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Combustion of Municipal Solid Waste in Fixed Bed Combustor for Energy Recovery

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Abstract: Municipal Solid Waste (MSW) disposal through landfill method have become less efficient nowadays because of the limited landfill sites, high land price and also bad impact towards environment and society. There is a need to find efficient alternative in dealing with the MSW generation that is growing rapidly parallel with the population growth. MSW utilization for energy recovery is the best solution in order to dispose MSW in an efficient way since it can reduce the volume of the MSW while provides energy to generate electricity. Currently, there are a few technologies that are being practiced worldwide including incineration, pyrolysis and gasification. In this study, MSW collected from Pulau Burung Sanitary Landfill, Pulau Pinang are combusted using pilot plant scale fixed bed combustor. The temperature of the hot combustion gas at the top of the bed was observed and studied for energy conversion. Based on the experimental data, a Heat Recovery steam Generator (HRSG) mathematical model will be developed to predict the energy recovered from the combustion process for power production. From the temperature profile of the gas produced, the maximum achievable temperature will be used as the input in the HRSG model. Theoretically, the heat produced will be used for steam production driving steam turbine to generate electricity.

Key words: Municipal solid waste, energy recovery, combustion, waste to energy, heat recovery steam generator (HRSG)

INTRODUCTION

Municipal Solid Waste (MSW) generation as the results of human activities and population growth has become a crucial problem in most developing countries including Malaysia. The rate of waste generation in Malaysia is continuously increasing every year because of the uncontrollable consumption from the increasing population, the attitude towards shopping and the high living standards (Saeed *et al*., 2009). It was reported that the average rate of MSW generated in Malaysia has increased to 1.7 kg person^{-1} day^{-1} (Kathirvale *et al*., 2003). From the trend of development in this country, it is believed that the waste generation rate would increase every year parallel with the increase of the human population in Malaysia.

Minimizing the wastes generation is needed in order to decrease the problems regarding the MSW. Currently, disposal of MSW through landfilling is the most conventional method that is being practiced in most of the states in this country especially Pulau Pinang. However, this method is no longer sustainable because of land scarcity, increase of land prices and high demands, especially in urban areas (Manaf *et al*., 2009). There is a need to the search for other alternatives that is sustainable and effective. Instead of adopting landfill method to dispose MSW, other method such as combustion/incineration process has been gaining attention because of the capability to reduce MSW volume and at the same time producing a combination of heat and electricity (Yang *et al*., 2002). This process is generally called Waste To Energy (WTE) technologies. WTE has many advantages compared to landfill methods. It reduces the amount of waste sent to landfills, prevent groundwater contamination and the most important part is the capability to replace fossil fuels for power generation.

Incineration/combustion, pyrolysis and gasification are considered to be the attractive methods for recovering energy from wastes. In this research, combustion of MSW becomes the topic of interest. Commonly, incineration or combustion process produced large amount of hot flue gas which holds thermal energy. However, the temperature of gas produced from the combustion depends on the type of fuel and also equipments used. The exit gas temperature for fixed/moving bed falls in the

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range of 450-650°C while for fluidized bed; it falls in the range of 800-1000°C (Basu, 2006). Instead of releasing to the atmosphere, the energy from the gas stream can be used for other purpose such as heating up water for steam production and hence generating electricity. Some researchers have investigated the combustion of MSW or biomass by using full-scale grate furnaces (Zhou *et al*., 2005). However, it is difficult and expensive to obtain detailed in-bed data. In order to understand the combustion process in the full scale grate furnace, simulation by using laboratory scale fixed bed was necessary. There are a few researchers investigated the combustion of waste particles using fixed bed combustor (Shin and Choi, 2000; Zhou *et al*., 2005; Zhou *et al*., 2006) for simulating the operation in full scale grate furnace.

