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GENERALIZATION, FORMULATION AND HEAT CONTENTS OF SIMULATED MSW WITH HIGH MOISTURE CONTENT

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Abstract

This paper presents a generalization technique for the formulation of simulated municipal solid waste. This technique is used for the elimination of the inconsistency in the municipal solid waste (MSW) characteristics due to its heterogeneous nature. The compositions of simulated municipal solid waste were formulated from four major municipal waste streams components in Malaysia namely paper, plastic, food and yard waste. The technique produced four simplified waste generalization categories with composition of paper (19%), plastic (25%), food (27%) and green waste (29%) respectively. Comparative study was conducted for proximate analysis for the determination of volatile matter, fixed carbon and ash content. Ultimate analysis was performed for carbon and hydrogen content. The heat content for simulated and actual municipal solid waste showed good agreement. The moisture content of the simulated municipal solid waste and actual municipal solid waste were established at 52.34% and 61.71% respectively. Overall results were considered to be representative of the actual compositions of municipal solid waste in Malaysia.

Keywords: Generalization technique, Municipal solid waste (MSW), Simulated MSW, Proximate analysis, Ultimate analysis, Heat content.

1. Introduction

Municipal solid wastes in Malaysia are abundant and cause a challenging effort for the authorities to dispose it off. Land filling is the main solid waste disposal method in Malaysia in which 80% - 90% of municipal solid waste is land-filled and mostly open dumping [1, 2]. Malaysia like all developing countries is facing an increase in

Nomenclatures

CV	Calorific values, kJ/kg
HHV	High heating value, kJ/kg
LHV	Low heating value, kJ/kg
MSW	Municipal solid waste
n	Number of moles
Greek Symbols	
ΔH_v	Heat of vaporization, kJ/kg

the generation of municipal solid waste (MSW) and the problem of managing this waste is also on the increase. The peninsular Malaysia (i.e. Kuala Lumpur and 11 of the 13 states in the country) generates about 17,000 tonnes of domestic waste per day or 6.2 million tonnes/year and the amount per capita varies between 0.5-0.8 kg/day and has increased to 1.7 kg/day in big cities [2-6]. The increase in municipal solid waste is an indication of the progress of Malaysia towards developed nation.

Municipal solid waste in Malaysia is generally land-filled but alternative method of solid waste disposal system is in need due to steady increase of municipal solid waste generation annually in Malaysia. Combustion and gasification are seen as potential alternatives to resolve this waste management issue and growing number of local waste incineration facilities have successfully adopted these techniques. Research on the combustion or gasification studies of MSW are difficult to be conducted in a full scale furnaces due to heterogeneous nature of waste compositions and expensive design, construction and commissioning stages. In the formulation of the simulated MSW, primary factors such as the actual MSW compositions, moisture content of waste, heating values, proximate and ultimate analyses are looked into as these factors are then compared to the properties of the simulated MSW. The aim of the formulation of simulated MSW is to prepare a test fuel that could be used and accepted in the laboratory scale combustors. It simplifies the waste streams significantly and gives an insight and improvement on the combustion and gasification reactions of actual MSW in commercial furnaces.

Efforts had been made by researchers to simulate the characteristics of MSW compositions of their respective countries using laboratory scale combustors. The formulation of the simulated municipal solid waste in China by was based on actual municipal solid waste composition which mainly consists of vegetable, sand and paper card with similar ash, moisture, fixed carbon contents as actual MSW [7]. A technique for the formulation of the simulated MSW in the United Kingdom was presented [8]. The major fuel in the simulated waste consisted of cardboard and vegetable and the weight ratio between the cardboard and vegetable was 1.85:1 which is in accordance to the ratio between paper and food content in a typical United Kingdom municipal solid waste. The chemical and physical characteristics of a synthetic fuel which represented the collective composition of municipal solid waste in the United States were presented [9]. The majority of fuel consisted of paper and wood whilst low density polyethylene was chosen to represent the plastic polymer and iron represented the metal content. Animal feed and water simulated the waste food organic contents and the inert component, silica made-up the rest of the fuel. The fuel was made in three stages: (i) waste components mixing (ii) size reduction by shredding, (iii) compaction into cylindrical pellets of 2.5 cm diameter and approximated length of 5 cm. Technical feasibility of a fluidized bed for burning of high moisture municipal solid waste was presented [10]. Pre-dried chicken manure pellets were used and water was added to generate the required percentage of moisture content. Combustion of substitution fuels that were made from compressed mixes of cardboard and polyethylene was also highlighted [11]. These two materials represent the two classical classes of waste components.

