08	12,002
Ferrous can	0.36	0.042	11.70	0.16	3,765
Copper wire	0.08	0.001	0.91	4.18	1,669
Other metals	0.30	0.005	1.83	0.20	570
Glass bottles	1.18	0.045	3.83	0.05	1,196
Plastic bags	10.19	0.389	3.82	0.09	18,014
Plastic sacks	0.93	0.122	13.03	0.06	3,699
Foam plastic	0.08	-	-	0.25	-
PET bottles	0.57	0.065	11.33	0.25	8,565
PET cups	0.66	0.041	6.28	0.20	4,368
HDPE	0.84	0.043	5.13	0.18	8,594
PVC	0.34	0.088	25.58	0.18	4,218
Other plastics	0.31	0.123	39.74	0.07	4,875
Total	17.28	1.128	6.53		75,010

TR = total recyclables, RM = recovered materials, Re = recoverability, RR = recovered revenue

Table 4: Average results of chemical characteristics in MSW sub-compositions

Compositions	M (%)	B (%)	Ash (%)	C (%)	H (%)	N (%)	HCV (MJ/kg)	LCV (MJ/ kg)
Food waste	78.77	19.23	2.00	41.73	7.00	1.97	2.65	0.33
Wood and leaves	57.12	38.01	4.88	43.63	5.82	1.43	2.56	0.56
Mixed paper	63.61	30.26	6.13	36.78	5.07	0.98	6.06	4.04
Cardboard	40.71	50.21	9.08	41.23	5.96	0.24	6.79	4.97
Rubber and leather	18.09	64.50	17.41	46.60	6.29	4.45	23.99	22.37
Textile	44.28	53.35	2.37	49.25	5.76	0.62	16.70	14.87
Nappies	58.29	39.96	1.75	65.93	10.11	0.50	6.89	4.49
Plastic bags	43.37	52.66	3.97	79.34	11.65	0.19	23.29	20.70
Plastic sacks	30.37	61.77	7.87	74.50	12.52	0.17	22.33	19.60
Foam plastic	24.84	70.80	4.36	80.37	8.88	2.49	25.45	23.30
PET bottles	2.21	97.60	0.19	62.56	4.06	0.02	33.29	32.33
PET cups	3.99	94.85	1.16	83.63	12.27	0.01	45.50	42.74
HDPE	0.35	99.65	0.00	86.96	9.76	0.06	49.78	47.57
PVC	0.22	99.78	0.00	87.99	7.99	1.20	60.27	58.46
Other plastics	5.77	89.92	4.31	75.78	11.85	0.23	36.23	33.56
Residues	22.73	45.21	32.06	24.21	1.13	0.55	4.62	3.84

M = moisture, B = combustible, C = carbon, H = hydrogen, N = nitrogen nappies (58.29%), wood and leaves (57.12%) and textile (44.28%). The moisture content of some plastics is also remarkable, especially that of plastic bags (43.37%), plastic sacks (30.37%) and foam plastic (24.84%). These moisture levels are caused not only by the monsoon season in Cambodia but also mixing of the waste altogether. The moisture content presumably transfers from one type of waste to another (Christensen, 2011). Because of moisture richness, the combustible content of food waste and mixed paper seems lower than that of low-moisture types such as PET bottles (97.60%), PET cups (94.85%), HDPE (99.65%) and PVC (99.78%). Conspicuously, ash is the largest component of the residues, at 32.06%, due to the presence of small incombustible particles.

The C/N ratio is 21.16 in food waste and 30.51 in wood and leaves. In 2003, it ranged from 15.8 to 18.3% in food waste and from 24.3 to 29.2% in grass and wood (JICA, 2005). A higher HCV and lower moisture content result in a higher LCV. LCV is 58.46 MJ/kg in PVC followed by 47.57 in HDPE and 42.74 in PET cups. Surprisingly, the LCV is lower in food (0.33 MJ/kg), wood and leaves (0.56), mixed paper (4.04), nappies (4.49) and cardboard (4.97) (Table 4). Overall, the MSW in Phnom Penh has a moisture content of 68.28% in the rainy season, 53.56% in the dry season and 60.92% on average. These levels are comparable to the result from JICA (2005), 60.70%. Apart from moisture, the MSW is composed of 35.89% combustible matter, 3.19% ash, 58.32% carbon, 8.3% hydrogen and 1.05% nitrogen. Calorific measurements indicate an average HCV of 10.03 MJ/kg and LCV of 7.77 MJ/kg. In the rainy season, the HCV and LCV fall to 9.68 and 7.37 MJ/kg. This LCV is higher than that reported in Iskandar Malaysia (Siti Norbaizura and Fujiwara, 2013), and the calculated value by fractions in Eq. 6 confirms an even higher HCV (11.99 MJ/kg) and LCV (10.12 MJ/kg) (Table 5).

