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Energy Recovery of Refuse Derived Fuel Components from Municipal Solid Waste in Bangkok, Thailand

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Abstract

Refuse derived fuel (RDF) from municipal solid waste (MSW) has been widely used in energy plants. The aim of this study was to investigate the characteristics of RDF components from the MSW generated in Bangkok, Thailand. The MSW generated profile was observed from 2015 – 2020 to analyze the composition, proximate, ultimate, and heating values. The combustible categories of MSW were considered as RDF components, namely paper, plastics, food waste, wood/yard waste, textiles, and rubber. The average MSW generated in Bangkok was approximately 13.5% of the total MSW generated in Thailand. The combustible category represented 86.5% of total MSW. The predominant combustible category was food waste (43.1%), followed by plastics (16.6%), and paper (13%). Moisture, volatile matter, fixed carbon, and ash contents ranged from 0.2 – 57.5, 74.5 – 95.2, 3.3 – 19.4, and 1.5 – 8.6 wt.%, respectively, depending on the materials. Lower heating values of RDF components ranged from 13.70 – 32.63 MJ/kg, of which plastics exhibited the highest value. The potential energy produced from RDF components was 513,123.4 x 10^2 GJ/yr, with approximately 1,847,757,371 kWh/yr converted into electricity. The findings from the research on characteristics of MSW from Bangkok city reveal that it has the potential to be used as an RDF resource in energy plants.

Keywords: Combustible waste; Heating value; Incineration process; Refuse derived fuel; Waste to energy

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1. Introduction

The generation of municipal solid waste (MSW) increases in accordance with the population size. In 2016, the world generated 2.01 billion tonnes of MSW, averaging 0.74 kg/capita/day. Global waste is expected to grow to 3.40 billion tonnes by 2050 (Kaza *et al.,* 2018). Improper MSW management potentially impacts public health and environmental pollution through vector diseases, bad odor, greenhouse gases emissions, as well as soil and groundwater contamination (Pan *et al.,* 2019). Many methods have been used to dispose of solid waste, such as landfilling, biological conversion, and thermal treatment (Arafat *et al.,* 2015). Each disposal method has its advantages and disadvantages, depending on the characteristics of the waste. The problem of MSW is becoming prevalent around the globe, particularly in developing countries. Thailand is one such country in Southeast Asia, with a current population of 66.19 million in 2021 (NSO, 2021). The total waste generated in Thailand was 27.35 million tonnes or 69,322 tonnes/day in 2020 (PCD, 2020). Approximately 11.19 million tonnes (41%) were disposed of using proper methods with waste utilization equating to about 11.93 million tonnes (44%) of the waste generated. The remaining 4.23 million tonnes (15%) was disposed of by improper methods such as open dumping (PCD, 2020). Bangkok is a big city with high population density. In 2020, the

Pollution Control Department (PCD) reported 3.32 million tonnes or 12,282 tonnes/day of MSW in Bangkok, representing 12% of the total MSW generated in Thailand.

Most MSW in Thailand has previously been disposed by traditional landfill, causing many problems such as greenhouse gases emissions and leachate (Manasakunkit and Chinda, 2017). Additionally, the limit land area available is also an important factor in the construction of new landfill sites. Thailand's roadmap for the years 2016 – 2021 was designed to enhance the efficiency of MSW management with the 3Rs (Reduce, Reuse, Recycle) and zero-waste concept. Waste to energy (WTE) is one solid waste management strategy applied to the industrial sectors in various countries (Brás *et al.,* 2017). The Thai government has an attractive policy of generating electricity from waste by increasing the purchase price of electricity per unit, called the feed-in tariff (FIT) program. Therefore, to solve the MSW problem and support government policy, WTE is one of the most attractive options for waste management in Thailand. The various processes of energy recovery from MSW include incineration, pyrolysis, and gasification (Zhou *et al.,* 2015). Incineration is the most broadly used WTE technology due to its capability for reducing the volume of original waste by 90% (Chol *et al.,* 2018). The MSW composition is influenced by heating value of the incineration process (Shi *et al.,* 2016) because waste composition is a heterogeneous process which depends on various factors such as geographical location, socio-economic, climatic conditions, and season (Pan *et al.,* 2019). MSW has a certain calorific value that may be applied as refuse derived fuel (RDF) in WTE co-incineration plants (Sarc and Lorber, 2013). RDF has been broadly applied in cement kilns or co-firing with coal in power plants (Chol *et al.,* 2018). Recent years have seen an increasing number of RDF power plants in Thailand. RDF is used in the mechanical process of MSW treatment, resulting in a high heating value than mixed solid waste. Therefore, the characteristics of MSW could be investigated as fuel feedstock in the incineration process. The MSW generated in Thailand comprises mainly of organic waste, high moisture content, and commingle waste. Therefore, its basis characteristics make it inappropriate for disposal by incineration. Otherwise, the composition of its combustible components may be of interest for energy utilization and reducing the final amount of MSW to be disposed of by landfill. The current MSW collected in Bangkok is approximately 12,000 tonnes/day, more than 30% of which is disposed of by landfill. Consequently, a significant amount of this waste should be recovered before being transferred to landfill. The MSW characteristics of Bangkok have been investigated by previous researches, but the data was not current (Chiemchaisri *et al.,* 2007), and the RDF production potential of MSW was observed only at a dumpsite (Prechthai *et al,* 2006). Therefore, the characteristics, combustible components, and energy production of MSW should be investigated.

