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Estimations and Mathematical Model Predictions of Energy Contents of Municipal Solid Waste (MSW) in Kandy

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ABSTRACT. *Waste to energy (WTE) concept is one of the best methods, which not only considers the environment but also generate energy from Municipal Solid Waste (MSW). Unfortunately, at present, 100 tonnes of MSW per day collected in the city are being dumped at the Gohagoda dumpsite. In order to materialize the concept, this research study was conducted to determine the energy potential of MSW in Kandy Municipality. In order to obtain bomb calorimeter energy values of different waste types, composition studies were conducted of the collected wastes. Furthermore, to validate the experimental results, Shafizadeh model was used and was modified to make it more suitable and accurate for MSW in Sri Lanka. This was compared with the Modified Dulong Model.*

For organic waste, the modified Shafizadeh model values were much closer to the Safizadeh model and Modified Dulong model when elemental composition values were adjusted. According to the experimental study, MSW produced considerable amount of energy; the lowest and highest calorific values on dry basis were 14,000 and 45,000 kJ/kg for wood and plastic wastes, respectively. Further analysis is required to substantiate model predictions for non-biodegradable waste. Even though MSW has the potential to produce 9.2 GJ/tonne of energy, only 75% of that could be converted to useful energy. Thus, 684 GJ/day can be obtained from the waste collected in Kandy and it amounts to 69.3 GWh/yr and it could replace 15% of annual energy requirement within the Kandy Municipality. The energy potential is more than twice the annual electricity consumption within the municipal limits. Thus, WTE can be introduced as energy efficient and environmentally sound disposal method of MSW in Kandy and elsewhere in the country.

INTRODUCTION

Solid waste consists of the highly heterogeneous mass of discarded materials from the urban community as well as the more homogeneous accumulation of agricultural, industrial and mining wastes. The principal sources of solid waste are residences, commercial establishments, institutions, and industrial and agricultural activities. The

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density and proportion of constituents vary widely from place to place and average waste generation rate can differ according to the development stage, income level and social background. Several disposal methods are available and more prominent disposal methods are open dumping, composting, incineration and sanitary land filling. However, lack of land for landfills and technologies for other treatment methods, open dump is resorted in Sri Lanka, leading to many environmental as well as health problems. Therefore in many counties, Waste to Energy (WTE) concept has been identified as one of the best methods, which not only considers the environment but also generates of energy from municipal solid waste (MSW) (Stengler, 2006; Sufian and Bala, 2006). In the waste management hierarchy, WTE has been considered as a mode for recovery of resources that must be considered before ultimate disposal of the final inert materials and reducing the amount to be land filled (Kathirvale *et al*., 2004; Komilis *et al*., 1999). Sri Lanka, as most developing countries needs cost effective solutions for any MSW infrastructure such as WTE facility with a landfill for operating considerable period of time. The potential to apply WTE concept in Sri Lanka is very high because per capita waste generation rate is high and more than 80% of waste is combustibles. Additionally there is public appreciation as an environmentally friendly waste disposal method. Four basic technologies have been investigated, which produce energy from MSW. They can be classified as incineration, gasification, generation of biogas and utilization in a combined heat and power (CHP) plant, generation of biogas and conversion to transport fuel (Murphy and McKeogh, 2004). WTE plant facilities generate electricity and reduce the volume of waste through the controlled combustion of MSW in specially-designed power plants (Ecke *et al*., 2000; Komilis *et al*., 1999). Therefore, WTE concept is ideal for power generation.

Calorific value of waste is the most important parameter to evaluate its potential for power generation using any of the above methods. Therefore, this research was focused on determining the calorific values of different kinds of waste using experimental as well as model predictions. Out of the models, Modified Dulong could be applied to estimate energy values of all types of waste, computed from elemental compositions of individual wastes, whereas, Safizadeh model was developed for organic wastes based on carbon content of the wastes (Shafizadeh, 1981). Comparisons were made for both of the models derived from literature and experimental values. Furthermore, Shafizadeh model was modified to make it more suitable and accurate for MSW found in Sri Lanka.

