INVESTIGATION ON COMBUSTION CHARACTERISTICS OF MUNICIPAL SOLID WASTE FROM PENANG STATE MALAYSIA

Siang Piao Chai, Ridzuan Zakaria*

School of Chemical Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, P.Pinang, Malaysia
(email: chduan@eng.usm.my)

ABSTRACT

Landfill, a common technique used for solid waste disposal in Malaysia, currently cannot effectively manage it due to the increasing volume of municipal solid waste (MSW) generated daily in this country. Alternatively, incineration of MSW should be implemented in view of the advantages in waste volume reduction, waste stabilization, waste to energy conversion and sanitization of waste. A case study for investigating the combustion characteristics of MSW from Penang State has been carried out in Pulau Burung Sanitary Landfill. The representative samples of MSW taken from this area were used in proximate and ultimate analysis as well as in higher heating value (HHV) determination. The findings of the proximate analysis showed that the investigated MSW comprised 44.66% of moisture content, 44.55% of volatile matter, 8.56% of ash content and 2.23% of fixed carbon content. The ultimate analysis of the MSW shows that the main content were 43.97% for carbon, 39.40% for oxygen and other compositions for hydrogen, nitrogen, sulfur and ash were recorded as 6.83%, 0.91%, 0.34% and 8.55%, respectively. The HHV of MSW obtained was 9.8532 MJ/kg, which is a typical value for developing countries. To further investigate the main sources that contributing toward HHV of MSW, the HHV obtained for the specific MSW was plotted against its physical composition (moisture, ash, volatile matter and fixed carbon) and chemical composition (C, H, O, N and S). There was a significant trend observed that volatile matter and carbon content showed a positive contribution to HHV of MSW whereas, moisture and oxygen content contributed negatively to the HHV.

KEYWORDS

Municipal Solid Waste, Combustion Characteristics, Higher Heating Value

1. INTRODUCTION

Human activities that generate waste materials have awakened the concern in environmental issue. In 1993, Malaysia's urban population had generated about 5.2 million tons of solid waste or equivalent to 0.34 – 0.85 kg/capita/day. The national average generation rate estimated for 1991 to 1994 was about 0.71 kg/capita/day and this figure has increased to about 1 kg/capita/day in 2000 [1]. As of 2001, the Municipal Solid Waste (MSW) generated in Malaysia has reached 1.4–1.6 kg/capita/day [2, 3]. The large quantity of wastes generated in Malaysia must be considered in order to organize the solid waste management well. Waste generation rate is increasing in Malaysia corresponds to the increase in the number of population, improvement of standards of living and changing life style of people. In addition, waste generation rate also relates to the activities carried out in the community concern such as residential, commercial, institutional, industrial and markets. However, the only method of disposal currently being practiced in Malaysia is landfill. Landfills always represent a common and economically acceptable method for waste disposal [3]. However, in Malaysia, it cannot effectively manage the solid waste disposal due to the large volume of MSW generated daily. Furthermore, the current landfilling process not only occupies an enormous amount of land, but also significantly contaminates the environment including the atmosphere, water and soil [4]. Incinerating MSW can be an ideal way to manage the MSW in Malaysia. A typical incineration facility can accomplish a 70% mass reduction and 90% volume reduction of the incoming municipal solid waste [5, 6]. Consequently, volume reduction in MSW generated will result in sanitary landfill life extension and the minimization of the land sites utilized for landfilling purpose. Incineration of waste at high temperature (800^{o}C – 1100^{o}C) has the potential to kill all the pathogens. Incineration also prepares a safety environment for handling and disposing the clinical/hospital waste as well as the food waste that contaminated by the microorganisms, which are the source of diseases. Due to that, it is wise to develop and to expand the technology so that a better MSW management could be tapped in the near future. One of the major problems encountered in applying incineration system in Malaysia is lack of comprehensive sense on the MSW generation rates, physical and chemical composition as well as heating value of Malaysian MSW [7]. In order to properly evaluate the performance of incineration plant in Malaysia, investigation of the influence of MSW's composition on its combustion characteristics is an essential.

2. MATERIALS AND METHODS

This project was scheduled into four stages which represent the physical composition analysis, physical analysis, chemical analysis and combustion analysis. The waste composition analysis was conducted in Pulau Burung Sanitary Landfill, Penang, Malaysia. This study adopted the truckload sampling method. The sorted waste samples were taken to laboratory for further analysis. For establishing a representative waste sample, the waste food organic content was simulated by potato which is recognized as the most suitable candidate in food waste imitation [8]. For plastic component, a mixture of low-density polyethylene (*LDPE*) and high-density polyethylene (*HDPE*) was chosen to represent the plastic polymer content after considering that *LDPE* and *HDPE* are the most widely used in consumer products [9, 10]. Wood was imitated by sawdust (pre-dried) after considering sawdust has the same constituent of wood and moreover, sawdust in this case represents the shredded wood. Imitate MSW was made followed the actual composition of MSW found in Pulau Burung Sanitary Landfill. The proximate and ultimate analyses as well as higher heating value of the waste sample were conducted in the chemistry laboratory, analytical laboratory and petroleum laboratory at the School of Chemical Engineering, University Science of Malaysia. One gram sample was used for the aforementioned tests. A series of test was conducted by using British Standard (BS) to determine the moisture content, ash contents, volatile matter and fixed carbon of the imitate MSW. The heat of combustion of imitate MSW was determined by using oxygen bomb calorimeter, model 1261 Parr Instrument Company and chemical composition of MSW was determined by using CHNS/O analyzer – model 2400 series II, Perkin Elmer.