Minimizing the waste generation is needed in order to decrease the problem regarding to the MSW. Instead of reuse and recycle, the technologies for energy recovery from waste can be performed to overcome the problems. In this paper, the temperature of gas from the combustion process will be studied in order to find its relevancy in generating electricity by applying to the Heat Recovery Steam Generator (HRSG) model. A simple HRSG mathematical model has been developed in order to optimize the thermal efficiency for the energy recovery process.

MATERIALS AND METHODS

In order to study the combustion process, the characterization of MSW which covered composition, proximate, ultimate and calorific value analyses were investigated. The composition analysis was conducted at Pulau Burung Sanitary Landfill, Nibong Tebal, Pulau Pinang by adopting truckload sampling method. The composition of MSW by components was shown in Table 1. The MSW samples were taken to School of Chemical Engineering Laboratories, Universiti Sains Malaysia for further analyses. Some materials, such as metals and glass, were removed from this experiment, not only because they have a commercial value, but also because they constitute a threat to the devices used. Apart from that, high temperature is needed to incinerate these components but the highest temperature of the fixed bed that could be reached is limited. The only combustible components left in the MSW streams were food, plastics, paper, rubber and textile. The composition of MSW component based on the combustible fraction was shown in Table 2.

Table 1: Composition of MSW dumped at Pulau Burung sanitary landfill, Pulau Pinang

Waste components	Weight (%)
Organic/Food	57.40
Paper	8.56
Plastics	13.93
Rubber	2.80
Textile	2.79
Glass	2.28
Ferrous	1.30
Others	10.94

Table 2: Composition of MSW based on combustible fraction (% by weight)

Food	Paper	Plastic	Rubber	Textile
67.15	10.01	16.30	3.28	3.26

Waste preparation: In this experiment, MSW was prepared by mixing food waste and paper waste together since those two components contributes high percentage in MSW composition in Pulau Pinang. Plastic wastes were not included in this experiment because of the environmental issues regarding to the dioxin emissions. Rubber and textile are neglected in the combustion experiment because their percentages are very low compared to other waste components. Besides, the presence of those components would increase the amount of hazardous emission from the combustion process. Since there are variety of food wastes at waste dumpsites, durians and egg cartons were used to represent MSW in this experiment. The durians were shredded into smaller pieces at approximately 30 mm of sizes. The shredded durians were mixed together with paper wastes and the MSW were ready to be used for characterization analyses.

Waste characterization: Small portions of the MSW were used for the proximate analysis, ultimate analysis and also calorific Value (CV) analysis. A series of test as prescribed by the American Society for Testing and Materials (ASTM) was conducted to determine the moisture content (ASTM E949-88), volatile matter content (ASTM E897-88), ash content (ASTM E830-87) and fixed carbon content of the MSW samples. At the same time, the chemical compositions for the individual component of MSW for ultimate analysis were investigated using CHNS/O Analyzer (Model 2400 Series II, Perkin Elmer). The calorific values of the MSW were investigated by using Oxygen Bomb Calorimeter (Model Nenken 1013-B) available at School of Mechanical Engineering Laboratory, Universiti Sains Malaysia. The proximate and ultimate analyses as well as CV for MSW were reported in Table 3.

Experimental setup and methodology: Combustion of MSW was conducted at Pilot Plant Laboratory, School of Chemical Engineering, Universiti Sains Malaysia by using fixed bed combustor (20 cm bed internal diameter) which

Table 3: Characteristics of MSW in Pulau Pinang

Parameter	Weight (%)
Proximate analysis (wet basis)	
Moisture content	54.68
Volatile matter content	18.78
Ash content	4.19
Fixed carbon content	22.35
Ultimate analysis (dry basis)	
Carbon	46.78
Hydrogen	8.13
Oxygen	43.73
Nitrogen	0.79
Sulfur	0.57
Higher heating value (MJ kg^{-1})	13.06