MATERIALS AND METHODS

This research study was based on MSW in Kandy Municipality. Therefore, required data such as waste generation rate, per capita waste generation, population density, and total energy and electricity consumptions were obtained from Kandy Municipality (EEDRB, 2005).

Composition analysis of municipal solid waste

Around two tonnes (3.4 m^3) of MSW was collected from different waste streams based on actual quantities from the Kandy Municipality and composition was analyzed. MSW was separated as combustibles and non-combustibles. Weights of different types of waste such as food waste, garden waste, wood, polythene, cardboard, paper, glass, plastic, rubber, metal, textile and leather were measured.

Sample preparation for Bomb Calorimeter testing

Combustible part of the MSW was used for the experiment. A sample of 100 g was taken from combustibles after separating non combustibles. They were kept in oven for 24 hrs under 105°C for calculating the moisture contents. The dried samples were size reduced using a blender and separated using a 1 mm sieve for achieving complete combustion in the Bomb Calorimeter tests that were carried out at the Department of Mechanical Engineering, University of Peradeniya. Two replicates of each type of waste were tested to obtain the calorific values in the apparatus. The samples were burnt in pure oxygen in an enclosed volume and the energy given off was measured as the temperature increase of the bomb and its surroundings (ANSI, 1977).

Comparisons with existing models

The results of the experimental values were compared with the existing models. Many authors from different countries have used Modified Dulong and Safizadeh models for calculating calorific values (Ayhan, 2006; MLSE & Associates report, 1995) using elemental percentages.

Modified Dulong model: It can be applied to all types of wastes and modified Dulong (Eqs. 1 and 2) has been used by Tchobanoglous *et al.* (1993) for finding High Heating Values (HHV) of solid waste.

Calorific Value Superior (CVS) (kJ/kg) =337C+1428(H-O/8) +95S …………………....(1)

Calorific Value Inferior (CVI) (kJ/kg) = CVS-2465(W+9H) …………………………(2)

Where,

C: Carbon %, H: Hydrogen %, O: Oxygen % S: Sulfur %, W: Mass of water

Elemental ratios for different waste types were obtained from Tchobanoglous *et al.* (1993) and applied directly to obtain the calorific values. However, the carbon percentages were different from reported values and thus the elemental ratios were then adjusted based on reported ratios between Hydrogen, Oxygen, Nitrogen and Sulfur. According to the experiments that have been carried out by Solid Waste Management Research Unit (SWMRU) at University of Peradeniya, Carbon content of MSW was found to be approximately equal to the Volatile Solid (VS) content/1.8. It could be validated with similar ratios for VS and Carbon percentages that have been reported in literature for MSW (Themelis *et al*., 2002).

Safizadeh model: Similar to the application of modified Dulong model, two sets of carbon values were obtained from reported values (Tchobanoglous *et al.,* 1993) and deduced values based on VS/1.8 (Eq. 3).

Heat of Combustion at 298K in kJ/kg = (94.19 x C%+55.01) 4.187 ……………………...(3)

Modified Safizadeh model: Both of the models with four sets of values differed with the experimental calorific values. Thus, the model developed by Safizadeh (1981) was modified.

It was derived by regressing experimental values of carbon percentages with the bomb calorimeter values. It could also be expressed in terms of VS% of wastes.
Heat of Combustion at 298K in kJ/kg = 202.02 x C% + 9197.3 ……………………….…(4)

Calculation of energy potential

According to the composition of MSW, energy components of different wastes were determined using dry matter amounts and the calorific values. Energy values for each type of waste were summed up to obtain the total (gross) energy in one tonne of MSW. The annual energy production potential was estimated based on daily waste generation and the value was compared with annual energy consumption level at present.

RESULTS AND DISCUSSION

Composition analysis of MSW

MSW composition could vary from place to place according to the location, population density, income level and social background (Wang and Nie, 2001). The composition of MSW collected in the Kandy Municipality is shown in Figure 1. The results indicate that WTE technology has very high potential as the waste streams consists more than 95% of combustible materials and it could be one of the best options to avoid large quantities, especially organic wastes ending up in landfills and open dumps (Chee *et al*., 2005). According to the composition, food waste was the highest fraction and contained more than 60% of water in weight basis, which is the core factor for variations in calorific values.