3. RESULTS AND DISCUSSION

Waste composition analysis had been done by sampling, sorting and weighing the individual components of the waste stream at Pulau Burung Sanitary Landfill. A breakdown, by weight, of the MSW materials obtained from the segregating activity is presented in Table 1. Combustible components reached up to 94.15% of the total MSW. The variations in wastes composition of municipal solid waste (MSW) in Penang State were relatively large. Food waste was the most abundant component of the MSW, accounting for 40.08%. Plastic was the second-largest component (24.04%), owing to the industries found in this municipality; whereas paper and paper products contributed 12.89%, being the third largest component. Comparatively, Penang MSW does not contain as much paper as in typical developing countries. To elucidate this phenomenon, we have to understand that the waste composition is directly influenced by the social activities. In Malaysia, most of the paper and paper products especially cardboard and newsprint are sold to old newspaper vendors. This practice reduces the amount of paper products being dumped into landfill site and directly causes shrinkage to the amount of paper and paper products in landfill site. Consequently, the paper and paper products segregated was lesser than what was expected in a developing country. Tin, metals and wood each constituted between 0.47 and 2.10 percent of the total MSW generated. On the other hand, rubber and textile combined made up 6.37 percent of MSW. The findings reveal that metal was the fewest component in MSW, only 0.47% of the total MSW. As we know, metal is the major component discarded by industrial activities, therefore it was practically marginal in domestic waste. Industrial waste is excluded from MSW in this project. The amount of plastic waste recorded was 24.04%. This figure is considered very high [11] and it is typical in fast developing countries. Undoubtedly, Penang State (Penang Island and mainland) is one of the fastest developing states in Malaysia where the majority of the resident**s** are from the high and middle income group.

Table 1: Mean composition (% by weight) of municipal solid waste dumped in Pulau Burung Sanitary Landfill

Waste Components	*Composition (wt%)*	*Waste Components*	*Composition (wt%)*
Food waste	40.08	Textile	5.08
Paper	12.89	Yard	9.23
Plastics	24.04	Glass	3.28
Wood	1.54	Ferrous	0.47
Rubber	1.29	Aluminum	2.10

3.1 Investigation on individual components

The ultimate analysis was performed for individual waste component for the determination of C, H, O, N and S, and proximate analysis was carried out for moisture and ash content. The result obtained is shown in Table 2. Combustion is a chemical process that changes the chemical composition of MSW. In consequent of that, the chemical composition of MSW must be clearly understood [5]. Wet samples were used in proximate analysis whereas dry samples for ultimate analysis. The experimental data shows that food waste comprised the highest moisture content, 81.76%. Yard waste was the second-highest moisture content component, comprising 80.75% while the third-highest category was wood, which comprised 36.55% of moisture content. The moisture content of textile and paper was 2.86% and 8.21%, respectively. The moisture in rubber and plastics waste combined made up of 0.96%. Consequently, from the results obtained, it was revealing that food and yard waste contribute the most for the moisture content in MSW. Therefore, in order to increase the fuel value of MSW, the volume of food and yard waste should be reduced or dried prior an incineration process. From the view of chemical constituent, carbon is the highest chemical component in plastic waste (62.90%), followed by textile (55.57%) and rubber (52.77%). On the whole, carbon content is the greatest chemical constituent in waste components.

Table 2: Typical moisture content (mass percentage as discarded), ultimate analyses (mass percentage on a dry basis), and experimental HHV (as discarded, in MJ/kg) of MSW major categories.

