Research Journal of Engineering and Environmental Sciences 1(1) 2016 pp. 154-161

Research Journal of Engineering and Environmental Sciences

Journal homepage: www.rjees.com

RJEES

Original Research Article

EXPERIMENTAL DETERMINATION OF THE COMBUSTION CHARACTERISTICS OF COMBUSTIBLE DRY SOLID WASTES

***Egware, H.O., Ebu-nkamaodo, O.T. and Linus, G.S.**

Department of Mechanical Engineering, Faculty of Engineering, University of Benin, PMB 1154, Benin City, Nigeria

*okechukwu.egware@uniben.edu; odudu.ebu-nkamaodo@uniben.edu; sunday.linus@uniben.edu

ARTICLE INFORMATION

Article history:
Received 09 November 2016
Revised 22 December 2016
Accepted 05 January 2017
Available online 20 February 2017

Keywords:
Combustion characteristic
Solid waste
Waste-to-energy
Flame temperature
Firing rate

ABSTRACT

The quantity of solid waste generated in Nigeria is increasing and its composition is becoming more diversified. Conversion of combustible solid waste to energy has been proven worldwide. The mechanism to recover the waste heat depends on the temperature and other characteristics of the waste heat gases. The aim of this study was to determine experimentally, the combustion characteristics of dry solid waste. These characteristics included firing rate, moisture content, flame temperature - time variation. Samples of combustible waste were collected, dried, weighed and combusted in a fabricated incinerator, and the desired data were collected for analysis. Results obtained, revealed that the average moisture content for the waste sample collected was 13.29%, firing rate was 2.60 kg/hr, flame temperature was 621.0 ^oC and mean range flame temperature 178 – 621 ^oC. Furthermore, the various combustible waste values obtained showed that this combustible waste can be utilized for water heating, space heating, and other medium range temperature heat recovery devices. Therefore, the information provided could be used for the design of heat energy recovery devices.

1. INTRODUCTION

Waste management in developing countries is difficult (Olorunfemi, 2011). The oldest form of waste management has been to use landfills, which are burial sites, for the disposal of waste. Another commonly used waste management technique, where large piles of waste are dumped above the ground level, is open dumping. However, leachates from landfills pose a threat to ground water aquifer, while open dumping reduces useful land mass, and increases the risk of epidemics (Agarwal et al, 2015).

Some waste materials can be incinerated directly. These are combustible solid wastes. Combustion of waste reduces its volume by as much as 95%, and provides the option of energy recovery (Haukohl et al., 1999). Much of the combustible solid wastes consist of organic materials such as wood, paper and fabrics. Their combustion does not contribute to the net output of carbon dioxide in the atmosphere, because these materials form part of a bio-cycle (Hollenbacher, 1992).

In Nigerian cities, 200 kg of solid waste, with density of 314 kg/m^3, is generated per capita, per year, on the average (Shridar, 2013). This gives a volume of 0.64 m^3 per capita per day. Hence, with a population of about 180 million, a volume of 115 million m^3 of solid waste is expected. While extensive research has explored waste characterization (Oyelola and Babatunde, 2008; Olukanni and Mnenga, 2015), and the combustion characteristics of various components of solid waste (Grammelis et al., 2009), however, solid waste differs, even for those within the same group, in terms of composition. There is, therefore, the need to conduct experiments in our local environment, and compare the results with empirical values for other locations.

Waste heat is heat generated in a process by way of fuel combustion or chemical reaction, which is then released in to the surroundings, and is not useful for economic purposes (ORNL, 2014). The mechanism to recover the unused heat depends on the temperature of the waste heat gases and the economics involved. Typical waste heat temperature ranges are classified as high (650 – 1650 ^oC), medium (230 – 650 ^oC), and low (27 – 230 ^oC) (Hartz et al., 1998). Upon determination of this information, the heat recovery device to be used can be selected. The combustion characteristics of the solid waste are, thus, required because waste-to-energy processes are being considered. For waste heat boilers, medium and high temperature range are needed. This explains the feasibility and desirability of the use of solid combustible waste for combination of power generation and domestic heating.

In utilising combustible solid wastes, some researchers have used calculated waste heat flame gas temperature and firing rate, based on equations of combustion, in hot water generation (Unachukwu and Anyanwu, 2010; Egware et al., 2016) (Unachukwu and Anyanwu , 2010) and power generation (Ujam et al., 2013; Akhator et al., 2016). These values, however, for dry waste have not been fully established experimentally. It is, therefore, necessary to determine these combustion characteristics experimentally to compare with calculated values. Hence, the aim of this study was to investigate the combustion characteristics of solid wastes (paper), in the Faculty of Engineering, University of Benin, Benin City, Nigeria.

