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Combustion Studies of Sawdust in a Bubbling Fluidized Bed

K.V.N. Srinivasa Rao
Vignan's Engineering College, India, kvnsrao@yahoo.com

COMBUSTION STUDIES OF SAWDUST IN A BUBBLING FLUIDIZED BED

K.V.N. Srinivasa Rao
Department of Mechanical Engineering,
Vignan's Engineering College, Vadlamudi-522 213
A.P. State, INDIA
T : +91863-2244735 ; F :+918632534468; E : kvnsrao@yahoo.com

ABSTRACT

Biomass fuels are difficult to handle due to high moisture and fines content. In the present work, the effect of secondary air injection on combustion efficiency of sawdust in the fluidized bed combustor has been discussed. An enlarged disengagement section is provided to improve combustion of fines. The maximum possible combustion efficiency with saw dust is 99.2 % and is observed at 65 % excess air.

INTRODUCTION

Fluidized bed energy technology offers several unique characteristics for using biomass in small-scale energy conversion operations. The potential of agricultural residues for energy production has been investigated by many researchers [Jenkins and Bhatnagar (1); Kjellstrom (2); Babu *et al* (3)]. Peel and Santos (4) and Peel (5) have investigated the combustion of sawdust, bagasse, rice husks, wood chips and corn cobs in a 200 mm diameter fluidized bed combustion test rig. It has been suggested that satisfactory combustion of the bagasse, sawdust and the rice husks could be achieved with under-bed feeding only. Hellwig (6) analyzed the heat distribution during the combustion of wood chips and straw and showed that over 67% of their calorific values were released through the combustion of the volatiles. Bhattacharya and Weizhang (7) have reported that the loss of unburnt carbon in the form of carbon monoxide (CO) is in the order of 3 to 10 %. The higher CO emissions have been observed at higher fluidization velocities and this could be because of shorter residence time. Salour *et al* (8) 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. Kouprianov and Permchart (9) 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. Permchart and Kouprianov (10) 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. Srinivasa Rao and Venkat Reddy (11) conducted combustion studies of rice husk in an atmospheric fluidized bed in high excess air environment (air fuel ratios 8.3 – 12.6) and temperature gradient along the bed height was found within the bed. From the literature it could be concluded that due to sudden devolatilization of biomass fuels, the combustion operations should be conducted in highly excess-air environment. Proper splitting of the total air into primary air and secondary air and supplying them at appropriate level could improve combustion efficiency. As the CO emissions in the flue gas were reported in literature at higher quantities, in the present work efforts are made to reduce these emissions.

EXPERIMENTAL SETUP

A circular cross-section bubbling fluidized bed combustor is fabricated with a inner diameter of 150mm and main combustion chamber of height 1000 mm is made of stainless steel material of thickness 3 mm. A pressure reduction vessel is attached to the main chamber of height 500 mm with diameter of 350 mm and is connected to the cyclone separator. The inner side of the vessel is coated with a castable refractory material to minimize the heat losses in the vessel. A copper tube of diameter 12 mm is wound around the vessel to control the bed temperature by circulating cooling water through the coil. Outer side of the vessel is covered with rock wool as an insulation material to reduce the heat transfer from the vessel. Thermocouples and pressure taps are provided at various points to measure temperatures and pressures respectively. A provision is also made to supply secondary air. A blower is used to supply the primary and secondary air, which is connected to 10 H.P. D.C. motor. A screw feeder is used to provide the required fuel feed into the combustion chamber. After the combustion flue gases and solid ash particles are separated in the cyclone separator. The schematic diagram of fluidized bed combustor is presented in Fig. 1.