Component	*Moisture (%)*	*Ash (%)*	*% C*	*% H*	*% O*	*% N*	*% S*	*HHV*
Food waste	81.76	4.06	37.97	8.41	47.34	1.78	0.44	3.25
Paper	8.21	6.72	41.44	8.19	43.2	0.11	0.34	16.23
Plastics	0.23	0.82	62.90	4.90	31.18	0.00	0.20	22.19
Wood	36.55	1.88	44.76	8.81	43.82	0.28	0.45	14.60
Rubber	0.73	23.08	52.77	9.44	13.52	0.78	0.41	24.86
Textile	2.86	1.81	55.57	6.02	36.27	0.08	0.25	20.61
Yard waste	80.75	8.24	40.47	7.47	41.85	1.53	0.44	5.50

The chemical composition of individual waste components is important in estimating the overall MSW chemical composition and this data may be useful in HHV evaluation. In the HHV analysis carried out for individual waste components, rubber was the highest energy contributor in MSW that giving out a calorific value of 24.8643 MJ/kg. The heat content of plastic was 22.1914 MJ/kg, followed by textile with a heat content of 20.6124 MJ/kg. Paper and wood each contributed 16.2270 MJ/kg and 14.5953 MJ/kg while food waste and yard waste showed the smallest HHV among all the components in MSW. The HHV recorded for food waste and yard waste were 3.2492 MJ/kg and 5.4992 MJ/kg, respectively. The heat content of inert (silica) is ideally zero but a small non-zero value is observed by calorimetry due to the presence of impurities. The small HHV values of inert and non-combustible materials such as glass and ferrous/aluminum were omitted in the determination of HHV for waste components in this report.

3.2 Investigation on bulk MSW

The previous section describes the combustion characteristics of major individual components in MSW. This section is devoted to a discussion on the combustion characteristics of bulk MSW reported in combustible basis and overall basis. The combustible basis of MSW is defined as the total waste components made up of MSW excluding the noncombustible materials such as metal, aluminum and glass. The overall basis of MSW is the actual composition of MSW that comprises the combustible and noncombustible materials. Evaluation performed for these two categories is vital for generating the total information that is needed in incineration management in view of the difference of the calorific values contributed by these groups. If we know the HHV for the aforesaid groups, we can make a decision on whether to remove all the noncombustible materials from the MSW stream or total MSW to be incinerated. The proximate analysis for overall MSW obtained by calculation method based on the combustible basis data. The proximate analysis shown in Table 3 elucidated that 44.66% of the total MSW weight was accounted for moisture content. The volatile matter content made up 44.55% of the total MSW weight. Ash content and fixed carbon content each contributed 8.56% and 2.23%, respectively. The HHV investigated for MSW was 9.8532 MJ/kg and 10.4673 MJ/kg in combustible basis. It was found that the MSW investigated had the typical HHV values of a developing country.

Table 3: Proximate analysis

Proximate analysis	*Overall MSW*	*Combustible basis of MSW*
Moisture content	44.6618	47.5298
Ash content	8.5591	2.7233
Volatile matter content	44.5503	47.3692
Fixed carbon content	2.2288	2.3778
Higher Heating Value (MJ/kg)	9.85320	10.46728

To calculate the chemical composition of MSW, its individual composition of C, H, O, N, and S for that particular waste component (obtained from ultimate analysis for individual components) were multiplied by their mass fraction and then totaling up the value. The summation of C, H, O, N and S of individual waste components represented total chemical composition of MSW. The ultimate analysis results explicated that carbon content was the largest chemical composition of MSW, being 43.97%. Oxygen content was the second most abundant chemical constituent in MSW accounting for 39.40%. The composition of hydrogen was 6.83% while 0.91% and 0.33% were accounted for by nitrogen and sulfur content, respectively. The ultimate analysis for overall MSW and MSW on combustible basis is given in Table 4.

Further investigation has been made on the contribution of moisture, volatile matter and fixed carbon content towards HHV. The result shows that the volatile matter significantly contributed to a higher HHV. In contrast, fixed carbon contributed negatively to the HHV of MSW [8] and its influence toward HHV was minimal. Another investigation was on the trend of the carbon, oxygen, nitrogen, hydrogen and sulfur content as compared to the HHV. The chemical composition and the HHV were selected from MSW on combustible basis in comparison. On the whole, there was a good relationship between the chemical compounds and HHV. Carbon and hydrogen content contributed positively to the energy content of MSW. However, the elemental analysis showed a negative contribution by oxygen and nitrogen for the energy content of MSW. Sulfur content could not be traced therefore it was concluded that sulfur did not contribute significantly to the HHV. The results obtained from the above analysis are similar to the theories stated by Dulong, Steuer, Chang, and Vondracek.

Table 4: Ultimate analysis

Ultimate analysis	*Overall MSW*	*MSW on combustible basis*
Ash (%)	8.56	2.72
% C	43.97	46.78
% H	6.83	7.26
% O	39.40	41.92
% N	0.91	0.97
% S	0.33	0.35

4. CONCLUSIONS

The combustion characteristics investigated in this project reveals the suitability for building an incineration plant in Penang State. This is due to Penang's MSW has a higher HHV (9.8532 MJ/kg), which is resulted from higher carbon content (43.97%) and volatile matter content (44.55%). MSW from Penang State contains large combustible materials (94.15%) and small amount of ash content (8.56%). The raw material for incineration plant, MSW, was found sufficient. It was estimated that 600 MT of MSW from Penang State to be disposed daily and this ensures a continuous waste supply to the incineration plant.

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