Development and Optimization of Pilot-scale Rotary Kiln Combustor for Municipal Solid Waste Incineration

Chelladurai Punithan *, N Raja Bharathi 2, Vinod Kumar 2, S R Chakravarthy 3, B V S S Prasad 1, T Sundararajan 1, R Vinu 4
1: Department of Mechanical Engineering, IIT Madras, Chennai-600036
2: National Centre for Combustion Research and Development, IIT Madras, Chennai-600036
3: Department of Aerospace Engineering, IIT Madras, Chennai-600036
4: Department of Chemical Engineering, IIT Madras, Chennai-600036
*corresponding author: punithan897546@gmail.com

ABSTRACT

The need for Municipal Solid Waste (MSW) management is increasing, as its generation is increasing at a rapid rate. Indian cities are projected to generate seven million tons of waste per year by 2021. Landfilling of such a humongous amount of waste needs a large land area, which is becoming unviable due to unavailability of land and associated environmental issues. Considering the situation, Waste-to-Energy technologies are gaining popularity through which energy can be produced with a simultaneous reduction in the volume of solid waste. There are many routes to produce energy from MSW among which incineration is the simplest and effective operation, that can provide maximum volume reduction and energy. In this study, a pilot-scale rotary kiln combustor has been designed and developed for controlled combustion of simulated MSW collected within IIT Madras campus. This paper illustrates that parameters such as moisture content of the feed, speed of rotation of the combustor and the feed rate are critical, which need to be optimized for better performance. The temperature profiles at various zones have been used to optimize the operating parameters.

Keywords: Municipal Solid Waste; Waste-to-Energy; Incineration; Rotary kiln; Process optimization

INTRODUCTION

Nowadays, landfills occupy enormous space and the wastes that are being dumped are often very harmful. With the passage of time, the wastes get mixed with the soil and completely degrade the soil quality in course of time. Moreover, some harmful chemicals of MSW can percolate through the soil and eventually contaminate the quality of groundwater (Li M, Xiang J. et al., 2004). Open burning of solid waste in a landfill causes severe atmospheric pollution because of incomplete burning. This releases CO, SO₂, NOₓ, Polychlorinated dibenzodioxins and Polychlorinated dibenzofurans (Suksankraisorn K, Patumsawad S. et al., 2004). Therefore, a proper disposal system which can also be used to generate energy from MSW is the need of the hour.

According to “Notification on Municipal Solid Waste Management (Management & Handling), Rules, 2000” imposed by GOI (2000), the following four methods could only be used for safe disposal of MSW. The methods recommended include composting, vermin-composting, anaerobic digestion and incineration. Of these, incineration is generally used only to treat hospital and hazardous wastes (Gupta N, Yadav K K. et al., 2015). Burning of MSW in conventional incinerator without any supplementary fuel is tedious as Indian MSW
has a high level of moisture content (Joshi and Ahmed, 2016). Importantly, Indian MSW is a heterogenous mixture of organics, plastics, paper, metals and other items. Therefore, innovations are necessary to process such complex MSW (Pershing D, Lighty J S. et al., 1993). This paper discusses a novel approach that has been made in the combustor design of rotary kiln incinerator for effective thermal treatment. For the effective burning of MSW fuel, certain operational parameters have also been optimized. Emission treatment is one of the main challenges that would be faced in burning MSW as it produces SOx, NOx, dioxins and furans (PCDD/F) and heavy metals such as mercury.

**MATERIALS AND METHODS**

**Preparation of samples:**

MSW is generally a mixture of organics, plastics, paper, heavy metals, glass, and inerts (Moya D, Aldas C. et al., 2004). It is a heterogeneous mixture, whose composition varies spatiotemporally. The changing trends in the composition of MSW in India have been reported by Joshi and Ahmed (2016). To mimic the real MSW, different components, viz., organic waste, plastics, paper and dry leaves, were collected within the IIT Madras campus, and mixed in different mass fractions to generate different grades of feedstock.

**Characterization:**

Three main techniques were used, namely, proximate analysis, ultimate analysis and bomb calorimetry, to characterize the mixture. Owing to the heterogenous nature of the feedstock, six representative samples were analyzed, and the average values of different parameters are reported in Table 1. Proximate and ultimate analysis were carried out according to ASTM-D3172 and ASTM-D3176, respectively. The results showed that the percentage of volatiles present in the MSW makes it a viable candidate for producing energy through incineration. The mass of air required for combustion of one kg of fuel was calculated using the ultimate analysis data, using the following expression,

\[
\text{Mass of air required / kg of fuel} = 11.521(C) + 34.56(H) + 4.32(S-O) \text{ kg} \quad (1)
\]

The calorific value of the MSW with higher amount of plastics obtained in this study is in line with the results of Sukarni (2016).