EXPERIMENTATION

The characteristics of bed material are presented in the Table 1. Fuel particles are introduced above the sand bed and their properties are given in Table 2. From the cold flow studies it is found that sand particle of size 0.4 mm is most suitable for sawdust to achieve low minimum fluidization point and good mixing with fuel particles without segregation characteristics. The proximate and ultimate analyses of sawdust are given in Table 3 and Table 4. The operating conditions of fluidized bed are presented in the Table 5. Before sawdust is burnt in the fluidized bed it is necessary to heat the inert bed of solids to about 500^0C using an auxiliary heating system. An over-bed LPG burner with small amount of additional oxygen (to expedite preheating process) directed at the surface of the bed for preheating purpose. The distributor plate is straight multi-orifice type with opening area of 7.6%. The minimum fluidization velocity is determined from the pressure drop measurements. The present experimentation is aimed to investigate the control CO emissions from the fluidized bed along with highest possible combustion efficiency. The combustion efficiency is calculated from the following relation:

Combustion efficiency = [Calorific value of rice husk – (Heating value of refuse at cyclone separator + Heating value in the flue gasses)]/ Calorific value of rice husk

RESULTS AND DISCUSSION

Effect of fluidizing velocity on temperature profile in the combustion chamber

The temperature profile in a fluidized bed with increase in fluidizing velocity along the vertical height above the distributor plate is shown in Fig.2. The constant feed rate of 10.2 kg/hr is maintained for sawdust. Experiments showed that a temperature gradient exists inside the bed at low fluidizing velocity. One possible reason is that low velocity results in inadequate mixing. If the fluidizing velocity is increased further, a strong combustion intensity zone will move to the top of the freeboard and losses in unburnt combustibles increase. The active combustion of fuel particles takes place between 150 and 600 mm height above the distributor plate. Armesto *et al* (12) carried out combustion of rice husk in a fluidized bed combustor and obtained a maximum temperature corresponding to the zone at 400 mm from the distribution plate.

Effect of feed rate on temperature profile in the combustion chamber

At the minimum fluidization state, feed rate of fuel is increased till the maximum possible temperatures are attained at all the locations of the combustion chamber along the axial height. This temperature profile is depicted in the Fig.3. At lower feed rates the temperatures are more uniform between 150 and 600mm height and above 600mm height there is a slight reduction in the temperature. Another notable feature is at low feed rates no temperature rise in the enlarged free board is noticed which indicates that no combustion is taking place in this section and the burning of particles is completed before it reaches enlarged section.

Effect of secondary air on temperature profile in the combustion chamber

To achieve higher combustion efficiency, the primary air is passed through the distributor plate at a rate slightly more than that required for char combustion and the remaining excess air is supplied as secondary air before the enlarged section of freeboard. A substantial increase in the temperatures throughout the combustor is observed as shown in Fig.4. A considerable rise in temperature at the enlarged free board is also observed. This indicates that air staging can improve combustion.

Effect of excess air on carbon carry over loss in combustion chamber

Figure 5 represents the heat loss owing to the incomplete combustion of fuel against the fluidizing velocity, when firing the fuels at maximum combustor loading. With increase in air velocity the percentage of CO is found to decrease for the sawdust fuel. Much change in CO levels has not been observed beyond the fluidizing velocity of 1.1 m/s. The minimum CO emission is observed to be 0.845% for sawdust.

The injection of secondary air in the freeboard above the fuel bed may be used to create an intense mixing of combustion air with the volatiles, thus enhancing gas phase combustion reactions. The corresponding heat loss against excess air for the same fuel loading is shown in the Fig.6. For sawdust the carbon loss is in the range of 0.4 to 0.1 % with the increase in excess air. The enlarged freeboard influences both formation of CO and combustion of fine char particles. 50 to 60 % excess air is found to be optimal to reduce carbon loss for burning the sawdust.

Effect of operating conditions on combustion efficiency

Fig.7 shows the combustion efficiency for the sawdust fuel at maximum combustor loads for different fluidizing velocity. The maximum possible combustion efficiency for sawdust is 97.4% at fluidizing velocity of 1.13 m/s. The Fig.8 represent slight rise in combustion efficiencies during the injection of secondary air at enlarged disengagement section. Permchart and Kouprianov (10) have revealed that for the maximum combustor load and at excess air of 50-100%, a combustion efficiency of over 99% could be achieved when firing sawdust and bagasse. In the present investigation the maximum combustion efficiency is found to be 99.2 % at excess air quantity of 65% and therefore higher combustion efficiency is achieved at relatively low excess air quantity which leads to minimum heat loss carried by the exhaust gases. The reason for higher combustion efficiency in the present study is due to modifications made in the fluidization vessel and supply of excess air quantity at free board.