2. METHODOLOGY

2.1. Description of Incinerator

The incinerator consists of a frame for the combustion chamber, a smoke regulator to control the volume of exhaust gas given off through the chimney, and a chimney frame. The digital thermometer is placed outside the chamber but two platinum wires proceed from the thermometer into the combustion chamber. The material specifications for the incinerator are presented in Table 1, while the exploded, isometric, and pictorial views are represented in Figures 1, 2, and 3 respectively.

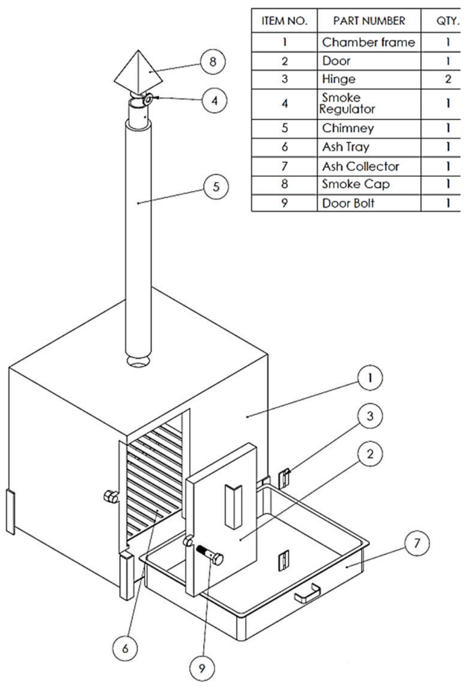
Table 1: The incinerator materials specifications

S/No	Part	Quantity	Material	Dimension
1	Door hinge	2	Mild steel	Φ20 mm x 60 mm
2	Door	1	Mild steel	280 mm x 35 mm x 433 mm
3	Smoke regulator	1	Mild steel	Φ5 mm x 80 mm
4	Ash collector	1	Mild steel	575 mm x 460 mm x 100 mm
5	Chimney	1	Mild steel	Φ80 mm x 868 mm
6	Chamber frame	1	Mild steel	626 mm x 525 mm x 595 mm
7	Ash tray	1	Mild steel	550 mm x 435 mm x 3 mm
8	Door bolt	1	Mild steel	20 mm major diameter
9	Smoke cap	1	Mild steel	90 mm x 90 mm x 40 mm

Φ represents the diameter of a circular part

Equation (1) was used to determine the volume of the combustion chamber, while other specifications are obtained to accommodate the arrangement of the combustion chamber. The incinerator was designed to have a 10kg-capacity of solid waste, while the density of paper ranges between 250 – 800 kg/m^3. The relationship between the mass, volume and density of the waste sample is expressed in Equation (1).

$$Density = \frac{mass}{volume} \quad (1)$$



ITEM NO.	PART NUMBER	QTY.
1	Chamber frame	1
2	Door	1
3	Hinge	2
4	Smoke Regulator	1
5	Chimney	1
6	Ash Tray	1
7	Ash Collector	1
8	Smoke Cap	1
9	Door Bolt	1

