CARD International Journal of Engineering and Emerging Scientific Discovery
ISSN: 2536-7250 (Print): 2536-7269 (Online)
Volume 2, Number 4, December 2017
http://www.casirmediapublishing.com

Characterisation of Sawdust Combustion in an Experimental Model Bubbling Fluidized Bed Combustor (BFBC)

Iseru, Ebike & Emifoniye Early Ufuoma
Department of Mechanical Engineering
Abdulsalami Abubakar College of Engineering, Igbinedion University Okada
Email: pelez2e@yahoo.co.uk
Corresponding Author: Iseru, Ebike

ABSTRACT

The need to explore alternative energy sources in meeting global energy demands is becoming more significant as a result of the twin problems of fossil fuel depletion and global warming. Biomass constitutes a readily available alternative source of energy. However, there are inherent difficulties in burning biomass due to its high moisture content. Among the available technologies that can be used for biomass combustion, the fluidized bed combustor is emerging as one of the best due to its flexibility and high efficiency. This study investigates the combustion characteristics of sawdust in a bubbling fluidized bed combustor. The experimentation was carried out in the locally fabricated BFBC under two biomass feed rates of 2.6kg/h and 3.5kg/h, and varying excess air (EA) values. The effects of fuel feed rate and excess air on the concentration of major gaseous emissions (CO and CO_2) in flue gas, combustion efficiency, and the thermal profile along the combustor height were studied. The combustion efficiency of the fluidized bed combustor was calculated for the sawdust fired under different operating conditions, based on the CO concentration in the flue gas. A maximum efficiency of about 99 % was obtained with acceptable CO emission.

Keywords: Biomass, Combustion efficiency, Feed rate, Excess air, Temperature

INTRODUCTION

Currently, a huge part of the world's energy demand is met by combustion of fossil fuel which is non-renewable and depleting. The global energy demand is expected to grow by 50% by 2025 (Agbro & Ogie, 2012), a significant part of this increase coming from emerging countries. Given the depleting fossil resources, increasing energy demand and concerns for global warming, the need for a sustainable alternative energy source has become imperative.

Alternatives to fossil fuel are nuclear power (5%), hydropower (6%) and biomass (13%) (Etim, 2012). Energy production from biomass is regarded as a carbon neutral process as the CO_2 generated during energy conversion is consumed by the subsequent biomass regrowth (Coelho, 2005).

Biomass resources with high energy content available in Nigeria includes agricultural crops, wood, grasses and shrubs, residues and wastes from agricultural, forestry, municipal and industrial processes, and aquatic biomass (Baklit, *et al.*, 2001). The forest residues consist of wood wastes from logging and wood processing activities. The residues from wood processing activities are wood materials generated from manufacturing plants like sawmills. These residues include logs, barks, sawdust and shavings (Agbro & Ogie, 2012). Biomass can be used to generate gaseous, liquid and solid fuels, heat and electricity (Milbrant, 2009).

The potential of these otherwise waste products to generate useful energy has led to various research activities into the development of appropriate technologies for their efficient conversion. Various technologies have been developed so far. Of these, the fluidized bed combustor (FBC) holds the potential for been the most versatile and efficient (Koorneef *et al.*, 2007). In a fluidized bed combustor, turbulence is created in a mixed bed of fuel and inert particles by a continuous flow of fluidization air. Due to turbulence and the constant mixing of particles, rapid heat and mass transfer occurs which leads to efficient combustion.

Numerous researches have been carried out on the feasibility of implementing biomass based FBC systems using different fuels. For a given fuel the combustion efficiency can be inferred from the amount of CO emission. The CO emission on its part is affected by operating variables such as the excess air factor. Srinath and Venket, (2011) studied the combustion and emission performance of rice husk in a rectangular FBC. Their study employed a laboratory scale FBC utilizing river sand as inert bed material to investigate the formation of CO and CO_2, as well as the combustion efficiency when firing rice husk at different operating conditions. They reported a direct proportionality between the condition of maximum CO_2 formation and the optimum combustion efficiency. It also appears from their results that an increase in the amount of excess air factor seem to have a significant effect on the combustion efficiency and that above a particular excess air value (EA > 80%) the formation of CO_2 began to drop, and hence the combustion efficiency. This was due to the reduced residence time of particles occasioned by the higher fluidization velocity brought about by the increased EA factor.