The objective of this study was to investigate the feasibility of energy recovery from the RDF components of MSW generated in Bangkok city. The MSW generated profile for Thailand and Bangkok was observed during the period from 2015 – 2020. The physical composition of MSW, proximate content, ultimate content, and heating value were examined, and the conversion of the RDF component into electricity estimated. This aim of this study was to evaluate the feasibility of using unprocessed MSW from Bangkok's waste transfer station as an RDF resource, which is defined as expected energy generation based on the most recent real MSW volume. The results of this study might be useful for the Bangkok Metropolitan Administration in the design and planning of an MSW management system for waste separation and the operation of resource recovery facilities for energy recovery in the future.

2. Materials and Methods

2.1 Data collection

The MSW data of the study was collected over a six-year period (2015 – 2020). The secondary data on the total MSW generated, and the generation rate for Thailand was collected from PCD annual report, and the MSW generated for Bangkok city was obtained from the PCD report, covering 50 districts (PCD, 2020).

2.2 MSW sampling and sorting

The MSW was collected from three transfer stations located in the Bangkok area. Transfer stations A, B, and C were operated at the capacities of 3,800, 2,300, and 3,600 tonnes/day of solid waste, respectively. These transfer stations collected MSW from 50 districts in Bangkok city (Figure 1), operating both directly and indirectly. The location map of Bangkok was made using QGIS software version 3.12.2. The sampling point of three transfer stations was covered of Bangkok's MSW that was collected by the Bangkok Metropolitan Administration, which was used as a representative of MSW. In addition, a waste composting processor was established at transfer station A to compost 1,200 tonnes/day, which about 300 tonnes/day of solid waste was incinerated at transfer station C. The remaining solid waste was transferred for disposal at the landfill sites in Kamphaeng Saen District, Nakhon Pathom Province, and Phanom Sarakham District, Chachoengsao Province.

This study was conducted during the period from May to July 2019. The samples were collected from the three transfer stations according to international standard ASTM D 5231 - 92, 2003. The MSW sampling was carried out over a one-week period (seven days) for each site. After the vehicle load reached the storage area, the samples were collected three times/day (9 a.m., 1 p.m., 5 p.m.) in order to be representative of the daily waste and then mixed together. The waste sample weighed 100 kg and prepared properly to determine the MSW composition following the quartering method. After sampling, manual sorting was applied for the classification of MSW. The same sampling method was used for the three transfer stations. The samples were classified into seven categories according to the material properties (AbdAlqader and Hamad, 2012) (Table 1).