Figure 1: Explode view of the incinerator

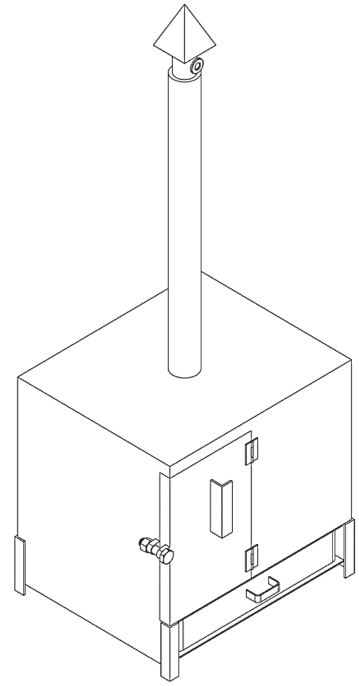


Figure 2: Isometric view of the incinerator

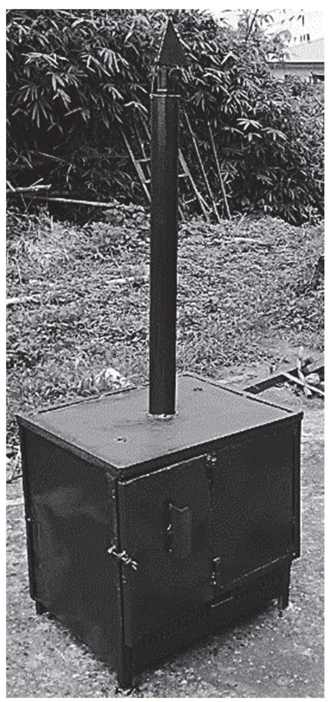


Figure 3: Pictorial view of the incinerator

2.2. Data Collection

Experimental data was collected using a microprocessor digital thermometer, digital stopwatch, pressure gauge, and 3 kg Avery lever scale in the Mechanical Engineering Laboratory, Faculty of Engineering, University of Benin, Benin City, Nigeria. The data obtained are temperatures distribution of combusted waste samples, rate of combustion of waste samples, weight variations of the waste samples after drying and combustion. The waste samples - mainly papers- were collected from the dumpsites around the Faculty of Engineering, University of Benin. The combustible waste was weighed after collection to obtain its mass. They were then left to dry at ambient temperature for about 2 – 3 hours under the sun. To avoid burning the initial waste, heating to dryness was done using a big pan supported by four metals at the bottom-vertex to raise the pan to a considerable height above the fire. Dry woods were used as fuels for the drying process. The dried waste was weighed to obtain its mass. The moisture content of the waste was obtained by subtracting the mass of the dry waste sample from the moist waste sample. After drying and weighing, the waste samples were burned to determine their combustion characteristics. The combustion chamber was loaded with a waste sample of known mass, which was then ignited by striking matches on the waste. The initial temperature at which combustion process began was recorded. The temperature readings with time variations were recorded at intervals of one (1) minute, for close monitoring, until complete combustion of waste sample was achieved. At the end of the process, the ash was collected, cooled and then weighed and its mass was recorded. The masses obtained were imputed into Equations (2) and (3) to determine the combustible solid waste moisture content and firing rate respectively. The moisture content, M of the combustible waste, which is expressed in percentage, is given by Equation (2)

$$M = \frac{m_{mst} - m_{dry}}{m_{mst}} \times 100 \tag{2}$$

Where:

m_{mst} =mass of moist waste samples (kg)
m_{dry} = mass of dry waste samples (kg)

Firing rate, τ_{cp} of the combustible solid waste, is the mass of the burnt sample per unit time taken to burn completely, in kg/s or kg/hr, and was calculated using Equation (3).

$$\tau_{cp} = \frac{m_{dry} - m_{ash}}{t_{cb}} \times 100 \tag{3}$$

Where:

m_{ash} = mass of combustible waste after burning (kg)
t_{cb} = time to complete combustion (seconds).

3. RESULTS AND DISCUSSION

The masses obtained for various conditions of the combustible waste samples used in the study are presented in Table 2. These values were inputted in Equations (2) and (3) to produce the data in Table 3. The moisture of the dry waste sample used for the combustion process were observed to be about 12.11% to 16.78% as shown in Table 3. These represent the amount of water contained in the waste before the combustion process. The firing rates obtained were 0.0005549 to 0.0008158 kg/s as shown in Table 3. These show the weight of waste needed to sustain the combustion process at the temperature obtained.

From the experiments carried out, the mean flame temperature time-variation for combustible solid waste were obtained, as shown in Figure 4. The solid waste sample had a combustion time of 34 minutes as shown in Figure 4. After 4 minutes, the maximum temperature of 621 ^oC was attained. At 15 minutes, the combustion temperature began decreasing.

Table 2: Mass of paper waste samples

Waste paper samples	Moist mass m_{mst} (kg)	Dry mass m_{dry} (kg)	Mass of ash m_{ash} (kg)
1	4.318	3.795	0.909
2	1.491	1.310	0.178
3	1.781	1.565	0.141
4	1.293	1.076	0.097

Table 3: Values of moisture content and firing rate of waste samples

Waste samples	Moisture content (%)	Firing rate (kg/s)
1	12.112	0.0008153
2	12.140	0.0005549
3	12.128	0.0006980
4	16.783	0.0008158

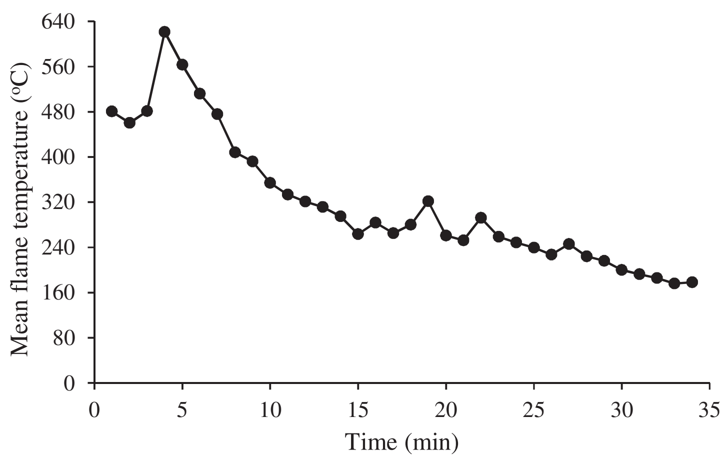


Figure 4: Variation of mean flame temperature

The linear regression model shown in Equation (4) was used to determine the relationship between the mean flame temperature (Y) and time (X) for the combustion process. The value of the coefficient of determination (R^2) was obtained as 0.82, which is above the recommended standard of 0.75. This shows that a good relationship exists between temperature and combustion time. These values were obtained by applying linear regression analysis to the data presented in Figure 4.