**EXPERIMENTAL SETUP**

The experiments were conducted in a rotary kiln combustor developed in-house. The feed was mixed and fed to the shredder to obtain particles of size not greater than 5cm X 5cm. The shredded feed was then fed to the combustion chamber via a belt conveyor. Once the mixture reached the combustion chamber, the feed was ignited using a butane torch. The air supply needed for combustion was provided with the help of a forced draft fan. A DC motor was used for rotating the sieve mesh whose rpm can be varied. This helped in separating the burnt ash particles during combustion. A shell and tube heat exchanger was used to transfer the heat from combustion exhaust gas to water. Ash was collected at the downstream of the rotary kiln. Temperature is an influential parameter in measuring the efficiency of the system, and also for the evolution of pollutants (Pershing D, Lighty J S. et al., 2004). So, continuous measurement of temperature and exhaust gas composition were carried out using K-type thermocouples and exhaust gas analyzer, respectively.
Table 1 Table showing results from proximate, ultimate and bomb calorimetry test

<table>
<thead>
<tr>
<th>S.no</th>
<th>Mixture composition (wt. %)</th>
<th>Proximate analysis (wt. % db)</th>
<th>Ultimate analysis (wt. % db)</th>
<th>Calorific value (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100 0 0 0</td>
<td>14.7 68.9 11.8 4.6</td>
<td>37.4 11.7 3.4 0 47.5</td>
<td>13.4</td>
</tr>
<tr>
<td>2</td>
<td>0 100 0 0</td>
<td>0 91.4 0 8.6</td>
<td>85.8 0 0 0 14.2</td>
<td>45.8</td>
</tr>
<tr>
<td>3</td>
<td>0 0 100 0</td>
<td>8.6 78.2 7.4 5.8</td>
<td>39.5 5.7 2.0 0 52.8</td>
<td>14.9</td>
</tr>
<tr>
<td>4</td>
<td>0 0 0 100</td>
<td>13.8 67.1 7.8 11.3</td>
<td>43.1 6.5 6.2 0 44.2</td>
<td>15.8</td>
</tr>
<tr>
<td>5</td>
<td>25 25 25 25</td>
<td>8.5 82.8 6.2 2.5</td>
<td>51.4 6.0 2.9 0 39.7</td>
<td>22.9</td>
</tr>
<tr>
<td>6</td>
<td>50 25 12.5 12.5</td>
<td>9.6 77.3 8.4 4.7</td>
<td>50.5 7.4 2.7 0 39.4</td>
<td>21.5</td>
</tr>
<tr>
<td>7</td>
<td>25 50 12.5 12.5</td>
<td>6.2 86.9 4.6 2.3</td>
<td>62.5 4.5 1.9 0 31.1</td>
<td>29.8</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Figure 1. Plot of temperature profiles at different locations at 3 RPM

Figure 2. Plot of temperature profiles at different locations when the rotation was switched off

Figure 3. Plot of temperature profiles at different locations at 1 RPM
In figures 1-3, T1, T2 and T3 denote the temperatures of exhaust gas before the heat exchanger, after the heat exchanger, and that of steam coming out of the heat exchanger, respectively for a feed rate of 10 kg/hr and fuel composition corresponding to S.no 6 in Table 1. When the RPM was set to 3, it was observed that the flame was continuously put off as the wet organic was falling over the burning flame. The higher RPM was giving an inverse effect rather than supporting the flame. The sudden increase in T1 and T3 in Figure 1 was observed when the feed was manually ignited again. The flame finally extinguished. In the next experiments (Figure 2), the sieve mesh rotation was switched off. The first peak in T1 corresponds to the initial burning of paper and plastics. Once the organic material was added the temperature dropped because the heat evolved in the furnace was mainly used to evaporate the moisture. This ‘evaporative-burning’ cycle repeated periodically. Although combustion of the feed was better with the static furnace, mixing of the reactants was poor, and this was reflected in the residual ash, where partially burnt and unburnt feedstock were present. Finally, when the rotation rate of the sieve mesh was maintained at 1 RPM, Figure 3 shows that the flame was sustained and the ‘evaporative-burning’ cycle continues. The temperature of the steam also increased and reached a steady temperature at around 20 min. Unburnt feed particles were sparsely seen in the final ash residue. Thus, the rotation rate optimization was found to be important for both operation and good energy release.

ACKNOWLEDGEMENT

The authors thank Ministry of Human Resource Development, Government of India, for funding the project through the UAY scheme, and Bharat Heavy Limited, Trichy, for useful discussions and suggestions.

REFERENCES

Gupta, N., Yadav, K K., Kumar, V., A review on current status of municipal solid waste management in India, Journal of Environmental Sciences, 37, 206-217, 2015
Li, M., Xiang, J., Hu, S., Sun, L S., Su, S., Li, P S., Sun, X X., Characterisation of solid residues from municipal solid waste incinerator, Fuel, 83, 10, 1397-1405, 2004
Notification of Municipal Solid Waste Management (Management & Handling), Rules, 2000
Pershing, D W., Lighty, J S., Silcox, J D., Heap, M P., Owens, W D., Solid Waste Incineration in Rotary Kilns, Combustion Science and Technology, 93, 1, 245-276, 1993
Sukarni, S., Exploring the potential of municipal solid waste (MSW) as solid fuel for energy generation: Case study in the Malang City, Indonesia, AIP Conference Proceedings, 1778, 2016
Suksankraisorn, K., Patumsawad, S., Vallikul, P., Fungtammasan, B., Accary, A., Co-combustion of municipal solid waste and Thai lignite in a fluidized bed, Energy Conversion and Management, 45, 6, 947-962, 2004