Knowledge of the physical characteristics and chemical composition of municipal solid waste are crucial as these parameters influence the overall behaviour of the combustion system. Municipal solid waste for example comprises of extreme variation of sizes and shapes, thus longer residence times are required to completely burn the waste. Physical and chemical characteristics of municipal solid waste are important in the design of a combustion system [12]. For example, information on the carbon, hydrogen and oxygen content of the municipal solid waste enables the calculation of air requirement for the complete combustion, excess air combustion or even starved air combustion (gasification), thus enabling the estimation of air compressor power and costing. Physical characteristic provides information of the waste itself such as the density of the waste which gives an indication of the mixing of the waste and air especially in a fluidized bed combustion system.

It is also important to determine the energy content or calorific values (CV) of the solid waste. The energy content of any material such as solid waste is a function of many parameters, namely physical composition of the waste, moisture content and ash content. It can also be used as an indicator to determine the quality of the fuel and a high caloric value is an indication of a high quality fuel. Municipal solid waste is a low quality fuel compared to other biomass waste such as rice husk and coffee husk. The low quality of municipal solid waste as a fuel is due to its high moisture content. High moisture content reduces the calorific values of waste. High moisture content can lead to poor ignition and reduce the combustion temperature and hinder the combustion of reaction products, thus affecting the quality of combustion.

Most of the work in the formulation of simulated MSW is based on country specific, thus not representative to the Malaysian MSW compositions and proper preparation technique of simulated MSW is important in simulating the actual MSW. The long term goal is to prepare a substitution fuel for the combustion and gasification studies and the evaluation of kinetics and reactions mechanisms. In line with the issues mentioned, the objective of this work is to simulate the physical and chemical characteristics of Malaysian MSW due to reasons associated with its heterogeneous and inconsistent compositions and varying sizes. The in-house waste characteristic study of Malaysian capital, Kuala Lumpur municipal solid waste was carried out for a year and the four commonly waste compositions in the Malaysian waste streams were identified as paper (23.12%), plastic (17.65%), food (25.24%) and green waste (26.29%) and used as a basis for this study [13].

2. Methodology

The formulation of the simulated MSW was based on data gathered from the actual municipal solid waste characteristic study conducted in Kuala Lumpur in 2001 [13]. Proximate analysis was conducted to determine the moisture content, volatile matter, ash and fixed carbon. Ultimate analysis was carried out to determine the chemical elements that make up the sample namely carbon content, hydrogen content and oxygen content. The method was separated into three segments namely; (1) Formulation and waste generalization technique of simulated MSW and (2) Physical and chemical properties of simulated MSW (3) Determination of heat content.

2.1. Formulation and waste generalization technique

The categorization and simplification of actual MSW compositions were first carried out and four main categories were chosen namely food waste, plastic, paper and green waste. Other wastes are discarded from the analysis because of little effect on the overall characteristics of MSW. The procedure was then followed by the categorization and formulation of simulated MSW in which four categories of wastes were selected. The simulated waste components were derived from rice boiled waste from restaurant for food waste, plastic film from plastic recycling factory for plastic waste, shredded paper waste from office for paper waste and vegetable waste from wet market for green waste. Lastly, the normalization technique was applied to calculate the percentage composition of the generalized simulated MSW.

2.2. Determination of physical and chemical properties of simulated MSW

Individual proximate and ultimate analysis of simulated MSW component was first carried out. Tests of interests for the proximate analysis were volatile matter, fixed carbon and ash contents. The tests were followed by the ultimate analysis with the determination of carbon and hydrogen contents. The total proximate and ultimate analyses for the simulated MSW were determined by the multiplication of individual proximate and ultimate analyses to that of the respective individual waste percentage of the simulated MSW.