$$Y = -5.3X + 504.9 \tag{4}$$

A mean flame temperature in the range of 178 – 621 ^oC was obtained, and this fit into the medium ranges of waste heat temperature that can be used for power generation, and district heating purposes. From previous work, flame temperature of flue gases were reported as 705 ^0C (Akhator et al., 2016), 560.7 ^oC (Ujam et al., 2013), and 577 ^oC (Egware et al., 2016). These results are in good agreement with the one obtained in this study. The firing rate of 0.0005549 kg/s – 0.008158kg/s is also comparable to that (0.0006667 kg/s) reported by Unachukwu and Anyanwu, (2010). This information about flame temperatures, firing rate and moisture content could be useful in the design of waste heat recovery devices for the University of Benin environment.

4. CONCLUSION

Various types of Paper samples were combusted, and various firing rates viz-a-viz moisture content, flame temperature variation with time were obtained. The mean moisture content and firing rate were 13.29% and 2.60 kg/hr respectively. The results of the study showed that about three or four distinct phases of breakdown occurred during the combustion process. The range of flame temperature, 178- 621 ^oC, obtained in this study showed that dry combustible solid waste has sufficient heat energy values that can be utilized domestically and industrially. The information provided will be useful in the design of waste heat recovery.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Agarwal, R., Chaudhary, M., and Singh, J. (2015). Waste Management Initiatives in India for human well being. *European Scientific Journal,* 11(10), pp. 105 - 127.

Akhator, E. P., Obanor, A. I., and Igbinomwanhia, D.I. (2016). Thermal Analysis of a Small-scaled Solid Waste-fired Steam Boiler for Power Generation in Benin City, Nigeria. *Nigerian Journal of Technology,* 35(3), pp. 555 - 561.

Egware, H.O., Ighodaro, O.O. and Unuareokpa, O.J. (2016). Experimental Design and Fabrication of Domestic Water Heating from Solid Waste Incinerator. *Journal of Civil Environmental Systems Engineering,* 14(1), pp. 180 - 192.

Grammelis, P., Basinas, P., Malliopoulou, A., and Sakellaropoulos, G. (2009). Pyrolysis kinetics and combustion characteristics of waste recovered fuels. *Fuel,* 88(1), pp. 195-205.

Hartz, K. E., Klink, R. E., and Ham, R. K. (1998). Temperature Effects: Methane Generation from Landfill Samples. *Journal of Environmental Engineering, ASCE,* 108, pp.629-638.

Haukohl, J., Rand, T., and Marxen, U. (1999). *Decision Makers' Guide to Municipal Solid Waste Incineration.* Washington: World Bank Publications.

Hollenbacher, R. (1992). Biomass combustion technologies in the United States. In: *Proceedings of the Biomass Combustion Conference, Reno, Nevada* (January 28-30, 1992).

Olorunfemi, F.B. (2011). Landfill development and current practices in Lagos Metropolis, Nigeria. *Journal of Geography and Regional Planning,* 4, pp. 656-663.

Olukanni, D.O., and Mnenga, M.U. (2015). Municipal Solid Waste Generation and Characterization: A Case Study of Ota, Nigeria. *International Journal of Environmental Science and Toxicology Research, 3*, pp. 1-8.

Oak Ridge National Laboratory (ORNL), 2014. "Industrial Waste Heat Recovery: Potential 905 Applications, Available Technologies and Crosscutting R&D Opportunities," Arvind Thekdi 906 (E3M Inc.) and Sachin Nimbalkar (ORNL), ORNL/TM-2014/622.

Oyelola, O.T., and Babatunde, A.I. (2008). Characterization of domestic and market solid wastes at source in Lagos metropolis, Lagos, Nigeria. *African Journal of Environmental Science and Technology,* 3, pp. 430-437.

Shridar, P.M. (2013). The Challenge of Waste Management in Nigeria: Recommendations towards a Functional National Policy. *Managing Our Environment for a Sustainable and Secure Future.* Abuja: National Conference on the Environment.

Ujam, A.J., Eboh, F., and Chinwe, T.O. (2013). Effective Utilization of a Small-scale Municipal Solid Waste for Power Generation. *Journal of Asian Scientific Research,* 3(1), pp. 18 - 34.

Unachukwu, G.O., and Anyanwu, C.N. (2010). Small-scale Incinerator for Domestic Hot Water Generation from Municipal Solid Wastes. *European Journal of Scientific Research,* 39(3), pp. 430 - 439.