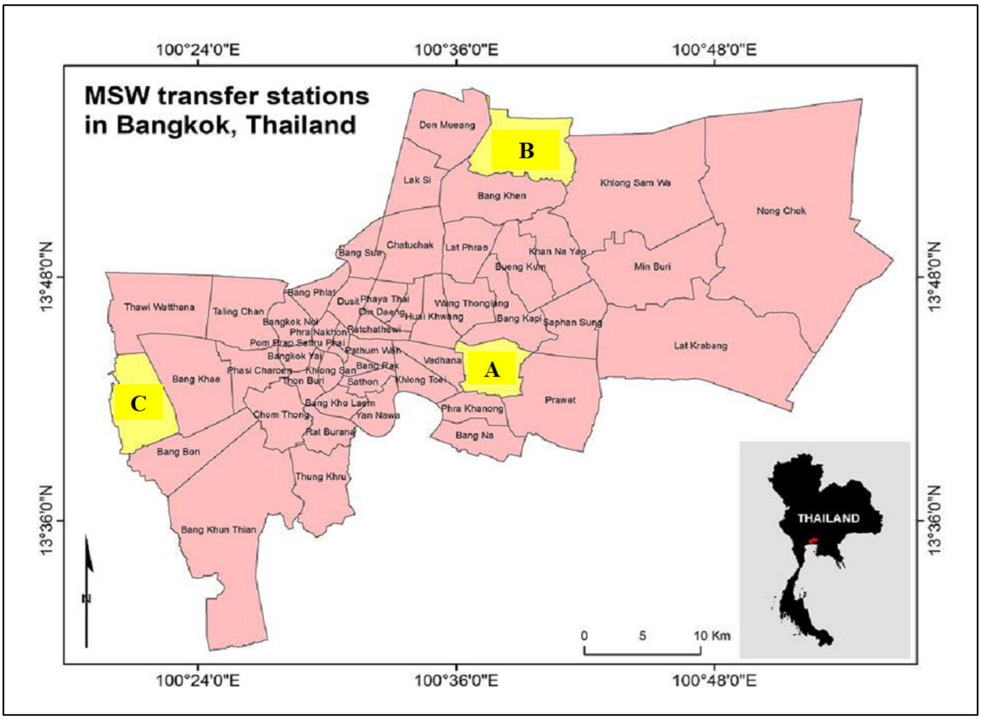

Figure 1. Waste transfer stations in Bangkok.

Table 1. Waste component categories

Category	Description
Paper	Office paper, computer paper, magazines, glossy paper, waxed paper, newsprint and cardboard
Plastics	All plastics
Food waste	All food waste except bones
Other organics/ combustibles	Yard waste (branches, twigs, leaves, grass, and other plant materials), wood, textiles, rubber, leather, and other primarily burnable materials not included in the above component categories
Metals	Ferrous (iron, steel, tin cans, and bi-metal cans), aluminum, and non-ferrous non-aluminum metals (copper, brass, etc.)
Glass	All glass
Other inorganics/ non-combustibles	Rock, sand, dirt, ceramics, plaster, and bones

Source: AbdAlqader and Hamad, 2012.

The combustible materials consisted of paper, plastics, food waste, and other organics, while non-combustible materials included metals, glass, and other inorganics. In this study, the combustible components were considered as the RDF resources, including paper, plastics, food waste, wood/ yard waste, textiles, and rubber (Dong and Lee, 2009).

2.3 Analysis of MSW characteristics

The moisture content, proximate analysis, ultimate analysis, and heating value were determined in the chemical laboratory, Faculty of Public Health, Thammasat University. The analysis was performed in triplicate for each parameter. The moisture content was measured using an oven drying procedure, according to ASTM D 1348 - 94, 2008. After determining the moisture content, the dried samples were grounded by grinders following the method used in a previous study (Shi *et al.,* 2016). The proximate analysis was conducted according to ASTM D 7582 - 12, 2015. The proximate analysis included the determination of moisture, volatile matter, fixed carbon, and ash content (Shi *et al.,* 2016). The ultimate analysis was performed using an elemental analyzer to determine the carbon (C), hydrogen (H), nitrogen (N), sulfur (S), and oxygen (O) compositions of the samples (Zhao *et al.,* 2016). The heating value was tested using a bomb calorimeter according to ASTM D 5468 - 02, 2007. The effective hydrogen to carbon molar ratio (H/C_{eff}) was calculated using Equation 1 (Shi *et al.,* 2016).

$$H/C_{eff} = (H-2O)/C \qquad (1)$$

Where, H, O, and C are the moles of hydrogen, oxygen, and carbon in the waste fraction.

