Fuel Particle Size Effect on Performance of Fluidized Bed Combustor Firing Ground Nutshells

Srinath Suranani and Venkat Reddy Goli

***Abstract*—Biomass fuels come from many varieties of sources resulting in a wide range of sizes, physical and chemical properties. Among the technologies that can be used for biomass combustion, fluidized beds are emerging as the best due to their flexibility and high efficiency. The emissions from Fluidized Bed Combustor (FBC) are dependent on a number of operating conditions (temperature, excess air, fuel feed rate, etc) and fuel particle size. In the present work the effect of fuel particle size on emissions and over all combustion efficiency of groundnut in the fluidized bed combustor has been discussed. 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 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. 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% for lower particle size (0.273mm)**

***Index Terms*—Fluidized bed combustion; groundnut shells; combustion efficiency; operating conditions; particle size; emissions.**

I. Introduction

Biomass fuels provide an attractive primary energy source because of their renewable nature, neutrality with respect to green house–compounds generation, and limited formation of pollutants. 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. Biomass offers a number of advantages compared to fossil fuels. Biomass is regarded as a renewable source with no net CO_2 emission in combustion [1, 10]. An evaluation of the CO_2 balance shows that compared with the combustion of hard coal, the CO_2 emissions can be reduced by 93%[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]. Biomass can be converted into desired gaseous, liquid and solid secondary fuels through thermo chemical conversion process like pyrolysis, gasification and combustion. Large scale introduction of biomass energy could contribute to sustainable development on several fronts namely, environmental, social, and economical [4]. Fluidized bed combustion is one of the most promising energy conversion technologies available today [5]. 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.

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 [6]. Permchart and Kouprinov [7] 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 [8] 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.Salour et al [9] have found that the combustion efficiency is dependent on the fuel particle size, excess air level, and bed temperature and gas velocity in bubbling beds. It is recommended that the height of free board must be increased to increase the combustion efficiencies. Srinivas rao [11] conducted combustion studies of rice husk in an atmospheric fluidized bed in high excess air environment. [12] investigated the emissions of thai ricehusk and the influence of fuel moisture on performance of conical fluidized bed combustor and found that temperature profile was noticeable effected by the fuel moisture content and excess air has sensible effect on emission in the bottom and freeboard regions. The emissions from fluidized biomass combustion system CO_2, CO, NOx, Char particles, polycyclic aromatic hydrocarbons and ash particles are affected by the

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operating conditions and fuel particle size and properties.

This paper deals with the experimental study of combustion of ground nutshells, 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.

II. Experimental Setup

Fig.1 shows a schematic diagram of the FBC. 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. River sand of 0.46mm mean particle size was used as the inert bed material to ensure the bubbling fluidization mode in the rectangular furnace. In all combustion studies, the static bed height of the sand was fixed at 25cm. The air distributor, which is placed at the bottom of the rectangular section, consists of nine stand-type nozzles. The air for combustion is supplied by a 15 hp roots blower. Feeding of groundnut shell was by means of combination of screw feeder and pneumatic air feeder, which pushes the groundnut shells via the feed port, sloped at 45^o and located above the distributor plate. Hence, this facilitates the smooth feeding of groundnut shells, directing towards the bed region. The ground nut shell feeding rate was controlled by the VFD of the motor. To monitor temperature profiles inside the combustor, temperature measurements were done using data acquisition system with an accuracy of $\pm$ 1^0C connected to K-Type thermocouples (15 No's), which are located at equal spacing along the height of the reactor. 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 $450 \times 440 \times 480$ mm. A cast able 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

A. Experimental Procedure

The composition of the flue gas was measured at the exit of the free board. In addition, temperature was measured along the combustor height and in the flue gas at the cyclone outlet. The excess air was determined based on the stoichiometry air requirment. 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.

