2011 International Conference on Biology, Environment and Chemistry
IPCBEE vol.24(2011) © (2011)IACSIT Press, Singapoore

Effect of Fuel Particle Size on Emissions and Performance of Fluidized Bed Combustor

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Abstract. Fluidized bed combustion (FBC) is one of the most promising energy conversion options available today. The emissions from FBC are dependent on a number of operating conditions (temperature, excess air, fuel feed rate, etc) and fuel particle size. This paper describes the experimental results taken in lab scale fluidized bed combustor (FBC), using groundnut shells as fuel and river sand as the inert bed material. The river sand was used for ensuring sustainable fuel ignition and combustion in FBC. The Fluidized bed was operated at constant feed rate 25 kg/h of groundnut shells feed for various excess air factors (20-100%) and for the different fuel particle sizes. The effect of excess air factor and fuel particle size on the concentration profiles of the major gaseous emissions (CO and CO2), combustion efficiency, as well as the temperature profiles along the combustor height, was investigated. The concentration of the CO was found to have a maximum value at active combustion zone. Based on CO emission and unburned carbon content in fly ash, the combustion efficiency of the Fluidized bed combustor was calculated for the ground nut shells fired under different operating conditions. The maximum combustion efficiency of the groundnut shells is found to be 89.5%

Keywords: Fluidized Bed Combustion; Groundnut shells; Combustion Efficiency; Operating Conditions; Particle Size; Emissions.

1. Introduction

Fluidized Bed Combustion (FBC) is one of the most promising energy conversion technologies available today [1]. FBC uses a continuous stream of air to create turbulence in a mixed bed of fuel and inert material. Due to turbulence and constant mixing of particles, rapid heat transfer and mass transfer take place, which leads to complete combustion. Fluidisation, combustion and emission formation constitute the fundamental issues of FBC.

In order to meet the increasing energy demand and growing concern for the environment, the development and implementation of newer, more efficient and cleaner energy conversion technologies are essential. The ever increasing use of biomass in energy systems is an important strategy to reduce the emissions as well as provide energy security. Biomass constitutes 14% of the global primary energy, the fourth largest following coal, oil and natural gas. However biggest merit of biomass is, it is renewable and produces no net CO_2 emission in combustion [2]. Biomass materials with high energy potential include agricultural residues such as straw, bagasse, groundnut shell, coffee husks and rice husks as well as residues from forest-related activities such as wood chips, sawdust and bark. Residues from forest-related activities account for 65% of the biomass energy potential whereas 33% comes from residues of agricultural crops [3].

Extensive experimental investigation has been carried out to date on the feasibility and performance of the fluidized bed combustion of different alternative fuels. CO and NOx (generally, as NO) are also the major harmful pollutants emitted from biomass combustion in fluidized bed systems [4]. Permchart and Kouprinov

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[5] have studied the effects of operating conditions(load and excess air), as well as the fuel quality and the bed height, on the major gaseous emissions(CO_2,CO and NO_x) in a conical fluidized bed combustor while burning a mixed sawdust generated from different woods in Thailand. It has been found that the bed height had a minor influence on the emission profiles. The CO_2 emission profiles along the combustor height were found to be almost independent of the combustor load and fuel quality. Kouprinov and permchart [6] have conducted experimental studies in a conical fluidized bed combustor with different biomass fuels: rice husk, sawdust and bagasse. It has been revealed that for the maximum combustor load and excess air of 50-100%, a combustion efficiency of over 99% could be achieved when firing sawdust and bagasse.

This paper deals with the experimental study of combustion of groundnut shells, in a lab scale fluidized bed combustor (FBC) using river sand as inert material. The objectives of the present work was to study the effect of particle size on formation of the major gaseous pollutants (CO and CO_2) in the FBC and to determine the combustion efficiency of the FBC at different operating conditions.

2. Experimental Setup

The entire experimental setup consists of three sections, rectangular furnace (at bottom), fluidized bed reactor (middle) and free board section (top). At the bottom of the rectangular chamber, a nozzle type distributor plate has been fitted. Free board section is connected to a cyclone separator by an insulated pipeline. The air for combustion is supplied by a centrifugal blower. The fuel is fed into the combustor with the help of a screw feeder. K-Type thermocouples (15 No's) are provided at equal spacing along the height of the reactor for continuous measurement of temperatures in the bed. Two thermocouples are also located to measure the temperature of residual ash and flue gas. To measure the water line temperature three thermocouples are provided at water outlet line and one thermocouple at water inlet line. To measure the pressure drop across the bed, there are 10 differential pressure transmitters (MODEL: CP100) along the height of the reactor. A heating coil of stainless steel 316 (of dia. 25 mm X 8 m length) has been provided inside main vessel in the form of helical shape through which water is circulated. A flue gas analyzer (MODEL: KM 9106), was used to measure the flue gas composition.