2.3. Determination of heat content

Comparison studies were also conducted for heat content of simulated MSW to that of actual MSW. Two terms of calorific values were used to describe the heat contents; High Heating Value (HHV) and Low Heating Value (LHV). The HHV is also known as the gross calorific value or gross energy. It is defined as the amount of heat released by a specified quantity once it is combusted and the products have returned to a temperature of 25°C. The HHV takes into account the latent heat of vaporization of water in the combustion products. The HHV of waste is estimated by Dulong Equation;

$$\mathrm{HHV}\ (\mathrm{kJ/kg}) = 33801\ (\mathrm{C}) + 144158\ \{(\mathrm{H}) - 0.125\ (\mathrm{O})\} + 9413\ (\mathrm{S}) \tag{1}$$

where (C), (H), (O) and (S) are the carbon, hydrogen and oxygen content (dry basis) respectively.

Low Heating Value (LHV) is also known as net calorific value of a fuel. It is defined as the amount of heat released by combusting a specified quantity and the final temperature of the combustion products is above the boiling point of water (100°C). The LHV assumes the latent heat of vaporization of water in the fuel and the reaction products is not recovered. Therefore, to calculate a LHV of a fuel from a HHV or vice versa, the moles of water produced when a mole of fuel is burned must be determined. Hence

$$HHV = LHV + n\Delta H_v (H_2O, 25^{\circ}C) \quad (2)$$

The heat of vaporization of water at 25°C is;

$$\Delta H_v (H_2O, 25^{\circ}C) = 44.013 \text{ kJ/mol or } 2.445 \text{MJ/kg} \quad (3)$$

Efforts were also made to compare of the calorific values (HHV and LHV) of simulated MSW and actual MSW in as received basis.

3. Results and Discussion

3.1. Formulation and waste generalization of simulated MSW

Waste generalization technique was used to reduce the waste composition in the municipal solid waste into only four main categories; paper, plastic, food and green waste. These compositions were used as a basis for the formulation of simulated MSW. The formulation of the simulated MSW was based on data gathered from the actual municipal solid waste characteristic study conducted in Kuala Lumpur in 2001 [13] and comparison was also made for residual medium income municipal solid waste characteristic in Kuala Lumpur [5]. Table 1 shows the generalized simulated MSW.

Table 1. Generalized Simulated MSW.

Municipal Solid Waste Category	Municipal Solid Waste [5] (%)	Municipal Solid Waste [13] (%)	Individual Waste (%)	Generalized Simulated MSW (%)
Food	Food /organic (38.42%)	Food waste (25.24%)	25.24	**27**
Plastic	Plastic (20.04%)	Plastic (17.65%)	17.65	**19**
Paper	Mix paper (7.22%) News print (7.76%) High grade paper (1.02%) Corrugated paper (1.75%) Diaper (7.58%)	Paper (13.55%) Cardboard (4.34%) Diaper (5.22%)	23.12	**25**
Green	Yard waste (1.12%)	Yard waste (8.55%) Fruit husk (17.74%)	26.29	**29**
TOTAL			**92.30**	**100**

The physical make-up and the origin of the simulated MSW for food, plastic, paper and green wastes categories were boiled rice waste from restaurant, plastic film from plastic recycling factory, shredded paper waste from office and vegetable waste from wet market respectively. Further tests were carried out to verify the acceptability of the make-up samples. Figure 1 shows generalized simulated MSW weight composition.