2.4 Evaluation of energy content from RDF components

The energy content was calculated based on the heating values of each combustible component (paper, plastics, food waste, wood/yard waste, textiles, and rubber) which are considered the RDF resources. The energy content of each type of RDF was calculated based on the proportions of generated waste materials (Chol *et al.,* 2018). The bomb calorimeter provided higher heating value (HHV) or gross calorific value (GCV), as the water vapor was condensed and contributed to the energy output (Chol *et al.,* 2018). Therefore, the HHV of RDF in this study was converted into a lower heating value (LHV) or net calorific value (NCV) using Equation 2 (Chol *et al.,* 2018).

$$LHV_i = HHV_i - W_e \cdot (9 \cdot H + W_i) \qquad (2)$$

where,
LHV_i is the lower heating value of i^{th} waste fraction (MJ/kg);
HHV_i is the higher heating value of i^{th} waste fraction (MJ/kg);
W_e is the standard heat of evaporation of water (2.441 MJ/kg);
H_i is the hydrogen content of i^{th} waste fraction (wt.%); and
W_i is the moisture content of i^{th} waste fraction (wt.%).

The total LHV of RDF components was calculated using Equation 3 (Chol *et al.,* 2018).

$$LHV_t = M_t \cdot \sigma \cdot \Sigma(P_i \cdot LHV_i) \qquad (3)$$

where,
LHV_t is the total LHV of RDF components (MJ/kg);
M_t is the total amount of MSW generation per year (3,850,070 tonnes/yr based on information on Bangkok MSW generated in 2019);
P_i is the proportion of i^{th} waste fraction (wt.%); and
σ is the efficiency of RDF production with 80% as the assumption in this study (Chol *et al.,* 2018).

The total LHV of RDF components obtained from Equation 3 was used to calculate the electricity production based on the incineration process using Equation 4 (Chol *et al.,* 2018).

$$E = \eta_{net} \cdot \mu \cdot LHV_t \qquad (4)$$

where,
E is electricity (kWh);
η_{net} is the net efficiency of incineration to electricity production (13%) (Gohlke and Martin, 2007); and
μ is the factor for converting the heating value into electricity (1 MJ ≈ 0.277 kWh).

2.5 Data analysis

Descriptive analysis was used to find the total MSW generated in Thailand and Bangkok city; average percentage, in comparison to the proportion of total MSW generated individually by Bangkok city and Thailand. The amount of MSW generated per day was calculated using the average data collected over a 12 - month period. The composition of MSW obtained from the three transfer stations: A, B, and C, along with the proximate and ultimate analyses of RDF components, have been expressed in percentage terms. The electricity generated from the RDF components was calculated based on the total amount of Bangkok MSW generated in 2019 (3,850,070 tonnes).

3. Results and Discussion

3.1 MSW generation

Figure 2 shows the profile of total MSW generated in Bangkok city in comparison to the total in Thailand from 2015 to 2020 (PCD, 2020). The MSW increased from 2015 to 2019 and decreased in 2020. The total amount of MSW generated in Bangkok was approximately 13.5% of the total MSW generated in Thailand.

In 2020, the average MSW production was about 12,282 tonnes/day in Bangkok, representing a decrease from 2019 (13,583 tonnes/day) (Figure 3). This could have been caused by the lock down imposed on Bangkok during the COVID-19 pandemic and its potential effect on the socio-economic factor of waste generation.

Based on the data collected on MSW generated in Thailand and Bangkok city, the total annual MSW has generated, although the roadmap for solid waste management in Thailand was applied in 2016 to reduce the amount of final disposal. However, Thailand has not yet solved the MSW management problem effectively. These results support those revealed in previous publications. In 2017, the UNEP reported on the annual MSW generation in the ASEAN and found that Indonesia generated the highest quantity of MSW at 64 million tonnes/year, followed by Thailand (27 million tonnes/year), Vietnam (22 million tonnes/year), while Lao PDR generated the lowest quantity of MSW at 0.07 million tonnes/year (UNEP, 2017).

As Thailand's capital, Bangkok has a high population density and MSW generation. Hence, investigating the characteristics of MSW in Bangkok and finding the most appropriate management solution has proven to be an interesting topic.

3.2 MSW composition analysis

The physical composition of the MSW samples collected from the three transfer stations in Bangkok city was analyzed following the 2003 ASTM standards, as presented in Table 2.

Most of the MSW was food-related (43.1%), followed by plastics (16.6%) and paper (13%). The amount of combustible and non-combustible components equated to 86.5% and 13.5%, respectively.