CONCLUSIONS

1. The axial temperature profiles in the fluidized bed combustion chamber are fairly uniform at all operating conditions.
2. The maximum temperature at all the velocities is obtained at a height of 250 mm from the bed and then a gradual drop in temperatures up to a height of 825 mm. Again rise in the temperature at a height of 1150 mm above the distributor plate is noticed; and that indicates a considerable burning of fuel in the freeboard.
3. With supply of secondary air before the enlarged section of freeboard, a substantial increase in the temperature through out the combustor has been observed. The effect of secondary air on temperature profile is predominant due to effective burning of fine sawdust particles in the free board.
4. With increase in air velocity the percentage of CO has been found to decrease. The injection of secondary air in the freeboard above the fuel bed created an intense mixing of combustion air with the volatiles, thus reducing the CO levels in the flue gas. The enlarged freeboard influences considerably in reducing the formation of CO, in addition to better combustion of char particles. The excess air between 50 to 60 % is found to be optimal in reducing carbon loss during the burning of the sawdust.
5. The maximum possible combustion efficiency of 99.25 % could be achieved with enlarged free board and supply of secondary air in the free board zone.

ACKNOWLEDGEMENT

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Table 1. Characteristics of bed material used for experimentation

S.No	Parameter	Sand
1	Mean particle size, d_p in mm	0.404
2	Max. Size of particle, mm	0.542
3	Min. Size of particle, mm	0.27
4	Particle Density, ρ_p in Kg/m^3	2519
5	Bulk Density, ρ_b in Kg/m^3	1600
6	Terminal Velocity of the particle, U_t in m/s	3.18
7	Static voidage, ε_o	0.36
8	Spherocity, ϕ_s	0.67

Table 2. Properties of sawdust

S.No.	Property	Saw dust
1	Mean particle size, mm	0.578
2	Bulk density, kg/m^3	286.4
3	Particle density, kg/m^3	716.2
4	Calorific value, kcal/kg	4464

Table 3. Proximate analysis of fuels

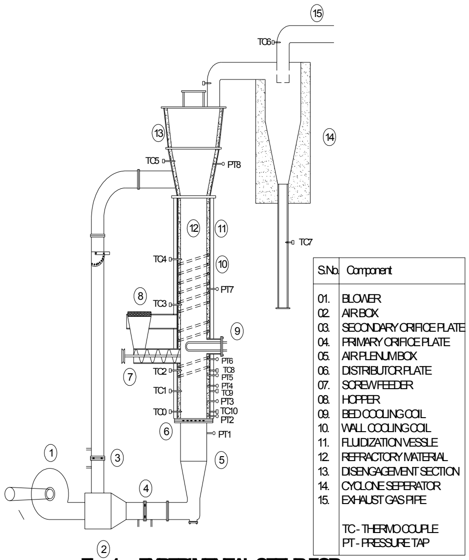
S.No	Property	Saw dust
1	Moisture, %	8.15
2	Volatile matter, %	81.17
3	Ash, %	1.994
4	Fixed Carbon, %	8.686

Table 4. Ultimate analysis of fuels

S.No	Property	Saw dust
1	Carbon, %	48.496
2	Hydrogen, %	3.96
3	Oxygen, %	27.15
4	Nitrogen, %	0.24
5	Sulpher, %	0.01