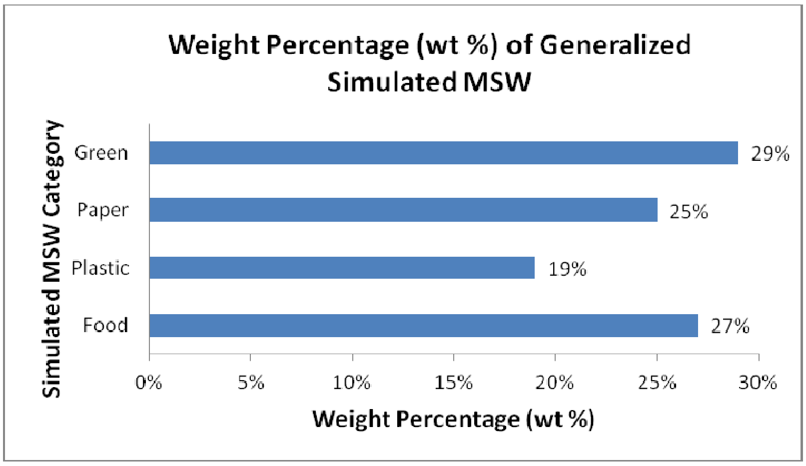

Fig. 1. Generalized Simulated MSW Weight Composition.

3.2. Physical, chemical and heat contents of simulated MSW

Each individual waste component of the simulated MSW was later subjected to proximate and ultimate analyses for the determination of physical and chemical properties. Result of ash analysis for the simulated MSW is shown in Fig. 2.

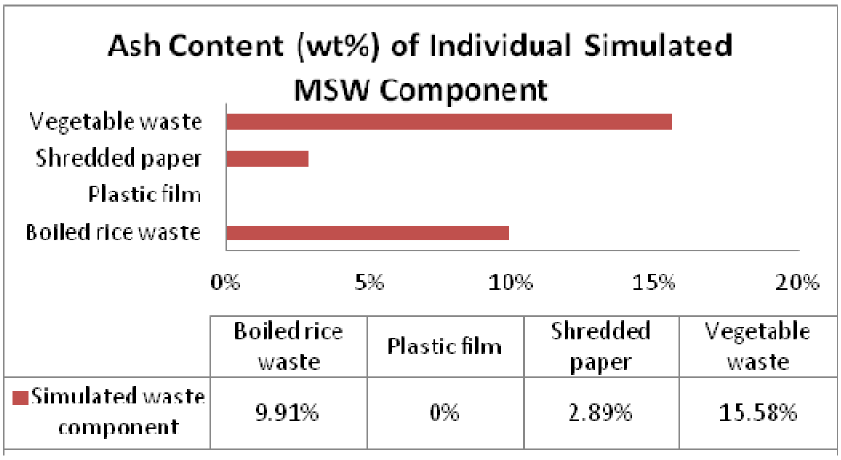

Fig. 2. Ash Content of Individual Simulated MSW Component.

Oxygen content was calculated from equation shown below

$$O = 100 - (C + H + ash) \quad (4)$$

Other chemical substances such as N and S were omitted since their amount was too little and neglected for ease of calculations. Figure 3 shows the results on the ultimate analysis (C, H and O) for individual simulated MSW component.

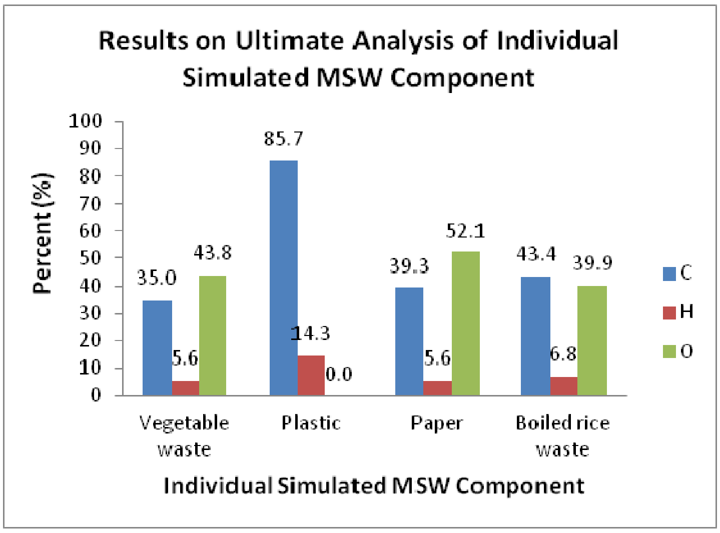

Fig. 3. Results on Ultimate Analysis of Individual Simulated MSW Component.

