Study of temperature profiles by optimized characteristic secondary air injection in the biomass fluidized bed.

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Abstract— The agriculture wastes are attracted to produce required form environmental friendly energy and efficient burning of these required optimized characteristic temperature contours in the fluidized bed. To study the effect of the different characteristic behavior of the fluidized bed combustor (FBC) with the temperature profile to maximize the heat release rate of the unburned hydrocarbons of the biomass particles (UBP) in the free board region, set up an experiment with the 2.5 m height and 0.1 m diameter laboratory FBC model with 8 axial strategic point thermocouples (T_1-T_8). The FBC was configured with 4 sets of angular fixtures (90^o,60^o,45^o and 30^o) for pressurized secondary air radial and tangential injection. By the experimental observation for Sawdust, Baggase and Ricehusk burning, the 30^o angle tangential secondary air injection with any pressure between 1.2 and 3.5 bar created optimized vorticity effect to release more heat as compared radial air injection (90^o) in the free board region of the FBC. The 3.5 bar secondary air injection operations were created favorable characterized vorticity and turbulence effects for efficient burning of UBP and more heat transfer between bed material and biomass particles in the free board region. Sawdust burning has more benefit at 3.5 bar vorticity effect in the free board region.

Index Terms— Fluidised Bed, Biomass, Temperature, Agriculture wastes, Vorticity, Natural energy sources, Air injection pressure.

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1 INTRODUCTION

BIOMASS can be used as an energy resource and can be converted into heat or other form of chemical energy by thermal, physical and biological processes [3-8]. The biomass gasification in the fluidized bed has been attracted the society because of its high energy conversion efficiency with less harmful emissions [5-11]. The biomass energy available in the agriculture and forest waste was estimated approximately 400 EJ/year, therefore these kind of energy resources are attracted to produce required form environmental friendly energy [10-22]. Hence the farming and genetic modification of such energies (200-300 EJ/year) resources was prime importance as concerned to the society and environment. The fluidized burning of biomass is one of the proven methodologies for more efficient heat transfer with many flexible parameters to study towards pollution free energy conversion [10-17]. Many researchers made their efforts to suggest most suitable optimized operation of the fluidized bed combustion or pyrolysis of the different kind of wastes [23-25] and some were studied the different characterized effects, temperature profile and operating parameters to burn biomasses in the fluidized bed and release more heat for application [1,2].

2 EXPERIMENTAL APPROACH

The temperature distribution contours within the fluidized bed combustor (FBC) affects the burning of the biomasses and it was felt necessary to construct an experimental set up to study the temperature profile. In the view of this, the 2.5 m height and 0.1 m diameter laboratory FBC model was designed by using the equations (3) and (4) from the literature [9-21] with the biomass screw feeding arrangement with flow rate regulating valve V_3 as shown in Fig.1, 0.4 m from the bottom of FBC. The TDH and H were taken as the literature suggested for equation (3) and (4) between $1.2 < \frac{H}{H_{mf}} < 1.4$, and assumed 1.3 for design. The thermocouple T_1 was instrumented to indicate the temperature immediately after the orifice meter and air distributor when the fluidization will initiate. Similarly T_2 was to indicate the temperature immediately after entering of the biomass and start ignition, T_3 to T_5 were to indicate fluidization axial temperatures. The T_6 thermocouple was instrumented to note the temperature in the section A-A of Fig.1 and T_7 and T_8 were to indicate the temperatures in free board region of the FBC. All the thermocouples mentioned in the Table 2 (T_1 to T_8) were calibrated to provide digital display.

$$U_m = \frac{d_p^2(\rho_{sand} - \rho_{air})g\epsilon^3 \emptyset^2}{150\mu(1-\mu)} \qquad \text{….. (1)}$$

$$U_t = d_P \left[\frac{4(\rho_{sand} - \rho_{air})^2 g^2}{225\rho_{air}\ \mu}\right]^{1/3} \qquad \text{….. (2)}$$

$$\frac{H}{H_{mf}} = 1 + \frac{10.978(U_f - U_{mf})^{0.738} \rho_P^{0.376} d_P^{1.006}}{U_{mf}\rho_f^{0.126}} \qquad \text{….. (3)}$$

$$H_t = TDH + H \qquad \text{….. (4)}$$

The blower of capacity as shown in Table 3 has been installed to supply primary fluidization air at the bottom and secondary air to the free board region section A-A of the FBC and valves V_1 and V_2 were incorporated to regulate secondary and primary airs' supply respectively as shown in the Fig.1.