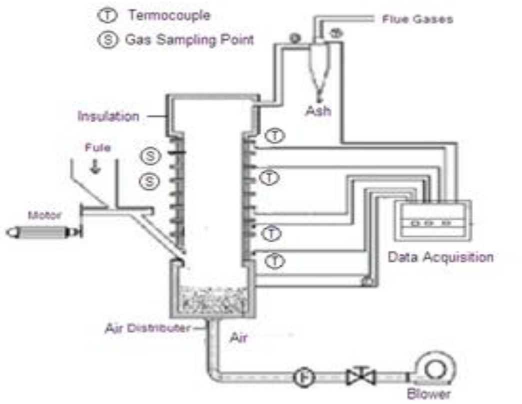

Fig. 1. Schematic diagram of the fluidized bed combustor

B. Materials

River sand of volume surface mean diameter of 0.46mm has been used as a inert bed material. Fuel, Groundnut shell collected from local mills was crushed to three fuel particle sizes and the volume surface mean diameter was determined by screen analysis. Proximate and ultimate analysis of groundnut shells is reported in Table I. Hydrodynamic properties are reported in Table II.

TABLE I: Properties of Groundnut Shells

Proximate Analysis	
Property	Wt%
Moisture	4.83
Ash	32.3
Volatile Matter	50.9
Fixed Carbon	12.0
Ultimate Analysis	
Property	Wt%
Carbon	32.7
Hydrogen	4.26
Oxygen	25.11
Nitrogen	0.55
Sulpher	0.33
Moisture	4.78
Ash	32.7
GROSS CALORIFIC VALUE (Kcal/Kg)	2960

TABLE II: Hydrodynamic Properties

Particle Size, mm	1.12	0.512	0.273
Bulk density Kg/m^3	300.5	310.4	337.1
Particle density Kg/m^3	800.5	728.3	662.4
Static void age	0.63	0.57	0.49
Specific surface area	195.6	253.85	305.1

III. Results and Discussion

A series of steady state experiments were carried out to investigate effect of particle size on the performance of FBC and gaseous emissions of groundnut shells. The static bed height was fixed at 25cm and excess air factor varied from 10% to 70%. Combustion behavior was found to be good in all tests.

A. *Effect of Combustion Parameters.*

1) *Temperature Profile*

The temperature profiles along the vertical height of the combustion chamber were plotted for the fuel ground nut shells fired in the FBC under different operating conditions are shown in fig 2. The constant feed rate of 25kg/hr is maintained for three particle sizes of the fuel 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 approximately 30^0 C rise from the bed temperature (635^0 C) at a height of 80cm 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 shown in Fig 2 at fixed excess air the temperature in the combustor for the large particle size 1.12mm is comparatively less than that of small particle size 0.273mm. After the splashing zone the temperature found to decrease with the 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 of particle increases and facilitates further combustion; as a result the temperature in free board increases. The effect of excess air on axial temperature profile is shown in fig 4. It has been observed that increase in excess air increases the air velocity which increases the turbulence inside the bed as a result the temperature increases with the increase in excess air up to 51% and further increase in excess air results in decrease in temperature due to the entrainment of particles at higher excess air factors. The active combustion of fuel particles takes place between 100 and 800mm height above the distributor plate.