Although the FBC technology is indicated to be the most suitable (among existing technologies) for biomass combustion due to its flexibility and high efficiency, the issue of agglomeration is still among a few potential problems associated with its operation. The main cause of agglomeration is the layers of ash formed around the inert bed materials during combustion (Khan et al, 2009). This can result in unscheduled shutdown of the plant as a result of de-fluidization. The effect of various running parameters on bed agglomeration has been studied. Haipen *et al.,* (2011) used a 100mm internal diameter laboratory scale BFBC utilizing wheat straw as fuel to study the effect of bed temperature, gas velocity and particle sizes on the de-fluidization time. Their results showed a strong influence of the bed temperature on the de-fluidization time. In fact, they reported a drastic drop in de-fluidization time from 13.83h for a bed temperature of 750°C to 0.17h for a bed temperature of 950°C. Though the agglomerate was sticky at the time of agglomeration, it was reported to have broken when temperature decreased to room temperature. The effect of increased gas velocity (at a bed temperature of 900°C) tends to extend the de-fluidization time. This is because the high gas velocity ensured better mixing of the particles and an increase in the force acting on the agglomerates. However, this only extended but could not prevent agglomeration. They also reported a minimal influence of varying fuel size particles on the de-fluidization time at the same temperature. These results emphasize the need for a stable bed temperature below that which facilitates ash fusion.

Biomass fuels come from a variety of sources resulting in a wide range of sizes and other inherent properties. The emission from their FB combustion is dependent on a number of operating conditions, including their particle sizes. Srinath and Venket, (2012) investigated the effect of fuel particle sizes on the emission characteristics and combustion efficiency of groundnut shells in a bubbling fluidized bed combustor with an enlarged freeboard section. The FBC was operated at a constant feed rate of 25kg/h of groundnut shells for various excess air (EA) factors and for different fuel particle sizes. The effect of EA factor and fuel size on the concentration of the major emissions (CO and CO_2), combustion efficiency as well as the temperature profile along the combustor height where reported. At a fixed EA factor the temperature in the combustor for the larger particles is comparatively less than that for smaller particle sizes. The highest temperature was recorded at the splash zone (the point of secondary air introduction). Above this zone the temperature was found to decrease with height up to the enlarged freeboard where there was a slight increase again. This rise was due to the enlarged freeboard. At the enlargement, there was a sudden reduction in the fluidization velocity and hence an increase in residence time of the particles which facilitates further combustion. Increasing the EA factor increases the velocity of the air, which in turn raises the level of turbulence inside the chamber. As a result, the axial temperature increases with increased EA. However, this temperature increase only occurs up to 51% EA. Further increase in EA values result in a decrease in temperature due to the entrainment of particles at these high air velocities. Their results also showed a very high CO concentration at low EA factor. Moreover, as the EA factor increased the formation of CO decreased. A direct relationship was also reported between CO formation and fuel particle size.

A paper by Raji T.O. *et al.,* (2012) outlined the design and construction of a BFBC with various performance enhancing features. These features include the inert bed temperature regulating unit (ITRU), the fluidization air / biomass feeding pipe's cooling attachment and modular construction of the combustion body. The ITRU was incorporated to maintain a stable bed temperature. It utilizes an electronic feedback system which automatically switches off - and – on the operation of biomass feeder motor once a preset temperature is reached. This is to eliminate the problem of de-fluidization caused by ash fusion in the bed. The fluidizing air / biomass feeding pipe's cooling attachment serves to ensure energy efficiency and to prevent the biomass feed from charring before it reaches the fluidized bed. The modular construction was adopted for the purpose of easy installation and maintenance. The effectiveness of these performance enhancing units in the design was evaluated by combusting palm kernel shells (PKS) and coconut shells (CS). The independent variable in the tests was the biomass feed rate. Its effect on the axial temperature distribution along the BFBC column was studied. As expected the varying biomass feed rate had no effect on the inert bed temperature as this was already preset via the ITRU. However, comparison of the temperature profiles along the column for the various feed rates revealed that the point to point corresponding values are higher for the larger feed rate value (5.2 kg/h) than for the lesser one (4.8 kg/h). This work investigates the effect of excess air and biomass feed rate on the combustion of sawdust in the bubbling fluidized bed combustor.

MATERIALS AND METHODS

In this study, sawdust collected from a local sawmill was used as fuel. The preparation of the fuel includes manual separation of non-combustibles, and sun drying. Proximate and ultimate analysis was performed on the sawdust and the results are summarized in Table 1. Sand of approximately 1 mm mean diameter was used as the inert bed material.