Suitable handling methods

The assessment shows that the moisture content in the rainy season seems too high to qualify food waste as a candidate for any treatment methods. When mixed, the MSW is suitable for landfilling in both seasons. Food waste is suitable for composting and co-composting with wood and leaves in the dry season. The C/N ratio of food waste also meets the requirement. In the rainy season, a mixture of food waste and wood and leaves would have an unacceptably high moisture content of 86.02%. Co-composting with dry materials, for example, rice straw, would be possible with efficient aeration, as demonstrated in experiments of Fernandes *et al.* (1994). Food waste is also suitable for the AD, as its C/N ratio is between 20 and 35 that is required for the system (Guermoud *et al.,* 2009). One response to high moisture content would be to examine AD with a one-stage continuous wet system requiring total solids less than 15%. The MSW seems unsuitable for RDF generation, though RDF generation from plastic merits some attention. Plastic makes a good candidate for RDF, not only by its moisture content but also its LCV, which serves demands of technology. The LCV also permits sufficient energy recovery from gasification with melting and incineration. The moisture content is still problematic for these technologies in the rainy season, except for incineration without energy recovery. If separated,

Table 5: Chemical characteristics of municipal solid waste

	MSW disposed of in 2014-2015			Phnom Penh 2003[a]	Iskandar Malaysia 2012[b]
	2014 (Rainy)	2015 (Dry)	Average		
M (%)	68.28	53.56	60.92	60.70	56.90
B (%)	28.42	43.36	35.89	30.70	34.90
Ash (%)	3.30	3.08	3.19	8.60	8.20
C (%)	60.89	55.75	58.32	-	45.08
H (%)	8.42	8.17	8.30	-	6.44
N (%)	0.98	1.12	1.05	-	1.12
Measured HCV (MJ/kg)	9.68	10.37	10.03	-	-
Calculated HCV (MJ/kg)	11.96	12.02	11.99	-	-
Measured LCV (MJ/kg)	7.37	8.17	7.77	-	6.66
Calculated LCV (MJ/kg)	10.07	10.18	10.12	-	5.17