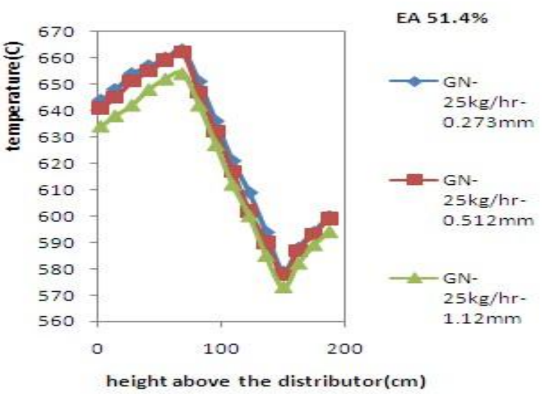

Fig. 2. Axial temperature profile

2) *Gas emissions*

Effect of excess air on carbon monoxide leaving with flue gas for the same operating conditions at which temperature profiles were observed is shown in fig 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. On increasing excess air the availability of the oxygenated radicals responsible for the CO oxidation also increases, thereby decreasing the CO in the flue gas. Further it can be observed that as the fuel particle size decreases, the formation of CO also decreases. 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. The combustion of char involves the diffusion of oxygen into the char and further it reacts with diffused oxygen to form CO. 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. Fig 6 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, 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 moles of CO_2 at higher excess air factors because of less residence time of the particle in the combustion chamber. The char combustion decrease with increase in particle size. The coarser particles require more residence time to burn due to its low diffusion rates.

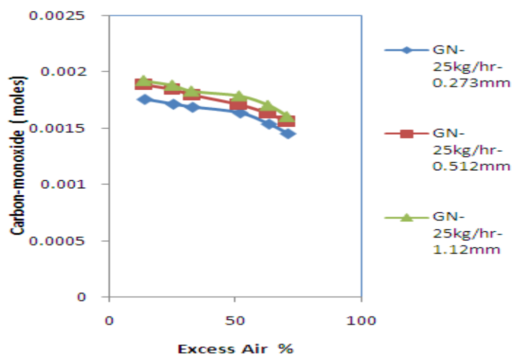

Fig. 3. Effect of excess air on CO leaving with flue gases for threearti pcle sizes

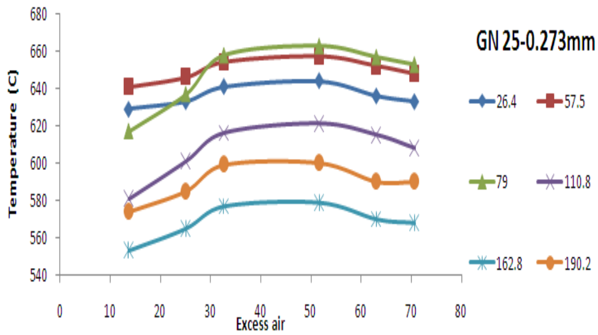

Fig. 4. Effect of excess air on Temperature at various locations along the height of the reactor for lower particle size

3) *Carbon losses*

The effect of excess air on unburnt carbon collected at the cyclone outlet is shown in fig 5. During combustion process a part of energy released can be lost either through CO present in the flue gas or in the form of unburnt combustibles along with the ash. The excess air affects the temperature profiles of the chamber. The high excess air which leads to the high fluidization velocity decreases the residence time of the fuel particle in the combustion chamber. Due to this high fluidization velocity, the volatile matter released in the bed and char is carried away from the bed without oxidation.

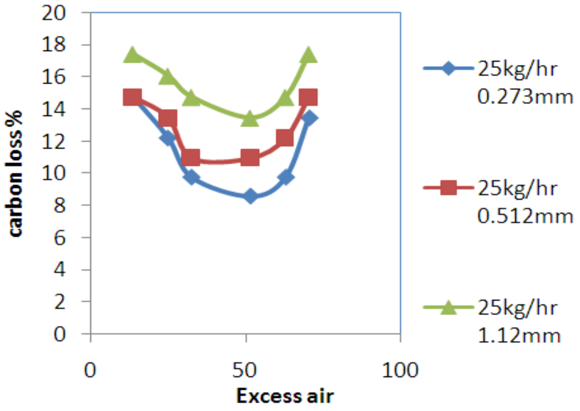

Fig. 5. Effect of excess air on carbon carryover (cyclone ash)