A locally fabricated experimental model BFBC (fig. 1) was utilized for the experimental runs. A control panel (fig. 2) that houses a microcomputer based digital temperature controller XMT*-808 series senses the temperature via eight thermocouples placed at different locations along the combustor. A Harthmann & Braun AG Temperature controller with analogue display is dedicated to monitoring the inert bed temperature. The temperature controller with a fabricated feedback system (inert bed temperature regulating unit) ensures the bed temperature could be fixed to a particular value. An inline gas analyzer (BACHARACH PCA3) probe is connected to a port on the flue gas outlet of the gas cyclone. This measures the CO and CO_2 composition and temperature of the exiting flue gas.

Fig. 1: Pictorial view of BFBC showing ITRU unit.

Fig. 2: Control panel with two temperature controllers and ten normally-open push buttons.

Experimental Procedure

Prior to when the sawdust was fed into the fluidized bed, the inert bed materials (sand) were heated to about 450°C using an auxiliary heating unit. To achieve this inert bed temperature, propane gas was burned on the bed surface. The gas was supplied via a hose connected to a pressurized gas cylinder. The propane gas mixes with the fluidizing air and is ignited by a splint inserted through an ignition hole by the side of the combustor body above the inert bed.

The composition of flue gas was measured at the exit of the freeboard. In addition, temperature was measured along the combustor height via eight thermocouples distributed along the combustor body. The flue gas exit temperature was recorded by the gas analyzer located at the cyclone outlet.

RESULTS AND DISCUSSION

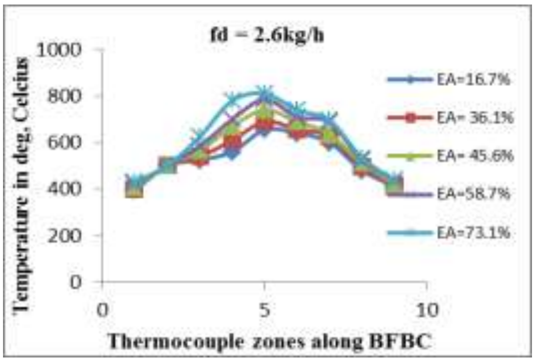
The combustion of sawdust was performed in a locally fabricated BFBC. The influence of fuel properties and various operating parameters on emission characteristics, thermal profile along combustor height and combustion efficiency are discussed.

Proximate analysis		Ultimate analysis	
Property	*Wt%*	*Property*	*Wt%*
Fixed carbon (%)	17.2	Carbon %	51.05
Volatile matter (%)	80.68	Hydrogen %	6.34
Ash (%)	1.4	Oxygen %	41.48
Moisture content (%)	12.38	Nitrogen %	0.39
Higher heating value, HHV (kJ/kg)	19870	Sulphur %	0.03

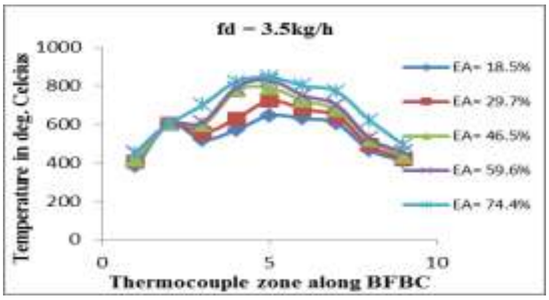
Table 1: Proximate and Ultimate analysis of sawdust

Axial temperature profile along BFBC

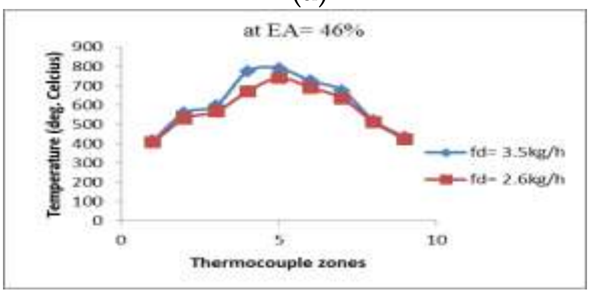
The temperature distributions along the BFBC at different EA factors for the two feed rates are shown in fig. 3(a) & (b). The highest temperature was recorded at the thermocouple zone 5 for all the studied EA values for both feed rates.