Source: [a] JICA, 2005; [b] Siti Norbaizura and Fujiwara, 2013

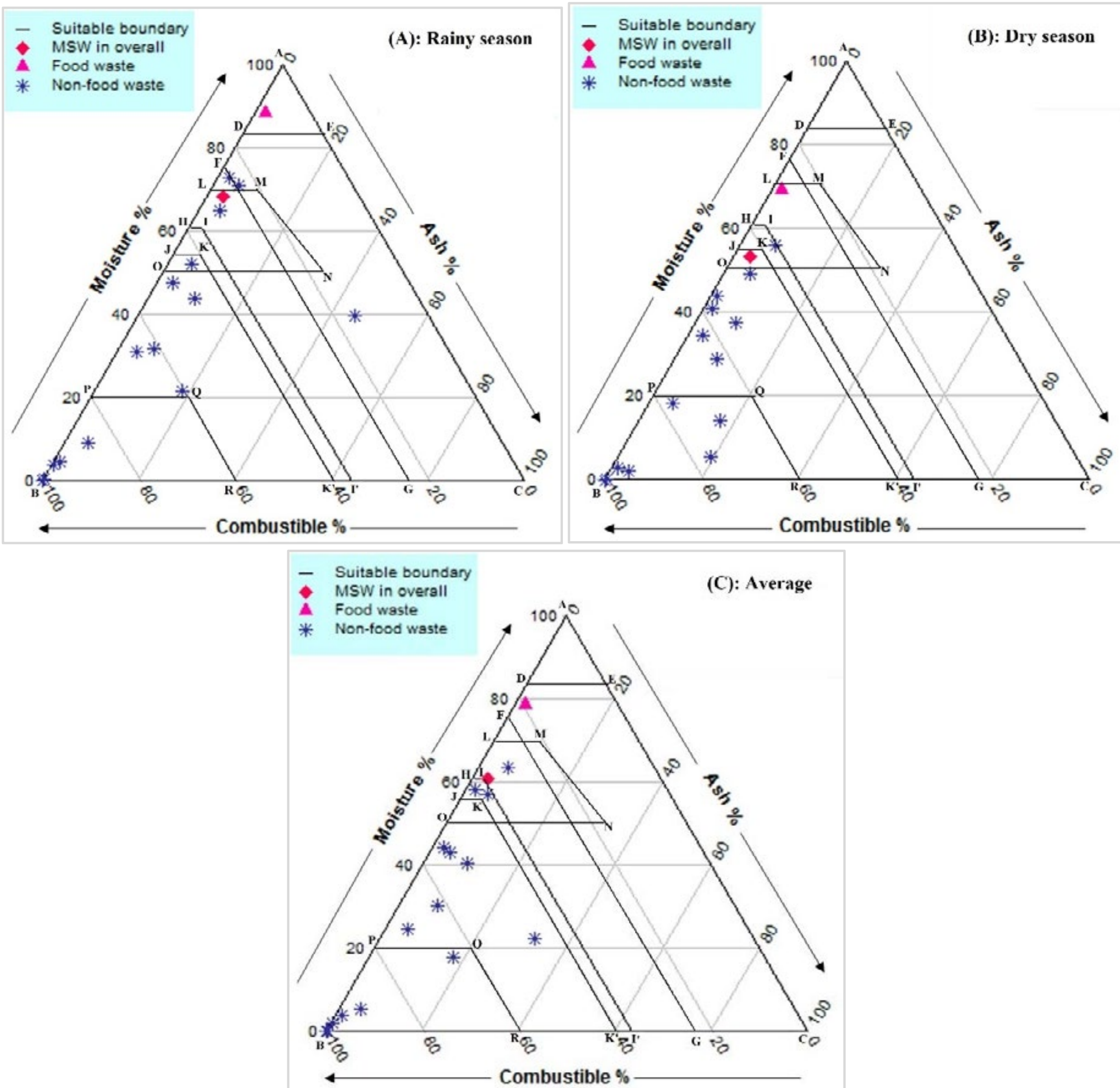

Fig. 4: Suitability in (A): Rainy season, (B): Dry season and (C): Average with trapezoid for direct landfilling (BDEC), composting (OLMN), RDF generation (BPQR), gasification with melting (BJKK'), incineration without energy recovery (BFG) and incineration with energy recovery (BHII')

textile, rubber and leather and plastic are suitable for gasification with melting. To incinerate with energy recovery, food waste, wood and leaves, mixed paper and nappies are too wet when the residues are full of ash content. Gasification with melting and incineration with energy recovery, however, both seem to be workable in the dry season (Fig. 4).

In consideration of the suitable handling methods, their application feasibility was discussed with the key informants. It found that the economic capacity in Phnom Penh city may be unfavourable for the advanced technologies even though the analysis proves the treatment suitability of AD for food waste, RDF generation and gasification with melting for plastic, textile, rubber and leather, and incineration without energy recovery for the mixed MSW. Deficiencies in technical and financial resources would make these technologies unfeasible. It is also confirmed by JICA (2005) and Kum *et al.,* (2005) that the equipment, expertise and financial resources have all been lacking in the city. Buysman and Mol (2013) also warned that long-term and large-scale development of an AD, in comparison to a small scale, seems to encounter major failure. Therefore, the MSW management system should set aside these technologies until the resources are more widely available in the city to ensure their socio-economical feasibility and sustainability. Subsequently, it would be an ideal to incorporate AD, incineration and RDF generation into the system when the resources are widely available. The selection of costless and attainable handling methods is a reasonable approach as recommended by Brunner and Feller (2007) and Zurbrügg *et al.* (2012) for starting an improved management system. The material recovery and organic composting are likely the two most practical alternatives. The current study confirms that the recyclables account for almost one-fifth of the MSW, and the material recovery is already taking place even though it is informal. High-priority efforts should be made to integrate this material recovery approach into a new management system adopted at both material recovery facilities and recycling markets. Velis *et al.* (2014) showed that integration of the informal sector into the management system could attain remarkable recycling rates about 20-30% in the developing countries. Co-composting also appears to be viable. The maximum composting capacity of CSARO at present is 4 Mg/day, with most of the compost sold to farmers and gardening suppliers (Interview with CSARO officer). This facility should be expanded on a decentralized scale in the future. Material recovery and composting, therefore, are recommended as primary components of the improved management system. Significantly, public participation is a crucial driving force for MSW management (Kum *et al.,* 2005; Brunner and Feller, 2007; Parizeau *et al.,* 2008). To start with, public education and source pre-segregation are important preconditions for management and treatment practices. Individuals should be well informed of the importance of the MSW system and the most practical and efficient pathways going forward, and 3R practices (reduction, reuse, and recycling). It is a prerequisite of the city to take source-pre-segregation of waste into action so that treatments can proceed. Pre-segregation and separate collection are crucial to make treatment more viable since the current MSW is still disposed of mixed. Pre-segregation is also recommended by (Parizeau *et al.,* 2006; Seng *et al.,* 2010; Seng *et al.,* 2013). However, changing behaviour is a daunting task that can be approached from a manageable scale at the outset. Education would raise the awareness and concerns of the public (Agamuthu *et al.,* 2009; Parizeau *et al.,* 2006; Thanh and Matsui, 2011), but would be insufficient without demonstrations. Academic institutions can be singled out as an initial target to enlighten students and encourage them to take part in the pre-sorting waste into recyclables, compostable, non-recyclable and hazardous materials. Thereafter, this practice can be introduced to public and private premises including governmental institutions and commercial buildings where the regulations are effectively enforceable before scaling up to the residential areas.