Fluidization chamber is a seamless cylindrical vessel made of stainless steel material with an inner diameter of 200 mm, thickness of 6 mm, height 1500 mm and bottom rectangular furnace is of 450× 440 × 480 mm. A castable refractory lining of 25 mm thickness is provided to minimize the heat loss during the combustion process. The vessel is insulted with ceramic wool of thickness 120mm. Induced draft fan was used to maintain a sufficient vacuum in the furnace, to avoid leakage of hot gases from the FBC.

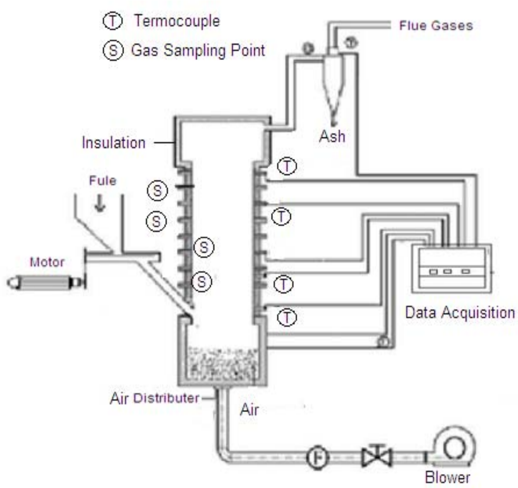


Figure 1. Schematic diagram of the FBC

Proximate analysis		***Ultimate analysis***	
Property	**Wt%**	**Property**	**Wt%**
Moisture (%)	6.1	Carbon, %	36.4
Ash (%)	20.6	Hydrogen, %	4.84
Volatile matter (%)	58.40	Oxygen, %	25.11
Fixed carbon (%)	14.9	Nitrogen, %	0.44
Calorific value, Kcal / kg	3420	Sulpher, %	0.17

Table .1: Properties of Groundnut Shells

2.1 Experimental procedure

The composition of the flue gas was measured at the exit of the cyclone. In addition, temperature was measured along the combustor height and in the flue gas at the cyclone outlet. The excess air % was determined using the flue gas composition at the cyclone outlet. Two parameters were chosen in this work as independent variables: fuel particle size and percent excess air (EA). Experiments were conducted using three fuel particle sizes. The biomass fuel (ground nut shells) used in this study was collected from local mills. Tables 1 &2 show the analyses of the fuel used. Further the effect of excess air was studied at different excess air factors.

3. Results and Discussion

The axial temperature, profiles along the height of the combustion chamber were plotted for ground nut shells fuel fired in the FBC under different operating conditions. Figure 2 shows the axial temperature profiles for the feed rate of 25 Kg/hr for three particle sizes, at optimum excess air factor i.e 51.4%. These profiles seem to be rather uniform and characterized by small temperature gradient along the height above the air distributor. The highest temperatures in the combustor were observed in splashing zone with proximately 30^0 C rise in temperature, above the distributor plate. This may be due to the combustion of fine char produced by attrition of coarse char in the splashing zone. The finer char has much larger burning rate owing to the very much larger specific surface area. As seen in figure 2 at fixed excess air, the temperature in the combustor for the large particle size 1.12mm is less than that of small particle size 0.273mm. The temperature decreases with the increase in height above the distributor plate up to 1600mm and again a small rise of 30^0C is observed at a height of 1800mm. This temperature rise is due to enlarged free board. In the enlarged free board because of increased diameter from 200 mm to 300 mm, there is sudden drop in the fluidization velocity and therefore residence time increases and facilitates further combustion; as a result the temperature in free board increases.