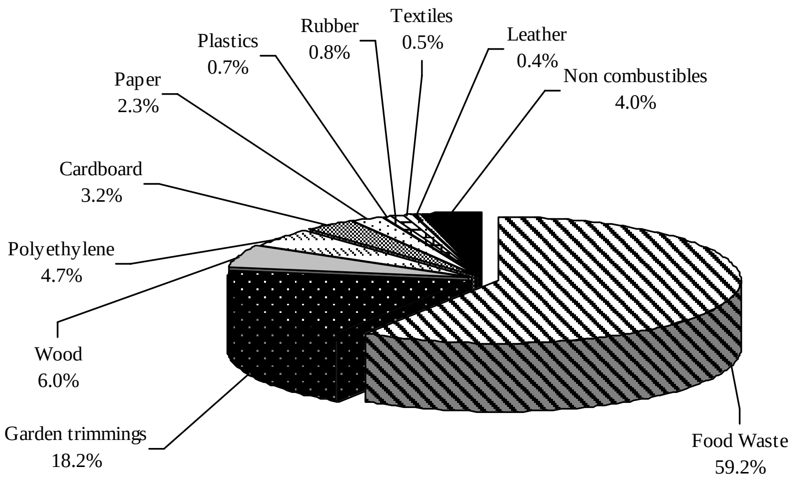

Figure 1. Composition variation of municipal solid waste in Kandy municipality.

Energy values of waste

The heat (enthalpy) released in combustion is an important parameter and combustion conditions are characterized by the amount of oxygen present. Thus, the oxygen content was adequate to combust completely the oven dry samples and the calorific values that were obtained are given in Figure 2. These results had high energy levels in comparison to most prominent fuels in the world (Kandpal *et al*., 1994). As expected, the highest energy values were obtained for polyethylene and plastics. Plastics, which include polyethylene, were classified as hard plastics, resulted in generating the highest quantity of energy as reported by Murphy and McKeogh (2004), which is also the major source of the energy in MSW. Whereas High and Low Density Polyethylene (HDPE and LDPE), produced less energy levels depending on the ratio of C:H. Various values are reported in many of the literature (Upadhyay *et al*., 2005). Unlike hydrocarbon based materials, food, wood, paper like wastes absorbs water immediately lowering the high heating values. Therefore, many countries have used various models to estimate accurate calorific values based on basic elements and prevailing water contents in MSW.

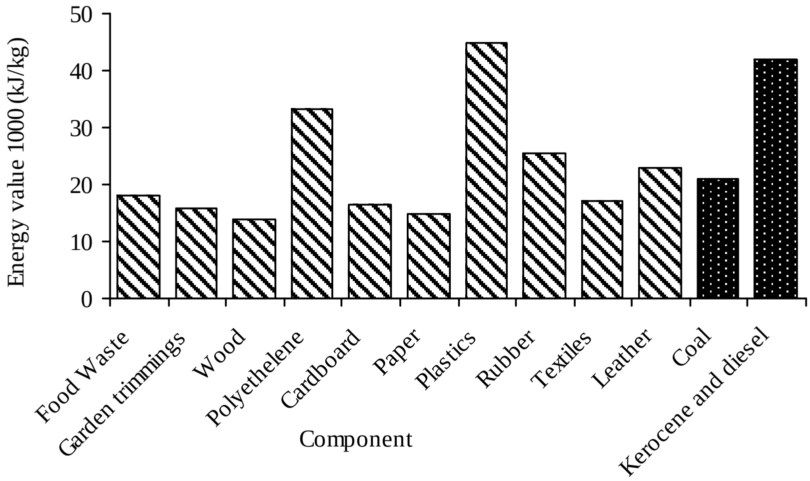

Figure 2. Calorific values of some fossil fuels and different types of municipal solid waste.

Note: Source: for energy value of Coal and Kerosene; Kandpal. *et al*. 1994.