CONCLUSION

The current study observed MSW characteristics to assess the suitability of handling methods that would be necessary for planning the improved management system in Phnom Penh city. The MSW contains abundant food waste and plastic, and presence of hazardous materials including batteries and medical waste that had no remark in the previous studies are discerned. Much of the recyclables are also dumped in the mixed MSW. A major proportion of recyclables remain worthlessly revitalized, even though three hundred scavengers were recovering those materials in the landfill. The monthly economic revenue of the recyclable materials recovered by the landfill scavengers is likely profitable. However, the economic loss of the materials that could not be recovered seems to be much larger. The properties of MSW vary from time to time, and the moisture content of waste is too high especially in the rainy season. In some cases, excessive water content renders waste unsuitable for treatment. Chemical properties of plastic meet the demand for RDF technology when the food waste and wood and leaves are suitable for co-composting and AD. Gasification with melting and incineration with energy recovery are inappropriate technologies when MSW can only be incinerated without energy recovery. Advancement of the material recovery initially can be an alternative to the improved MSW management. Composting should be another handling method for consideration as the city is short of requisite resources to run AD or incineration technologies. In this study, the suitable MSW treatment methods for the city were assessed, but the discussions are at an early stage to management improvement. Further research should analyze feasibility and sustainability of technologies for the development of integrated management system.

ACKNOWLEDGMENT

The authors sincerely acknowledge officers of MoE, Phnom Penh City Hall, JICA, CINTRI (Cambodia) LTD., COMPED, CSARO and Dangkor Landfill for kind cooperation. Authors gratefully to appreciate the financial support of SATREPS Project on 'Development of Low Carbon Society Scenarios for Asian Regions'.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

ABBREVIATIONS

AD	Anaerobic digestion
B	Combustible
C	Carbon
COMPED	Cambodian Education and Waste Management Organization
Eq.	Equation
CSARO	Community Sanitation and Recycling Organization
Gg	Gigagram
H	Hydrogen
H_W	Hydrogen content of wet waste basis
HCV	High calorific value
JICA	Japan International Cooperation Agency
kg	Kilogram
LCV	Low calorific value
M	Moisture
Mg	Megagram
MJ	Mega Joule
MoE	Ministry of Environment
MP_X	Market price of material X
MSW	Municipal solid waste
N	Nitrogen
RDF	Refuse-derived fuel
Re_X	Recoverability of material X
RM_X	Recovered amount of material X
RR_X	Recovered revenue of material X
TR_X	Total recyclable amount of material X
UNEP	United Nation Environment Programme
USD	United State Dollar
%	Percentage

REFERENCES

Abu Qdais H.A., (2007). Techno-economic assessment of municipal solid waste management in Jordan. Waste Manage., 27(11): 1666-1672 (**7 pages**).

Agamuthu P.; Khidzir K.M.; Hamid F.S., (2009). Drivers of sustainable waste management in Asia. Waste Manage. Res., 27(7): 625-633 (**14 pages**).