(a)



(b)



(c)

Fig. 3: Thermal profiles along combustor height for various EA values

As can be seen from fig. 3(c), at a fixed EA value, the higher feed rate produced a comparatively higher temperature. It is also clear from fig. 3(a) & (b) that higher EA will produce a better fuel burnout due to the presence of more oxygenated radicals. More heat is thus generated resulting in higher temperatures. Beyond thermocouple zone 5 (about 1700mm above distributor plate) all the temperature values began to fall. This indicated that most of the combustion was completed as at that point. A closer look at the temperature distribution will suggest that the fuel particle absorbs heat from the bottom of the bed resulting in the lower bottom temperature (thermocouple zone 1). And by the time the sawdust particles ignite and combust, they are already higher in the bed. This important combustion behaviour can be explained by the devolatilization process (Sami, et al, 2001). With the presence of high volatile matter (> 80%) and relatively low ignition temperature, the sawdust will start to devolatilize before zone 5 and will be mostly burned before leaving the combustor.

Analysis of Carbon Monoxide Formation

The effect of EA factor on the amount of CO leaving with the flue gas is shown in fig. 4 for the two feed rates tested. The concentration of carbon monoxide is high when the excess air factor is low, but as the EA increases there is an observed decrease in CO concentration in the exiting flue gas. On increasing the excess air, the amount of oxygenating radicals responsible for CO formation increases, thereby decreasing the CO in the flue gas. Further it is observed that as the feed rate increases, the formation of CO decreases in proportion. This is because the combustion is more efficient for the higher fuel feed rate. Besides this, the CO formation is higher for the lower combustor temperature.

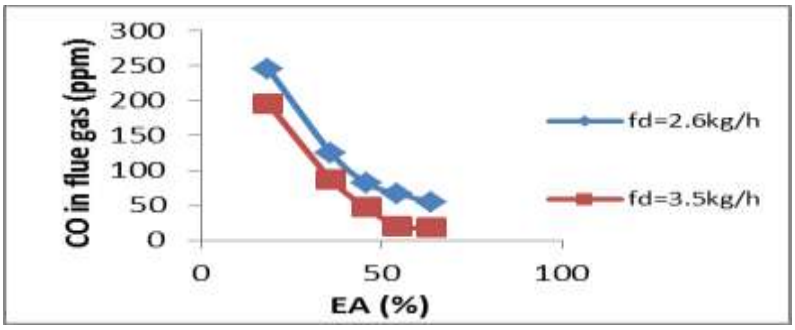


Fig. 4: Effect of EA on CO formation

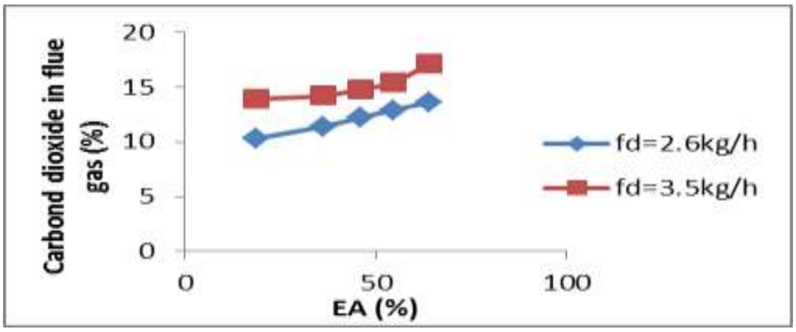


Fig. 5: Carbon dioxide in flue gas for different EA values.

Analysis of Carbon Combustion Efficiency

Combustion efficiency is an important indicator of the performance of a fluidized bed combustor. This study employs a simple method in estimating the carbon combustion efficiency of the locally fabricated BFBC using the data collected from the combustion of sawdust, whose properties are shown in Table 1. Data were collected for the two feed rates and the results are presented in Tables 2 & 3. The efficiency (E_c) is defined mathematically by (1) (Madhiyanon *et al.*, 2010):

$$E_c = \left[\left(E_f - E_{ash} \right) \right] \times 100\% \quad \text{.................................... (1)}$$

Where E_f is the higher heating value (HHV) of the sawdust, E_{ash} is the energy loss as unburned carbon in the ash and E_{fg} is the energy loss as carbon monoxide in the flue gas. Energy loss as carbon monoxide is estimated by (2) (TSI Incorporated, 2004):

$$E_{fg} = [\%CO \div (\%CO_2 + \%CO)] \times 10{,}160 \times C_b \quad \text{...................................... (2)}$$

Where, C_b is the fractional carbon content in the sawdust. Due to the low ash content in the sawdust (see Table 1), the E_{ash} was assumed to be negligible (Permchart & Tanatvanit, 2009).