Comparison of results: Experimental and Dulong

Modified Dulong model estimated maximum value differed by 19% higher than experimental value. It should be noted that elemental analysis data obtained from literature (Table 1) was used in the model. However, the values became much more realistic, when the elemental compositions were modified with the experimental carbon contents (Table 2 and Figure 3). After this modification, the calorific value can be predicted with a maximum variation of 6% for biodegradable as opposed to 19%. This model can be used in any part of the world since it is based on VS content of the waste. Nevertheless, non-biodegradable values still differ from the experimental energy content (Figure 3).

Table 1. Experimental and Dulong model predictions and available energy in one tonne of Municipal Solid Waste.

Component	Weight (%)	Weight (kg)	Moisture (%)	Dry matter (kg)	Experimental Calorific Value (kJ/kg)	Modified Dulong model (Reported C%) (kJ/kg)	Modified Dulong model (Experimental C%) (kJ/kg)	Energy from experimental values (kJ)
Food Waste	59.2	592.0	65.0	207.2	18200	18642	18395	3771040
Garden trimmings	18.2	182.0	40.0	109.2	15800	17922	11474	725360
Wood	6.0	60.0	40.0	36.0	14000	17637	9635	504000
Polyethylene	4.7	47.0	0.0	47.0	33300	48459	47502	1565100
Cardboard	3.2	32.0	0.0	32.0	16360	15311	14554	523520
Paper	2.3	23.0	3.0	22.4	15000	15393	15679	336105
Plastics	0.7	7.0	0.0	7.0	45000	26432	22422	315000
Rubber	0.8	8.0	0.0	8.0	25500	40566	41080	204000
Textiles	0.5	5.0	0.0	5.0	17000	22405	21874	85000
Leather	0.4	4.0	0.0	4.0	23000	29611	29818	92000
Non combustible*	4.0	40.0						
Total	**100**	**1000**		**477.8**				**9121125**

Note:* has not taken for energy calculations.

Table 2. The derived elemental composition percentages using experimental carbon contents and ratios of elements given by Tchobanoglous *et al* (1993).

Type of Organic Waste	VS%	C%	H%	O%	N%	S%	ASH%
Food waste	87.00	48.33	5.47	32.13	2.22	0.34	11.50
Garden trimmings	55.73	30.96	3.44	21.80	1.95	0.17	41.67
Wood	44.76	24.87	7.88	56.06	0.26	0.13	10.80
Coir	90.60	50.33	4.71	36.94	0.42	0.15	7.45
Paper	79.71	44.28	6.19	45.37	0.31	0.21	3.65
Card board	75.70	42.06	4.65	35.19	0.24	0.16	17.71

Note: VS: Volatile Solids

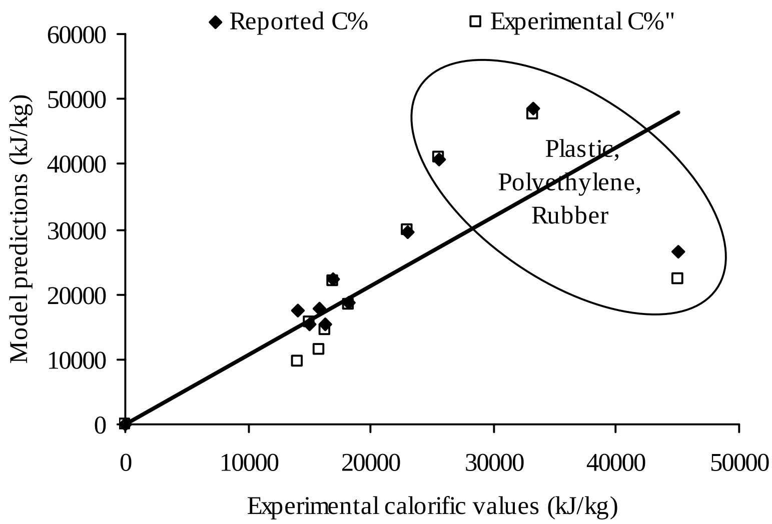

Figure 3. Variations of Modified Dulong model predictions with the experimental energy contents.