Multiplying the values of C, H and O of the individual simulated MSW with their respective composition (%), yielded the total C, H and O of the simulated MSW. Example calculation for carbon content is as follows;

$$C = \left(\frac{43.39}{100}\right)\left(\frac{27}{100}\right) + \left(\frac{39.33}{100}\right)\left(\frac{19}{100}\right) + \left(\frac{85.71}{100}\right)\left(\frac{25}{100}\right) + \left(\frac{35}{100}\right)\left(\frac{29}{100}\right) \quad (5)$$

$$C = 50.77\ \%$$

Comparison on the ultimate analysis between the simulated and actual MSW [5, 13] is shown in Table 2.

Table 2. Ultimate Analysis of Simulated and Actual MSW.

Waste Type	Carbon (%)	Hydrogen (%)	Oxygen (%)
Municipal Solid Waste [13]	47.71	6.66	34.67
Municipal Solid Waste [5]	46.11	6.86	28.12
Simulated MSW	50.77	8.10	33.39

Proximate analysis (%-dry basis) was conducted for simulated MSW and Table 3 shows results of the proximate analysis (volatile contents, fixed carbon and ash) of the individual simulated MSW component.

Table 3. Proximate Analysis of the Individual Simulated MSW.

Proximate Analysis (%-dry basis)	Individual simulated MSW component			
	Boiled rice waste (%)	Plastic film (%)	Shredded paper (%)	Vegetable waste (%)
Volatiles	83.36	89.92	96.57	71.01
Fixed carbon	6.73	8.08	0.54	13.41
Ash	9.91	0.00	2.89	15.58

Similarly, the percentage composition of the individual simulated municipal solid waste was multiplied with its individual content of volatiles, fixed carbon and ash to give the average volatiles, fixed carbon and ash. Example calculation for volatile content is as follows;

$$\text{Volatiles} = \left(\frac{83.36}{100}\right)\left(\frac{27}{100}\right) + \left(\frac{89.92}{100}\right)\left(\frac{25}{100}\right) + \left(\frac{96.57}{100}\right)\left(\frac{19}{100}\right) + \left(\frac{71.01}{100}\right)\left(\frac{29}{100}\right) \tag{6}$$

Volatile = 83.93%

Comparison between proximate analysis results of actual MSW and simulated MSW is shown in Table 4. The overall properties of simulated MSW and actual MSW are tabulated in Table 5. The heating values (HHV and LHV) for both dry basis and as received (raw) for simulated MSW and actual MSW are also calculated. Results showed that the percentage composition, ultimate, proximate and calorific values of simulated MSW were identical with actual MSW with minimum percentage errors.

Table 4. Proximate Analysis of Simulated and Actual MSW.

Proximate Analysis (%-dry basis)	Municipal solid waste [5] (%)	Municipal solid waste [13] (%)	Simulated MSW (%)
Volatiles	69.70	83.21	83.93
Fixed carbon	9.71	8.04	7.83
Ash	20.58	8.75	7.74

Table 5. Properties and Heating Value of Simulated and Actual MSW.

Ultimate Analysis (wt % - dry basis)	Municipal solid waste [5]	Municipal solid waste [13]	Simulated MSW
Carbon	46.11	47.71	50.77
Hydrogen	6.86	6.66	8.10
Oxygen	28.12	34.67	33.39
Ash	20.58	8.75	7.74
		Waste Properties	
Moisture Content (%)	55.01	61.71	52.34
Dry waste content (%)	44.99	38.29	47.66
		Proximate Analysis (wt% - dry basis)	
Volatiles	69.70	83.21	83.93
Fixed carbon	9.71	8.04	7.83
Ash	20.58	8.75	7.74
		Heating Value (MJ/kg)	
High Heating Value (*HHV* – as received)	*Not available*	7.46	10.88
Low Heating Value (*LHV* – as received)	*Not available*	5.95	9.60
High Heating Value (*HHV* – dry basis)	*Not available*	19.48	22.82
Low Heating Value (*LHV* – dry basis)	*Not available*	17.97	21.54