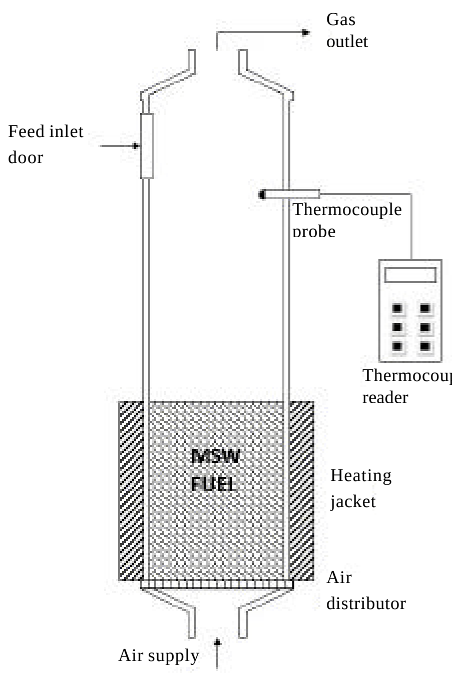

Fig. 1: Schematic diagram of the experimental fixed bed combustor used in combustion study

is surrounded by heating jacket (240 V, 2500 W). Figure 1 shows the schematic diagram of the experimental rig. A K-type thermocouple with a reader was installed at the top of the bed to observe the temperature of the combustion gas. The thermocouple was located below the feeder door inlet so that the heat loss through the door could be avoided. Another K-type thermocouple was installed at the bottom of the bed to measure the temperature of the bed during the combustion process. Air preheated to 120°C was supplied at the bottom of the bed. 0.5 kg of MSW was loaded into the bed and the bed was heated up using heating jacket. The temperature of the combustion gas was observed for every 30 sec. to see the fluctuations of temperature profile. In this experiment, the MSW was assumed to be uniformly distributed inside the bed.

RESULTS AND DISCUSSION

Temperature profile for combustion of MSW: In this research, fixed bed combustor was used for combustion of MSW. About 0.5 kg of wastes was combusted for each set of experiments by varying airflow rates (0.06, 0.11 and 0.17 m^3 min^{-1}). From the experimental work, the temperature profiles of the process for each run were plotted and shown in Fig. 2-4. The dotted line represents temperature in the bed during the combustion process while solid line represents the temperature of the gas produced at the top of the bed. From the graphs, the fluctuation of the gas temperature can be clearly seen (solid line).

Effect of airflow rate on combustion behavior: From the temperature profiles above, it can be seen that the time needed for combustion of MSW decreased by increasing airflow rates. Figure 2 shows that the combustion was started by introducing heat from the heating jacket. In this phase, the MSW was heated up through radiation from heat source that come from the fixed bed wall. The MSW at the bed wall would be heated up first instead of the surface of the fuel since the heat source come from the heating jacket surrounded at the bed wall.

For the lowest airflow rate, the time needed to evaporate the moisture was longer compared to the other airflow rates. At t = 60 min, there was a sudden change in the temperature of gas. In the graphs, the temperature change could be seen as the highest peak produced. At this peak, the moisture of MSW was completely driven off and the combustion MSW was started. It can be seen from the gradient of temperature increase inside the bed (dotted line). The time of combustion was about 5 min since the amount of fuel used was only 0.5 kg. At the same time, the temperature of gas produced from the combustion drastically increased to 531°C. After a while, the temperature dropped and finally reached steady state. The final gas temperature was believed to be the temperature of the heat source. Similar trends could be seen for airflow rates of 0.11 and 0.17 m^3 min^{-1} . However, the time for combustion to occur was shorter for high airflow rate. Increasing of airflow rates would increase the drying process of the MSW fuel and shorten the time of combustion. Based on the Fig. 2-4, the combustion process for each airflow rate was started between 200 to 300°C. During the process, a single sharp peak for time interval of 5 min was seen for every airflow rates in which the combustion process occurred.