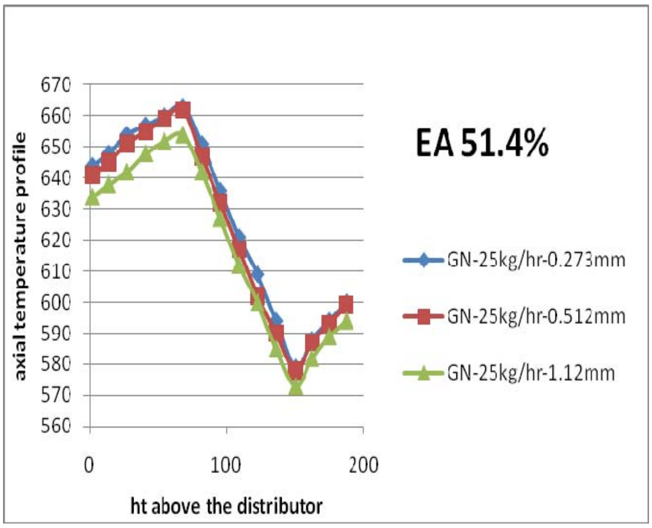
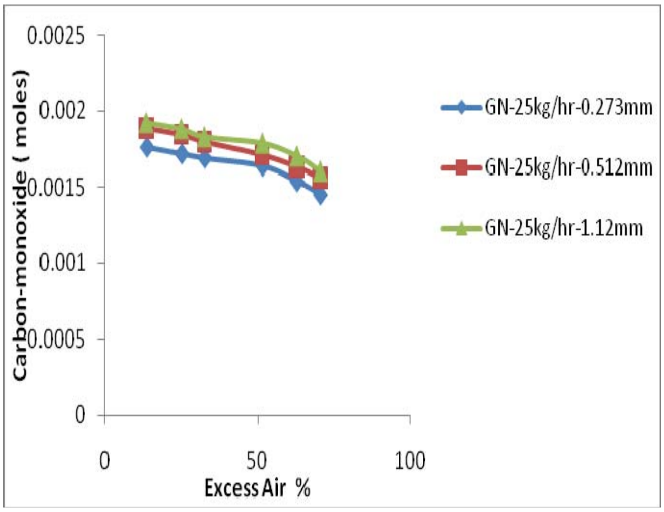


Figure.2 Axial Temperature Profile

Hydrodynamic Properties			
Particle Size, mm	1.12	0.512	0.273
Bulk density Kg/m^3	300.5	288.4	337.1
Particle density Kg/m^3	800.5	728.3	662.4
Static voidage	0.63	0.61	0.49
Specific surface area m^2/gm	195.6	253.85	305.1

Table .2: Properties of groundnut shells



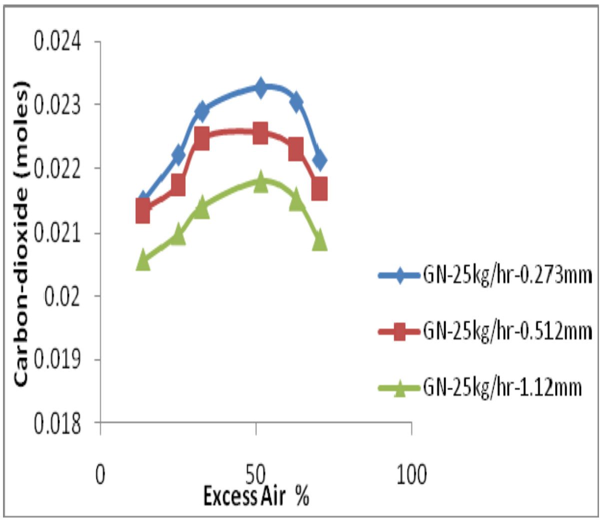


Fig3. Effect of excess air on CO leaving with flue gases cyclone separator

Fig4. Effect of excess air on CO_2 leaving at the exit of with flue gases at the exit of cyclone separator

Figure 3 shows the CO concentration leaving with flue gas for the same operating conditions. It can be seen from the figure 3, the concentration of CO is very high when the excess air factor is low, but as the excess air factor increases, the formation of CO decreases. Further it can be observed from the Fig. 3 that as the fuel particle size decreases, the formation of CO also decrases. The reason for this phenomenon, is that the combustion is more efficient when the particle size is smaller and as a result the CO formation is less.