The MSW composition in this study was similar to a previous study on Bangkok (Chiemchaisri *et al.*, 2007) which reported that MSW mostly comprised food waste (43%), followed by paper (12.1%), plastic (10.9%), yard waste (6.9%), glass (6.6%), textiles (4.7%), ceramics (3.9%), metal (3.5%), rubber/leather (2.6%), and others (5.8%). In the Gaza Strip, the MSW was composed

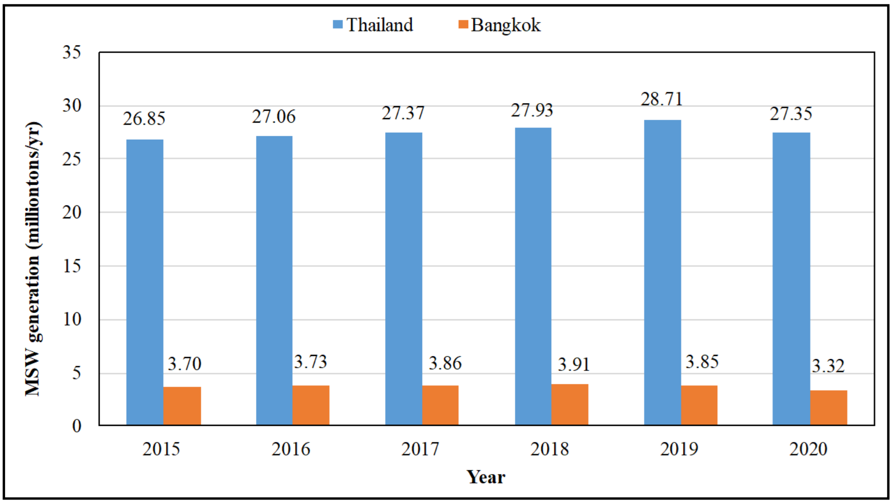

Figure 2. Total MSW generated in Bangkok and Thailand from 2015 – 2020.

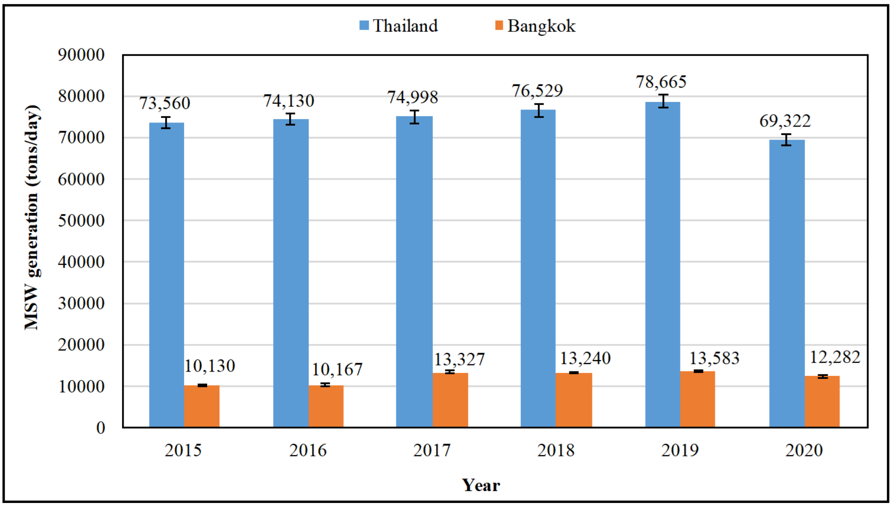

Figure 3. Average MSW generation from 2015 – 2020.

of food waste (52%), plastics (13%), papers (11%), metals (3%), glass (3%), and other waste, including sand and ceramics (18%) (AbdAlqader and Hamad, 2012).

However, the composition of MSW reported in this current study varied from the research conducted on Nanjing City, China, where most MSW was glass (39.74%), paper (22.2%), plastic (18.2%), food waste (12.6%), and textiles (3.9%) (Dong *et al.,* 2003). The organic waste in Ho Chi Minh city consisted mainly of food, equating to 85.8% (Schneider *et al.,* 2017), which was higher than that found in Bangkok. Furthermore, the non-combustible waste in this current study was different from previous research on Pyongyang, South Korea, where non-combustible material constituted 71% of MSW (Chol *et al.,* 2018). In addition, the UNEP reported that as of 2017, the MSW generated in the ASEAN comprised mainly organic waste, plastic, paper, glass, and metal. In Thailand, 64% of the MSW is organic waste, followed by plastic (17.62%) and paper (8%). In Cambodia, 60% of the MSW is organic waste, followed by plastic (15%), paper (9%), and glass (3%). In Indonesia, 60% of the MSW is organic waste, followed by plastic (14%) and paper (9%). In Vietnam, 55% of the MSW is organic waste, followed by plastic (10%) and metal (5%) (UNEP, 2017). The differences in MSW composition depend on various factors such as economics, geographical location, and lifestyle (Mian *et al.,* 2016).