Comparison of results of Experimental, Modified Dulong, Shafizadeh and modified Shafizadeh models

Modified Dulong equation (Eqs. 1 and 2) as explained earlier gave a better prediction than Shafizadeh for biodegradable wastes (Table 3), since the latter was developed for agriculture wastes (FAO, 1993). However, when experimental carbon values were used, rather than reported ones, it resulted in a very good traight line relationship to give a modified model of Shafizadeh, (Figures 4 and 5). The hypothesis being, the variation of fixed carbon and ash contents within a waste type in two different locations can be differed. Also as pointed out by Safizadeh, contamination of municipal solid waste and agricultural waste could substantially increase the inorganic content (Shafizadeh, 1981).

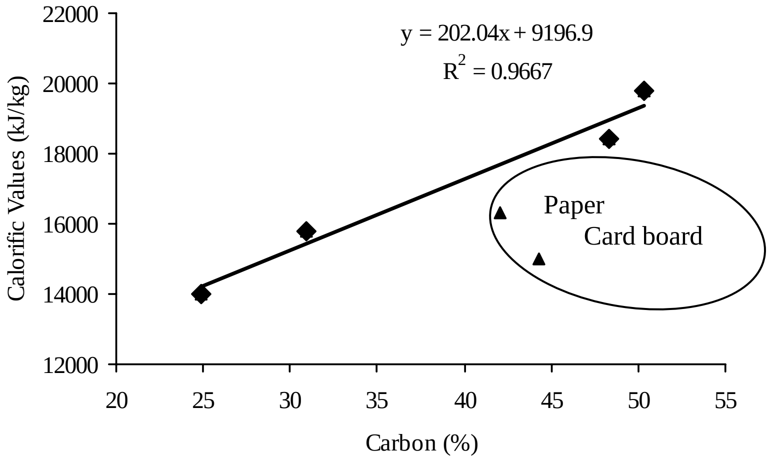

Figure 4. A plot of experimental calorific values *vs* experimental carbon percentages to realize a Modified Shafizadeh model.

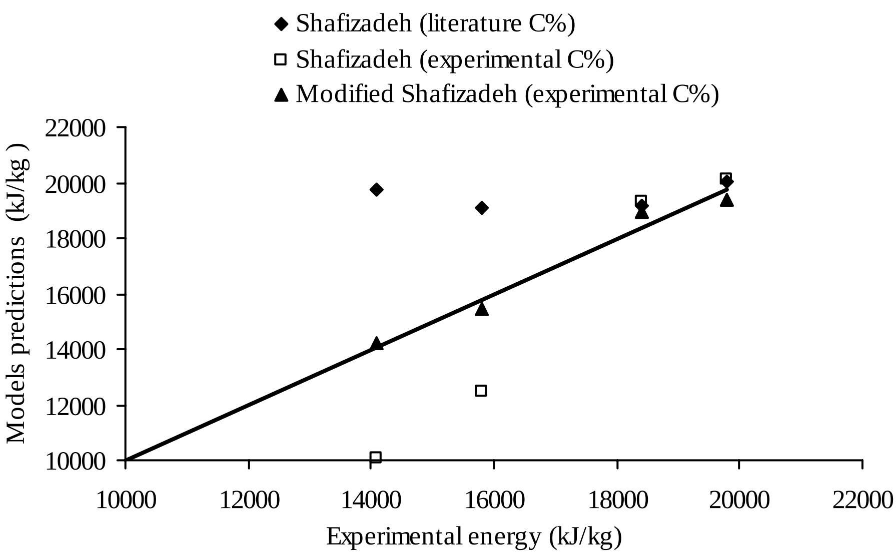

Figure 5. Variation of Shafizadeh model predictions with the experimental energy contents.

Table 3. Experimental and model predicted calorific values (kJ/kg) for different types of biodegradable wastes.