Table 5. Operating conditions of fluidized bed

S.No	Parameter	Sand
1	Air flow rate, L/s	3.12 –18.47
2	Superficial velocities in the vessel, U_g in m/s	0.18 – 1.05
3	Superficial velocities in Disengagement section, m/s	0.04 – 0.26
4	Voidage at minimum fluidization, ε_{mf}	0.49
5	Pressure drop at minimum fluidization, $(\Delta p)_{mf}$ in N/m^2	1532.63
6	Static bed height of inert particles, L_s in mm	100
7	Minimum fluidization velocity, U_{mf} in m/s	0.66
8	Bed height at minimum fluidization, L_{mf} in mm	124



S.No.	Component
01.	BLOWER
02.	AIR BOX
03.	SECONDARY ORIFICE PLATE
04.	PRIMARY ORIFICE PLATE
05.	AIR PLENUM BOX
06.	DISTRIBUTOR PLATE
07.	SCREW FEEDER
08.	HOPPER
09.	BED COOLING COIL
10.	WALL COOLING COIL
11.	FLUIDIZATION VESSLE
12.	REFRACTORY MATERIAL
13.	DISENGAGEMENT SECTION
14.	CYCLONE SEPERATOR
15.	EXHAUST GAS PIPE
	TC - THERMO COUPLE
	PT - PRESSURE TAP

Fig 1. EXPERIMENTAL SETUP FOR COMBUSTION STUDIES

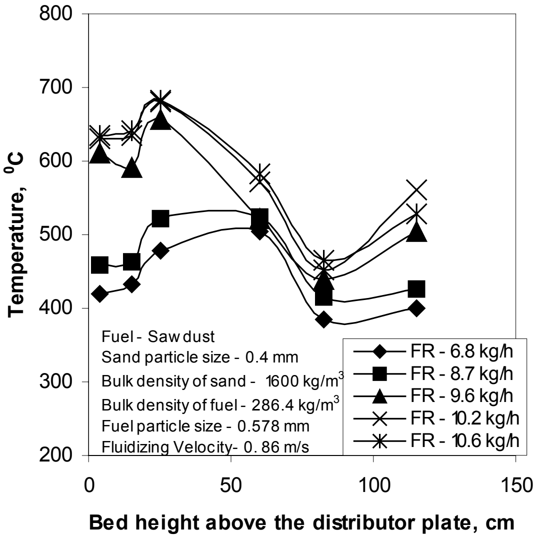


Fig.3 Temperature profiles along axial height above the distributor plate at different feed rates and at constant fluidizing velocity of 0.64 m/s

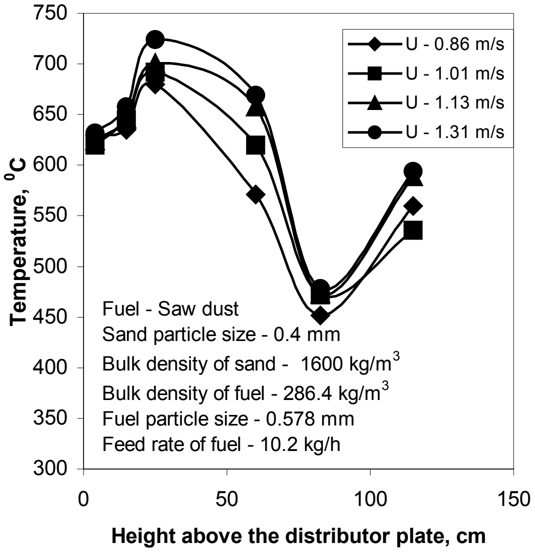


Fig. 2 Temperature profiles along axial height above the distributor plate at different fluidizing velocities

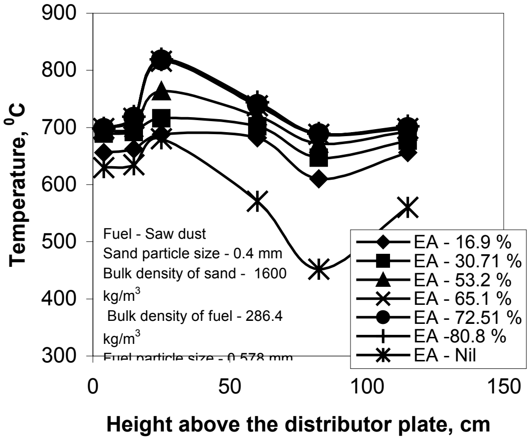


Fig.4 Temperature profiles along axial height above the distributor plate at different excess air flow rates