3.3 Proximate and ultimate analyses of RDF components

The six types of potential RDF based on their combustible properties consisted of paper, plastics, food waste, wood/yard waste, textiles, and rubber. Moisture, volatile matter, and ash content could provide a good indication of MSW combustibility (Zhao *et al.,* 2016). The moisture content of the MSW varied significantly, depending on the type of material. The results showed that food waste and wood/yard waste samples had the highest moisture content at 57.5 wt.% and 38.2 wt.%, respectively. This exceeded the quality standards of solid recovered fuel used in Sweden's cement plants (30 wt.%) and the quality of RDF from households in Finland (25 – 30% wt.%), Italy (25%), and the United Kingdom (7 – 28%) (Gendebien *et al.,* 2003). However, the moisture content of solid recovered fuels according to the British standard did not exceed 50 wt.% (BIS, 2011). Moisture content is one of the key parameters when considering material for use as an energy source (Białowiec *et al.,* 2017). The volatile matter, fixed carbon, and ash contents ranged from 74.5 – 95.2 wt.%, 3.3 – 19.4 wt.%, and 1.5 – 8.6 wt.% on a dry basis, respectively. The volatile matter and ash content of each material met the British standard (volatile matter > 25%, ash < 60%) (BIS, 2011), while ash content met the European standards of Finland (5 – 10%), Italy (20%), and United Kingdom (12%) (Gendebien *et al.,* 2003).

Table 2. Composition of the MSW generated in Bangkok

Waste category	Composition (wt.%)*	Subtotal (wt.%)
Paper	13.0±1.8	13.0
Plastics	16.6±1.9	16.6
Food waste	43.1±5.2	43.1
Other organics		
- Wood/yard waste	7.2±2.0	13.8
- Textiles	3.8±1.2	
- Rubber	2.8±0.4	
Metals		
- Ferrous	2.0±0.2	3.7
- Aluminum	1.7±0.2	
Glass	5.4±1.0	5.4
Other inorganics		
- Ceramics	4.4±0.5	4.4
Total	100	100

* n= 3

Table 3. Proximate analysis of RDF components

Waste category	Moisture (wt.%)	Volatile matter (wt.%)	Fixed carbon (wt.%)	Ash (wt.%)
Paper	4.2	79.1	12.3	8.6
Plastics	0.2	95.2	3.3	1.5
Food waste	57.5	77.7	17.4	4.9
Other organics				
- Wood/yard waste	38.2	74.5	19.4	6.1
- Textiles	8.6	85.2	12.0	2.8
- Rubber	9.0	86.4	8.0	5.6

The results indicated that all waste categories were suitable for use as RDF resources except the moisture content of food waste. Therefore, the pre-treatment process for food waste should be considered prior to feeding it into WTE plants or separating food waste from RDF components for other objectives such as composting or anaerobic conversion to biogas.

The waste component generally had high carbon and moderate hydrogen content, indicating good energy potential (Zhao *et al.,* 2016). The sulfur content of RDF components met 0.4% of the European standard for co-firing in the cement industry (Białowiec *et al.,* 2017). The H/C_{eff} ratio of RDF components varied from 0.17 – 0.93. The H/C_{eff} ratio of plastics, textiles, and rubber ranged from 0.61 – 0.93, which was similar to that of coal (0.5 – 1.1) due to their petroleum-derived properties. However, the H/C_{eff} ratio of paper, food waste, and wood/yard waste were below 0.5, similar to that of biomass. The RDF components of MSW from Bangkok exhibited a low fuel grade.

3.4 Evaluation of potential energy content from RDF components

The potential energy content from RDF components was evaluated using Equations 2 and 3 (Table 5).