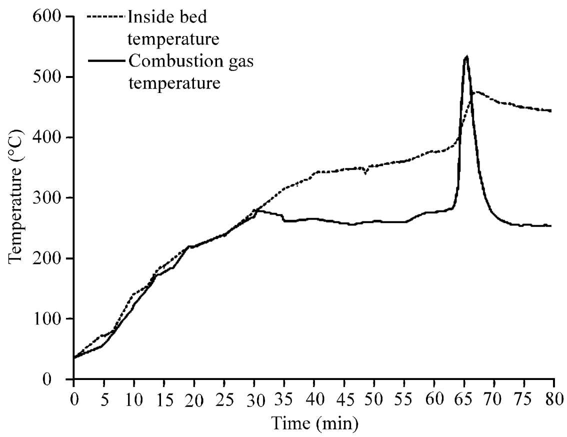

Fig. 2: Temperature profile for MSW combustion with airflow rate: 0.06 $m^3 min^{-1}$

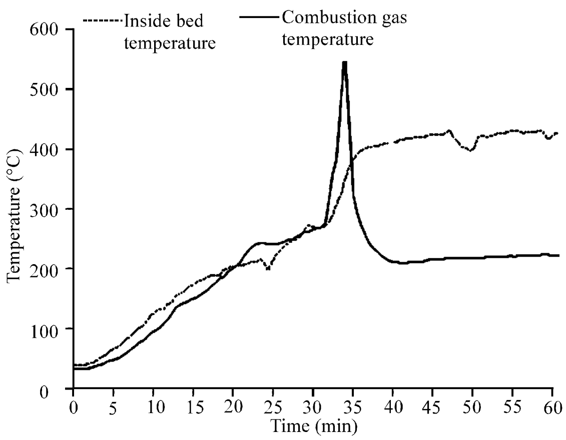

Fig. 3: Temperature profile for MSW combustion with airflow rate: 0.11 $m^3 min^{-1}$

Energy recovery from combustion of MSW: From this study, it was found that increasing the amount of air supply would cause the increasing of the combustion gas temperature. The highest achievable gas temperature was observed. Table 4 shows the results of the maximum gas temperature (T_{max}) achieved for each run. From the experiment, the gas temperature reached above 500°C. The value agrees the exit gas temperature for fixed bed ranging from 500-600°C (Williams and Larson, 1996). The value will be used as the input for HRSG model as proposed by Butcher and Reddy (2007). HRSG is chosen in this study because it can recover the high temperature waste heat from the combustion process. Normally, HRSG was used to recover waste heat from gas turbine, but in this study it will be used to capture heat from combustion process. The energy that contains in the combustion gas raises the steam to drive steam turbine for electricity generation.

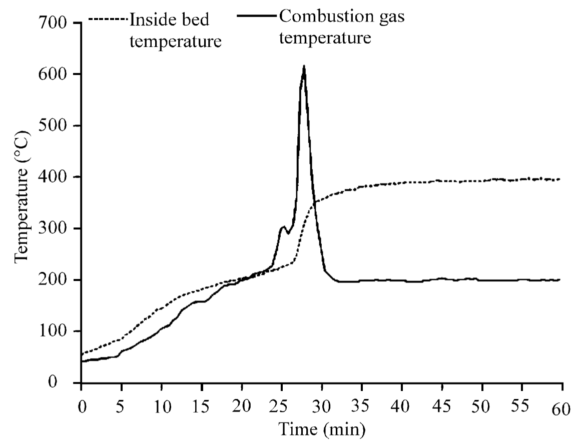

Fig. 4: Temperature profile for MSW combustion with airflow rate: 0.17 $m^3 min^{-1}$

Table 4: Maximum gas temperature achieved for different airflow rates

Run	1	2	3
Mass of fuel (kg)	0.5	0.5	0.50
Air flow rate ($m^3 min^{-1}$)	0.06	0.11	0.17
T_{max} (°C)	531	545	593

CONCLUSION

From the combustion experiments, it was found that increasing airflow rate would decrease the time of combustion and increase the maximum gas temperature. The highest combustion gas temperature reached was 593°C for highest airflow rate studied in this experiment. The temperature can be used to heat up water for steam production and generate electricity. The process can only be optimized in the HRSG mathematical model that will be developed at the end of this project. The model would give a good idea of the steam generated and the performance of the HRSG based on different inlet conditions.

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