ASTM International, (2004a). Standard test method for residual moisture in a refused-derived fuel analysis sample. E 790-87. West Conshohocken, PA United State.

ASTM International, (2004b). Standard test method for ash in the analysis sample of refuse-derived fuel. E 830-87. West Conshohocken, PA United State.

ASTM International, (2004c). Standard test method for volatile matter in the analysis sample of refuse-derived fuel. E 897-88. West Conshohocken, PA United State.

ASTM International, (2004d). Standard test method for gross calorific value of refuse-derived fuel by the bomb calorimeter. E 711-87. West Conshohocken, PA United State.

Brunner P.H.; Fellner J., (2007). Setting priorities for waste management strategies in developing countries. Waste Manage. Res., 25(3): 234-240 (**7 pages**).

Buysman E.; Mol A.P.J., (2013). Market-based biogas sector development in leaste developed countries-the case of Cambodia. Energy Policy, 63: 44-51 (**8 pages**).

Chiemchaisri C.; Juanga J.P.; Visvanathan C., (2007). Municipal solid waste management in Thailand and disposal emission inventory. Environ. Monit. Assess., 135(8): 13-20 (**8 pages**).

Christensen H.T., (2011). Solid waste technology and management. Vol. 1, A Jonh Wiley and Son, Ltd., Publication

Costi P.; Minciardi R.; Robba M.; Rovatti M.; Sacile R., (2004). An environmentally sustainable decision model for urban solid waste management. Waste Manage., 24(3): 277-295 (**19 pages**).

CSARO, (2015). Annual report 2015. Phnom Penh. Campodia.

Fernandes L.; Zhan W.; Patni N.K.; Jui P.Y., (1994). Temperature distribution and variation in passively aerated static compost piles. Bioresour. Technol., 48(3): 257-263 (**7 pages**).

Guermoud N.; Ouadjnia F.; Abdelmalek F.; Taleb F.; Addou A., (2009). Municipal solid waste in Mostaganem city (Western Algeria). Waste Manage., 29(2): 896-902 (**7 pages**).

Guerrero L.A.; Maas G.; Hogland W., (2013). Solid waste management challenges for cities in developing countries. Waste Manage., 33: 220-232 (**13 pages**).

Hotta Y.; Aoki-Suzuki C., (2014). Waste reduction and recycling initiatives in Japanese cities: lessons from Yokohama and Kamakura. Waste Manage. Res., 32(9): 857-866 (10 pages).

Inazumi S.; Ohtsu H.; Shiotani T.; Katsumi T., (2011). Environmental assessment and accounting fro the waste disposal stream in Bangkok, Thailand. J. Mater. Cycles Waste Manage., 13: 139-149 (**10 pages**).

JICA, (2005). The study on solid waste management in the municipality of Phnom Penh in the Kingdom of Cambodia, final report, main report. Phnom Penh, Cambodia.

Kum V.; Sharp A.; Harnpornchai N., (2005). Improving the solid waste management in Phnom Penh city: a strategic approach. Waste Manage., 25(1): 101-109 (**9 pages**).

Linzner R.; Salhofer S., (2014). Municipal solid waste recycling and the significance of informal sector in urban China. Waste Manage. Res., 32(9): 896-907 (**12 pages**).

Matter A.; Dietschi M.; Zurbrügg C., (2013). Improving the informal recycling sector through segregation of waste in the household - the case of Dhaka Bangladesh. Habitat Int., 38: 150-156 (**7 pages**).

MoE and COMPED, (2006). Environmental guidelines on solid waste management in Kingdom of Cambodia. Phnom Penh.

Mongtoeun Y.; Fujiwara T.; Sethy S., (2014). Current status of commercial solid waste generation, composition and management in Phnom Penh city, Cambodia. J. Envir. Waste Manag., 1(3): 031-038 (**8 pages**).

Naik N.; Tkachenko E.; Wung R., (2013). The anaerobic digestion of organic municipal solid waste in California. University of California, Berkeley.

Ngoc U.N.; Schnitzer H., (2009). Sustainable solutions for solid waste management in Southeast Asian countries. Waste Manage., 29(6): 1982-1995 (**14 pages**).

Parizeau K.; Maclaren V.; Chanthy L., (2006). Waste characterization as an element of waste management planning: lessons learned from a study in Siem Reap, Cambodia. Resour. Conserv. Recy., 49: 110-128 (**19 pages**).