Waste type	Experimental	Modified Dulong (Reported C%)	Modified Dulong (Experimental C%)	Shafizadeh (Reported C%)	Shafizadeh (Experimental C%)	Modified Shafizadeh (Experimental C%)
Food Waste	18400	18642	18395	19160	19292	18962
Garden trimmings	15800	17922	11474	19081	12440	15452
Wood	14000	17637	9635	19752	10037	14221
Coir	19800	17100	17105	17105	20079	19365
Paper	15000	15311	14554	17386	17695	18143
Card board	16300	15393	15679	17583	16816	17693

Even though Modified Shafizadeh equation (Eq. 4) predicted best for naturally built biodegradable wastes, notable differences were identified in plotting with structurally modified biodegradable wastes like paper and card board (Table 3 and Figure 4). These deviations were similar to once encountered in analyzing non biodegradable wastes. Therefore, predictions were difficult and inaccurate with the existing and the modified models.

Gross energy content in municipal solid waste from Kandy municipal council

Apart from the usefulness of comparing models, the experimental values were used to deduce the gross energy content of one tonne of MSW. The individual energy contents of different types of wastes and the gross energy contents are given in Table 1. It is apparent that the moisture contents of waste played a crucial role in reducing the energy values. It is noteworthy that although food waste retained the highest moisture content of 65%, amounted to 59% of composition that produced 41% of the total energy. In comparison, 4.7% of polyethylene, relatively a very small quantity released under experimental conditions 17% of the total energy. A considerable energy content of the gross value of 9.12 GJ/t of MSW will be lost if the water will be allowed to evaporate in a thermal power plant without it being condensed. Thus the gross value will be reduced to an inferior calorific value by an amount of 2465 (9H+W) where H: Hydgrogen% and W: Moisture%. Further 25% will likely to be ravaged as system losses in most power generation plants, including biochemical processes of WTE. However, biogas production systems in integration with Residual Derived Fuels (RDF) can reduce the expected initial losses in dehydrating the wastes for thermal systems, unless the thermal systems are closed looped (Chee *et al.*, 2005). Therefore, energy potential for consumption is 6.84 GJ/t of MSW.

Energy potential and consumption in Kandy

In analyzing further this numerical value, the total energy potential would be 684 GJ/day in Kandy municipal limits. Thus total usable energy generation possibility is 69.3 GWh/yr. It will satisfy 15% of the present energy demand of the 110,000 persons living within the Municipality. The reported maximum per capita energy consumption rate is 5000 kWh/yr (EEDRB. 2005), leading to annual total of 440 GWh. On the other hand, per capita maximum electricity consumption rate in Sri Lanka is 300 kWh/yr (EEDRB. 2005). Based on that, 33 GWh of power is required per year and it is half of the energy production potential from MSW. Therefore, application of WTE concept is an appropriate and cost-effective method for supplementing energy requirements in Kandy.

Environmental Benefits of waste to energy concept

Throughout the world, there have been great reductions of greenhouse gases emissions attained by WTE facilities in the last 15 yrs. It has been reported that 1.3 times the carbon dioxide increase takes place for every tonne land filled (Themelis, 2004). As Tchobanoglous *et a.,l* (1993) has explained, older method of combustion sometimes led to problems such as fly ash, containing toxins, escaping and contaminating nearby areas, or to the production of a toxin residue. Modern waste incineration techniques are much more thorough and more self-contained with low contamination risk. Therefore, WTE concept is appropriate to reduce green house gases as well as other pollutants.

CONCLUSIONS

The Kandy City, like most urban centers in Sri Lanka, generates high percentage of organic wastes, thus reducing the calorific value if used in most thermal power plants. The calorific values of organic wastes were predicted accurately by modifying Shafizadeh model than Modified Dulong model. Altering the carbon content and thus the elemental compositions that were used in the Modified Dulong model gave very similar values to experimental. However, there were large variations in the model values for none-biodegradable waste in relation to the experimentally determined results. Further investigations are required to find a plausible model for other wastes that were not tallying with the developed models. The experimental values were used to find the energy potential of wastes collected in the Kandy City and it will be substantial if used in a WTE plant, preferably biochemical processes to produce gas and liquid fuel and integrating with a thermal plant to use the RDF. It is then with adequate confidence one could use these calorific values to design WTE plants for enhancing the environment of the Kandy City and elsewhere in the country.

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