EA	CO(ppm)	CO_2 (%)	E_c (%)
16.7	246	10.3	87.7
36.1	125	11.4	94.3
45.6	82	12.2	96.5
54.4	63	12.8	97.5
63.9	67	12.9	97.3

Table 2: Carbon combustion analysis for fd = 2.6kg/h

EA	CO (ppm)	CO_2 (%)	E_c (%)
18.5	196	13.9	92.7
29.7	87	14.2	96.8
46.5	47	14.8	98.4
59.6	19	15.1	99.4
74.4	21	15.6	99.3

Table 2: Carbon combustion analysis for fd = 3.5kg/h

It can be observed from Tables 1 & 2 that the combustion efficiency increases with excess air values for the EA factors considered. The combustion efficiency is higher for the increased feed rate. This improved efficiency can be attributed to increased bed temperature which is caused by the high rate of reaction of the sawdust particles. There is a higher rate of conversion of carbon to carbon dioxide as the feed rate increases.

CONCLUSION

The combustion of sawdust in a locally fabricated fluidized bed combustor was investigated under two feed rates and varying excess air values. The temperature profile was found to approximately uniform along the combustor height as a result of thorough mixing of particles in the bed. The highest temperature was observed at a height of about 1700 mm above the bed (thermocouple zone 5) for all excess air values. The temperature then decays towards the flue gas exit. The combustion efficiency is found to be influenced by the excess air values. A maximum combustion efficiency of 99 % was obtained with the combustion of sawdust in the locally fabricated BFBC with an acceptable CO emission.

REFERENCES

Agbro E.B and Ogie N.A, A comprehensive Review of Biomass Resources and Biofuel potential in Nigeria. *Research Journal in Engineering and Applied Sciences. Vol. 1, No. 3,* 2012, 149-155.

Baklit G, Dashe A.O, Mwansat G.S, Best K.S.C and Bulus H., The Problem of Biomass Resource Research in Nigeria. *Biomass Research Communications, Vol. 13, No. 6,* 2001, 669-672.

Coelho S.T, Biofuels – Advantages and Trade Barriers. *A report for the United Nations Conference on Trade and Development*, 2005.

Etim E.E, The Prospects of Biofuels in Complementing Nigeria's Energy Needs. *International Journal of Environment and Bioenergy, Vol. 4, No.2*, 2012, 74-85.

Haipeng T., Shiyuan L. and Qinggang L., 2011. Agglomeration during fluidized bed combustion of biomass. *The 13th international conference on fluidization - new paradigm in fluidization engineering*. http://dc.engconfint1.org/fluidization_xiii/36, retrieved on 9th Nov. 2012.

Khan A.A., de Jong W., Jensens P.J and Spliethof H., Biomass combustion in fluidized bed boilers: potential problems and remedies. *Fuel processing technology 90,* 2009, 21-50. www.elsevier.com/locate/fuproc, retrieved 18th Nov. 2012.

Koorneef J., Junginger M. and Andre F, Development of Fluidized Bed Combustor – an overview of trends, performance and cost. *Progress in Energy and Combustion Science, Vol. 33,* 2006, 19-55.

Madhiyanon T., Sathituangsak P. and Soponronnarit S., Combustion Characteristics of Rice-husk in Short Combustion Chamber Fluidized Bed Combustor (SFBC). *Applied Thermal Energy, Vol. 30,* 2010, 347-353.

Milbrant A., Assessment of Biomass Energy in Liberia. *Document Prepared for USAID under the Liberia Energy Assistance Program (LEAP),* 2009.

Permchart W. and Tanatvanit S., Preliminary Investigation on Combustion Characteristics of Rice-husk in FBC. *World Academy of Science, Engineering and Technology, Vol. 56,* 2009, 183-186.

Raji T.O., Oyewola O.M. and Salau T.A.O., 2012. New features for performance enhancement of experimental model bubbling fluidized bed combustor. *International journal of science and engineering research, vol. 3, issue 1.* http://www.ijser.org, retrieved 9th Nov. 2012.

Srinath S. and Venket G.R., 2011. Combustion and emission characteristics of rice husk in a rectangular fluidized bed combustor. *2nd international conference on environmental science and technology, IPCBEE vol. 6,* 2011, 343-546._______ and ___________, Fuel Particle Size Effects of Fluidized Bed Combustor Firing Groundnut Shells. *International Journal of Chemical Engineering and Application, Vol. 3, No. 2,* 2012, 147-151.

TSI Incorporated, 2004. Combustion Analysis Basics - an overview of measurement methods and calculations used in combustion analysis.