The LHV of RDF components varied from 13.70 – 32.63 MJ/kg. The plastics had the highest LHV compared to other waste categories, in similarity to previous research. The LHV of three MSW components, namely paper, plastic, and wood, were 6.42 – 73.91 MJ/kg (Arafat *et al.,* 2015), the LHV of RDF components from MSW ranged from 14.39 – 34.11 MJ/kg (Shi *et al.,* 2016), while the LHV was 23.7 MJ/kg based on the Singapore RDF composition of the MSW (Zhao *et al.,* 2016). The MSW of RDF exhibited gross calorific values varying from 14.6 – 40.2 MJ/kg (Chol and Kim, 2017) while the LHV varied from 13.20 – 32.51 MJ/kg (Chol *et al.,* 2018). Alternatively, a previous study on recycled plastic waste from the dumpsite for RDF production revealed a calorific value of 29.5 MJ/kg (Prechthai *et al,* 2006), while another study on open-dump solid waste found 29 MJ/kg of RDF components comprising mixed plastic, textiles, food residue, paper, leather, and rubber (Weerasak and Sanongraj, 2015). Although the heating value of MSW was relatively low compared to fossil fuels like coal and natural gas (Chol *et al.,* 2018), the RDF components in this study met the European Standards requirements of Finland (13 – 16 MJ/kg), Italy (15 MJ/kg), and the United Kingdom (18.7 MJ/kg) (Gendebien *et al.,* 2003). The total energy content from RDF components based on LHV was approximately 513,123.4 x 10^2 GJ/yr. The plastics and food waste exhibited a significant level of total LHV due to a high proportion of waste in the category. The electricity produced from RDF components by incineration could be estimated at 1,847,757,371 kWh/yr based on the method proposed by Chol *et al.,* 2018.

The MSW sampling in this current study was collected over a short period during the rainy season (May – July) in 2019 and therefore did not cover all seasons of the year. Hence, the composition of MSW might vary in different seasons for each component, which was the limitation of this study.

Table 4. Ultimate analysis of RDF components

Waste category	C (%)	H (%)	O (%)	N (%)	S (%)	H/C_{eff} molar ratio
Paper	41.6	6.0	43.4	0.3	0.1	0.17
Plastics	65.5	7.3	25.6	0.1	0.0	0.75
Food waste	45.6	6.9	40.1	2.2	0.3	0.49
Other organics						
- Wood/yard waste	47.0	6.5	39.0	1.3	0.1	0.41
- Textiles	56.2	6.6	30.0	4.2	0.2	0.61
- Rubber	67.8	7.2	15.5	3.6	0.3	0.93

C: carbon; H: hydrogen; O: oxygen; N: nitrogen; S: sulfur, wt.% on a dry basis

Table 5. Total energy content of RDF components

Waste category (i)	Proportion (P_i, wt.%)	Moisture content (W_i,wt.%)	HHV_i (MJ/kg)	LHV_i (MJ/kg)	Total LHV (10^2 GJ/yr)	Energy value (%)
Paper	13.0	4.2	15.12	13.70	54,853.1	10.7
Plastics	16.6	0.2	34.24	32.63	166,840.8	32.5
Food waste	43.1	57.5	18.45	15.53	206,168.9	40.2
Other organics						
- Wood/yard waste	7.2	38.2	17.16	14.80	32,820.1	6.4
- Textiles	3.8	8.6	25.51	23.85	27,914.7	5.4
- Rubber	2.8	9.0	30.24	28.44	24,525.8	4.8
Non-combustibles	13.5	-	-	-	-	-
Total	100	-	-	-	513,123.4	100

HHV: higher heating value; LHV: lower heating value

4. Conclusion

The MSW generation in Thailand and Bangkok city was increased with Bangkok, representing 13.5% of the total MSW generation in Thailand from 2015–2020. The RDF component or combustible material was 86.5% of total MSW, with the physical composition mostly of food waste (43.1%), plastic (16.6%), and paper (13%), respectively. The proximate and ultimate contents were appropriated for use as RDF resources, but only the food waste component should be considered for high moisture content. The LHV of RDF components ranged from 13.70–32.63 MJ/kg, meeting the European standard. Bangkok's MSW in 2019 was converted into electricity, equating to approximately 1,847,757,371 kWh/yr. The results of this study suggest that the MSW of Bangkok could be used as an RDF resource to produce energy. The limitation of this study is that the MSW composition was observed only during the rainy season. For further study, the MSW sampling should cover all seasons in the year, with chlorine and heavy metal contents also investigated as important parameters of RDF quality in the feedstock for WTE plants.

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