Parizeau K.; Maclaren V.; Chanthy L., (2008). Budget sheets and buy-in: financing community-based waste management in Siem Reap, Cambodia. Environ. Urban, 20(2): 445-463 (**19 pages**).

Paul J.G.; Arce-Jaque J.; Ravena N.; Villamor S.P., (2012). Integration of informal sector into municipal solid waste management in the Philippines - what does it need? Waste Manage., 32: 2018-2028 (**11 pages**).

Pham Phu S.T.; Hoang M.G.; Fujiwara T., (2018). Analyzing solid waste management practices for the hotel industry. Global J. Environ. Sci. Manage., 20(2): 19-30 (**12 pages**).

Sang-Arun J.; Chau K.H.; Uch R.; Sam P., (2011). A guide for technology selection and implementation of urban organic waste utilisation projects in Cambodia. Institute for Global Environmental Strategies.

Sasaki S.; Araki T., (2014). Estimating the possible range of recycling rates achieved by dump waste pickers: the case of Bantar Gebang in Indonesia. Waste Manage. Res., 32(6): 474-481 (**8 pages**).

Seng B.; Hirayama K.; Katayama-Hirayama K.; Ochiai S.; Kaneko H., (2013). Scenario analysis of the benefit of municipal organic-waste composting over landfill, Cambodia. J. Environ. Manage., 114: 216-224 (**9 pages**).

Seng B.; Kaneko H.; Hirayama K.; Katayama-Hirayama K., (2010). Municipal solid waste management in Phnom Penh, capital city of Cambodia. Waste Manage. Res., 29(5): 491-500 (**10 pages**).

Singh A.S.; Masuku M.B., (2014). Sampling techniques & determination of sample size in applied statistics research: an overview. Int. J. Econ. Commer. Manage., 2(11): 1-22 (**22 pages**).

Siti Norbaizura M.R.; Fujiwara T., (2013). Characterization of household solid waste in Iskandar Malaysia and its suitability for alternative waste handling methods. 土木学会論文集G(環境), 69(5): 209-216 (**8 pages**).

Sothun C., (2012). Situation of e-waste management in Cambodia. Proc. Envir. Sci., 16: 535-544 (**10 pages**).

Thanh N.P.; Matsui Y., (2011). Municipal solid waste management in Vietnam: status and the strategies actions. Int. J. Environ. Res., 5(2): 285-296 (**12 pages**).

Troschinetz A.M.; Mihelcic J.R., (2009). Sustainable recycling of municipal solid waste in developing countries. Waste Manage., 29(2): 915-923 (**9 pages**).

UNEP, (2013). Guidelines for national waste management strategies: moving from challenges to opportunities. Nairobi, Kenya.

Velis C.A.; Wilson D.C.; Rocca O.; Smith S.R.; Mavropoulos A.; Cheeseman C.R., (2014). An analytical framework and tool (‘InteRa’) for integrating the informal recycling sector in waste and resource management systems in developing countries. Waste Manage. Res., 30(9): 43-66 (**26 pages**).

World Bank, (1999). Municipal solid waste incineration. DC, USA.

Zurbrügg C.; Gfrerer M.; Ashadi H.; Brenner W.; Küper D., (2012). Determinants of sustainability in solid waste management – the Gianyar Waste Recovery Project in Indonesia. Waste Manage., 32: 2126-2133 (**8 pages**).

AUTHOR (S) BIOSKETCHES

Seng, B., Ph.D. Candidate, Graduate School of Environmental and Life Science, Okayama University, 3-1-1 Tsushima, Kita, Okayama 700-8530, Japan. Email: *bandithseng@gmail.com*

Fujiwara, T., Ph.D., Professor, Waste Management Research Center, Okayama University, 3-1-1 Tsushima, Kita, Okayama 700-8530, Japan. Email: *takeshi@cc.okayama-u.ac.jp*

Seng, B., Ph.D., Instructor, Department of Rural Engineering, Institute of Technologies of Cambodia, Russian Federation Blvd, Phnom Penh, Cambodia. Email: *seng.bunrith@gmail.com*

HOW TO CITE THIS ARTICLE

Seng, B.; Fujiwara, T.; Seng, B., (2018). Suitability assessment for handling methods of municipal solid waste. Global J. Environ. Sci. Manage., 4(2): 113-126.

DOI: 10.22034/gjesm.2018.04.02.001

url: http://gjesm.net/article_29396.html