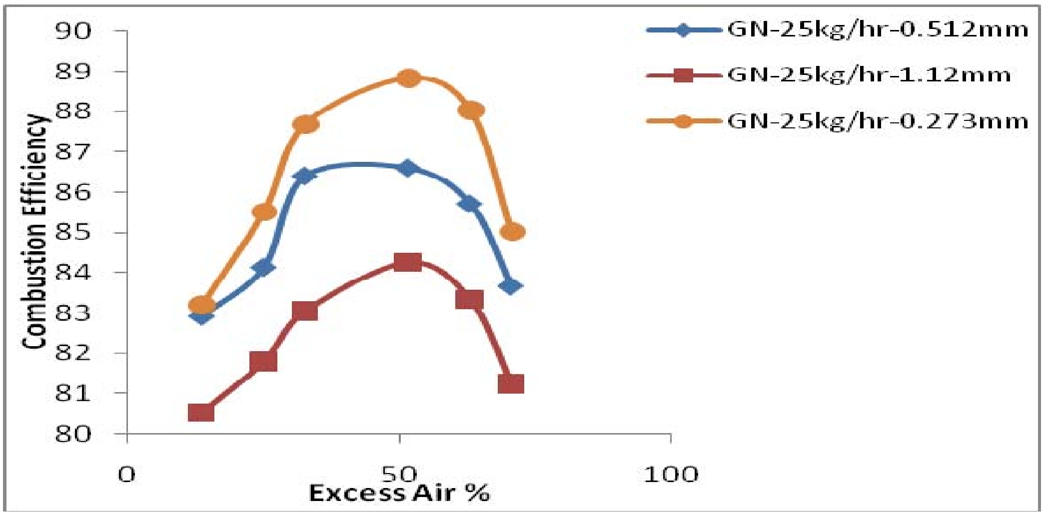


Figure 5. Combustion efficiency of FBC at Different Excess air Factors

The combustion of char involves the diffusion of oxygen into the char and reaction of that diffused oxygen with carbon in the char. The diffusion of oxygen depends on the fuel particle size. The available oxygen for inner part of the coarse char is less which results in partial combustion (high concentration of CO). Besides this the rate of CO formation is high for the low temperature of the combustion chamber. This released CO is further oxidized in the splashing and freeboard region.

Figure 4 shows the kilo-moles of CO_2 per kilogram of fuel burnt, leaving with flue gases for different excess air factors at fixed feed rate. As shown as in figure, the maximum moles of the CO_2 is observed at 51.4% excess air factor for particle size of 0.273 mm and at 56% excess air factor for particle size of 1.12 mm. The velocity of air increases with excess air supplied to the combustion chamber, which results in decrease in concentration of CO_2 because of less residence time of the particle in the combustion chamber. Decrease in residence time of particle leads to increase of unburnt carbon in the ash and decrease in combustion efficiency.

4. Combustion Efficiency

Combustion efficiency is a very good measure of the performance of fluidized bed combustor. For estimation of combustion efficiency, the heat losses owing to incomplete combustion and unburnt carbon in the ash are determined. The combustion efficiency of groundnut shells has been shown, in Figure 5 at different excess air factors. Combustion efficiency is mainly affected by biomass fuel particle size and velocity of air in the combustion chamber. The complete combustion of the carbon in the fuel gives the highest combustion efficiency. The incomplete combustion of the carbon to carbon monoxide and unburnt carbon in the ash will affect the combustion efficiency of the fluidized bed combustor. The maximum combustion efficiency is observed at the same excess air which has highest CO_2 concentration in the flue gases. The combustion efficiency is low for large particle size 1.12-mm at same excess air factor. This is due to the incomplete combustion of groundnut shells, because of bigger particle size. Further increase in excess air results in decreasing of residence time of particle which leads to the increase in unburnt carbon in ash. The maximum combustion efficiency is 89.5% at 51.4% excess air for particle size of 0.273.

5. Conclusions

The combustion characteristics of three particle sizes of groundnut shells in a lab scale fluidized-bed combustor were evaluated. Temperature profiles in the combustion chamber indicated axial variation of temperatures between 580–680°C, as a result of thorough mixing in the bed. The excess air factor has significant effect on combustion efficiency. The maximum combustion efficiency of 89.5% was observed at 51.4% excess air factor for particle size of 0.273, and the combustion efficiency of 84% is observed for particle size of 1.12 at 56 %, excess air. With further increase in excess air the combustion efficiency is reduced due to unburnt carbon and incomplete combustion.

6. Acknowledgments

The authors wished to acknowledge the financial support provided by MHRD (Ministry of Human Resource and Development) under R&D scheme.

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