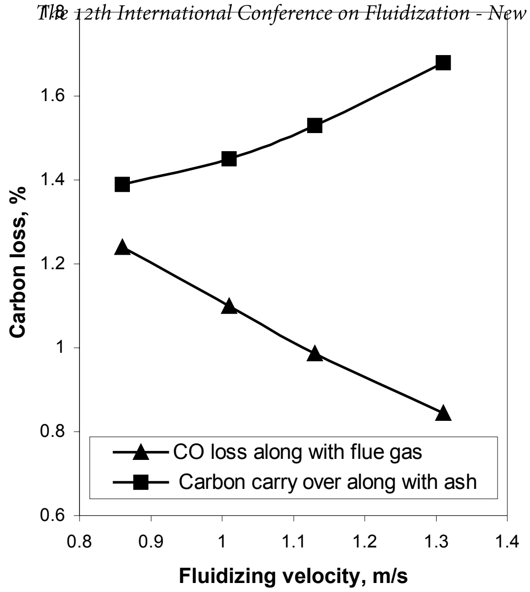


Fig.5. Effect of fluidizing velocity on carbon loss during the combustion of saw dust

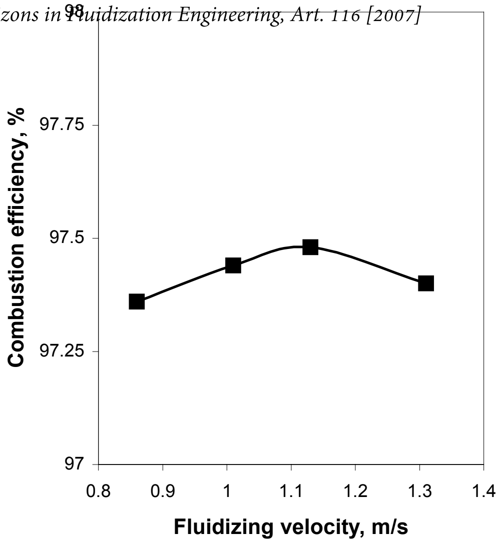


Fig.7 Effect of fluidizing velocity on combustion efficiency

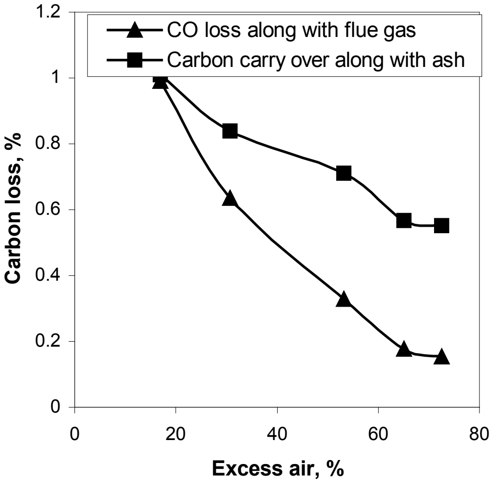


Fig.6 Effect of excess air on carbon loss during the combustion of sawdust

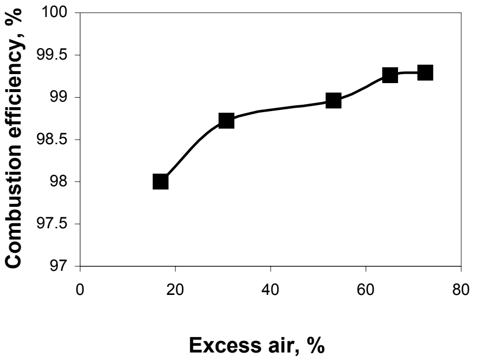


Fig.8 Effect of excess air on combustion efficiency