IV. 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 cyclone ash are determined. The effect of excess air on combustion efficiency of FBC is shown in fig 5. 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. From the fig 7it can be observed that the maximum combustion efficiency is obtained 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. Fig 8 shows the effect of particle size on performance (combustion efficiency) of fluidized bed combustor for groundnut shells at optimum excess air factor i.e. 51.4%. The char combustion mechanism involves two steps. Initially the oxygen in the air has to diffuse into the char particle and it reacts with carbon. The combustion products again diffuse back to the bulk flow of gases. For coarser particles the char combustion is controlled by the diffusion of oxygen into the char. The char combustion decreases with increase in particle size. The coarser particles requires more residence time to burn due to its low diffusion rates. The small particles burn more quickly than the coarser ones. But in contrary the increase in excess air decreases the residence time of the particle which leads to the increase of unburnt carbon in the flue gases. The combustion efficiency decreases with increase in unburnt carbon in the flue gases.

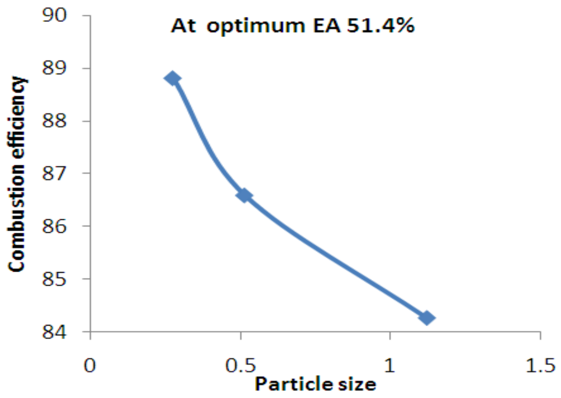

Fig. 6. Effect of fuel particle on Combustion efficiency

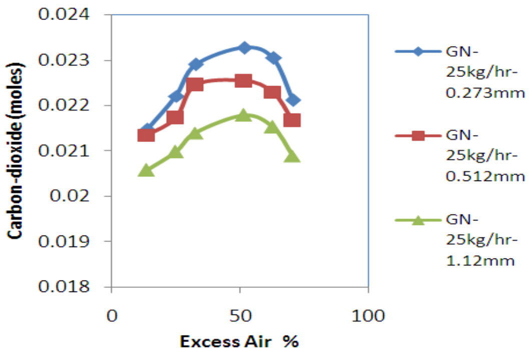

Fig. 7. Effect of excess air on CO leaving with flue gases

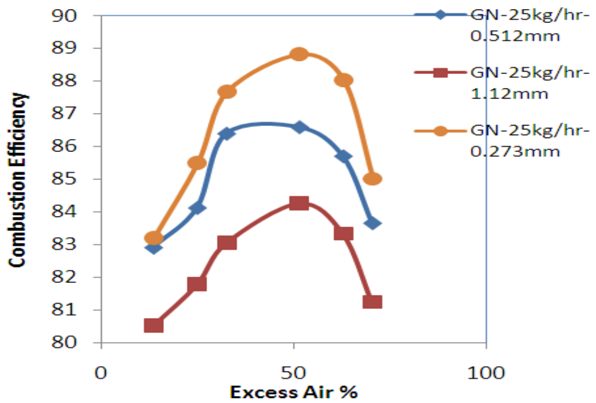

Fig. 8. Effect of Excess air on Combustion efficiency

V. Conclusion

The Fluidized bed combustion of groundnut shells was investigated with a focus on the effect of fuel particle sizes of the fuel. The axial temperature profiles in the fluidized bed combustion chamber are fairly uniform at all operating conditions as a result of thorough mixing in the bed. The maximum temperature at all excess air factors is obtained at height of 800mm from the bed and then gradual drop in temperature up to height of 1600mm. Again rise in the temperature at a height of 1900mm above the distributor is obsedrved.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 lower particle size of 0.273, and the combustion efficiency of 84% is observed for higher particle size of 1.12 at 56 %, excess air. The excess air between 45 to 55 % is found to be optimal in reducing the carbon loss during the burning of groundnut shells.

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