4. Conclusions

Simulated MSW used in this study was formulated based on major waste compositions obtained from the municipal solid waste characteristic study conducted in Kuala Lumpur in 2001. The generalization technique was used to estimate the properties of simulated MSW. The technique was developed to overcome the heterogeneous complexity of actual MSW. The compositions of simulated MSW were generalized into four main components which consist of paper (19%), plastic (25%), food (27%) and vegetable waste (29%). Proximate and ultimate analyses were carried out on the simulated MSW and it was established that its properties were almost identical to the actual MSW and was considered to be representative of the actual compositions of municipal solid waste in Malaysia.

References

1. Ngoc, U.N.; and Schintzer, H. (2009). Sustainable solutions for solid waste management in South East Asian countries. *Waste Management*, 29(6), 1982-1995.
2. Ahmed, S.I.; Johari, A.; Hashim, H.; Alkali, H.; and Ramli, M. (2011). Renewable energy and carbon reduction potentials of municipal solid waste in Malaysia. *IEEE* 1st *Conference on Clean Energy and Technology* (*CET*), 280-286.
3. Malaysian Government Report on National Solid Waste Management Policy, In: Manaf, L.A.; Samah, M.A.; and Zukki, N.I. (2009). Municipal solid waste management in Malaysia: Practices and Challenges. *Waste management*, 29(11), 2902-2906.
4. Yip, C.H.; and Chua, K.H. (2008). An overview on the feasibility of harvesting landfill gas from MSW to recover energy. *The International Conference on Construction and Building Technology ICCBT* 2008, F(28), 303-310.
5. Kathirvale, S.; Yunus, M.N.M; Sopian, K.; Samsuddin, A.H. (2003). Energy potential from municipal solid waste in Malaysia. *Renewable Energy*, 29(4), 559-567.
6. Ghani, W.A.W.A.K.; and Idris, A. (2009). Preliminary study on biogas production of biogas from municipal solid waste (MSW) leachate. *Journal of Engineering Science and Technology* (*JESTEC*), 4(4), 374-380.
7. Liang, L.; Sun, R.; Fei, J.; Wu; Shaohua; Liu, X.; Dai, K.; and Yao, N. (2008). Experimental study on effects of moisture content on combustion characteristics of simulated municipal solid wastes in a fixed bed. *Bioresource Technology*, 99(15), 7238-7246.
8. Yang, Y.B.; Yamauchi, H.; Nasserzadeh, V.; and Swithenbank, J. (2003). Effect of fuel devolatilization on the combustion of wood chips and incineration of simulated municipal solid wastes in a packed bed. *Fuel*, 82(18), 2205-2221.
9. Thipse, S.S.; Sheng, C.; Booty, M.R.; Magee, R.S.; and Bozzelli, J.W. (2001). Chemical makeup and physical characteristics of a synthetic fuel and

methods of heat content evaluation for studies on MSW incineration. *Fuel,* 81(2), 211-217.

10. Patumsawad, S.; and Cliffe, K.R. (2002). Experimental study on the fluidised bed combustion of high moisture municipal waste. *Energy Conversion and Management*, 43(17), 2329-2340.
11. Salvador, S.; Quintard, M.; and David, C. (2004). Combustion of a substitution fuel made of cardboard and polyethylene: influence of the mix characteristics – experimental approach. *Fue*l, 83(4-5), 451-462.
12. Johari, A.; Hashim, H.; Ramli, M.; Jusoh, M.; and Rozainee, M. (2011). Effects of fluidization and air factor on the combustion of mixed solid waste in a fluidized bed. *Applied Thermal Engineering*, 31(11-12), 1861-1868.
13. Rozainee, M. (2001). Municipal solid waste characteristics in Kuala Lumpur, *A report submitted to the Ministry of Housing and Local Government for designing of waste incinerator*, 2001.