The air compressor as specified in the Table 2, was provided at the secondary air line between air blower and section A-A of FBC to supply pressurized air to the free board region and regulator and analog gauge were also incorporated to regulate and monitor the required air pressure. As the agriculture waste was natural energy resource to burn for less pollution in the exhaust, selected three biomasses (Ricehusk, Baggase and Sawdust) from the field, and their characteristics were studied in the published literature [1-17] as shown in the Table 1 and were used for calculation and analysis. The 20 % volume of the FBC was filled by the fluidizing bed material (Alumina Sand) as specified in the Table 2 from the studied literatures [3-17].

Table 1: Characteristics of Biomasses and Alumina Sand

Characteristic	Ricehusk	Baggase	Sawdust	Alumina Sand
Moisture in %	10.6	12.3	10.4	-
Porosity	0.64	0.8	0.5	0.46
Mean Particle Size in µm	-	-	-	342
Sphericity	0.49	0.49	0.49	-
Bulk Density in Kg/m^3	375-410	300-325	310-330	1582
LHV in MJ/kg	17.62	18.12	19.8	-
Volatile matter in %	78.6	71.5	44.1	-
Fixed Carbon in %	16.82	16.6	36	-
Ash in %	3.72	2.8	4.3	-
S in %	0.13	0.2	0.34	-

The fluidization and terminal velocities of the Alumina Sand and biomasses were calculated from equations (1) and (2) referred from the literatures reviewed [1-13] and got 0.46 m/s minimum fluidization velocity and 0.7 m/s terminal velocity. After the dry run of an experimental set up for fluidization of sand and biomass particles, the better result was obtained with 0.7 m/s velocity and it was selected for all the experiments for primary air supply. An arrangement to set characterized vorticity in the free board region (A-A horizontal section) of the FBC, one set of radial (90° angle) and 3 sets of tangential (30°, 45° and 60°), were designed to inject the secondary air from compressor to the section A-A as shown in Fig.2.

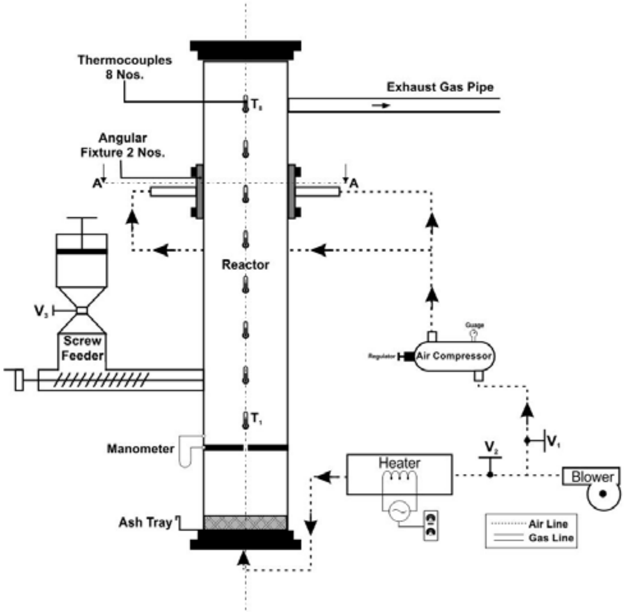

Fig. 1: Schematic diagram of Experimental Set-up

The heating coil arrangement has been made to heat the primary to initial ignition temperature with dimmer stat to regulate current and voltage for required temperature as in Fig.1. For initial experiment 90° angle air injection with Sawdust biomass burning operation was arranged. The biomasses samples were collected from the nearby field and dried them over night in the dryer with 50°C and chopped them to convenient size and shape. The blower was started and set primary air velocity to 0.7 m/s with the help of valve V_2 as in Fig.1 and observes the fluidization of the bed material for stability and streamlined operation.

Table 2: Detailed Specifications of experimental set up parts

Part	Description
Air Compressor	Dual Cylinder, Max. 4 bar auto stop, Outflow: 35 LPM
Blower	Supply: 12 V DC, Centrifugal, 64 m^3/h
Thermocouples	Type K, Temperature Range:0-1260°C, Ref. Junction: 0°C, Tolerance: ±2.2 or ±0.75%

The ignition temperature was set to 500 to 550°C with the help of dimmer stat of the primary air heater and ran whole experimental system for 20 minutes. After the stable condition of the set up was reached, gradually the Sawdust feeding was started with the help of valve V_3 and screw feeder and rammer. The secondary air supply was started by operating the valve V_1 to the compressor and then the pressure was regulated 1.2 bar for initial experiment.

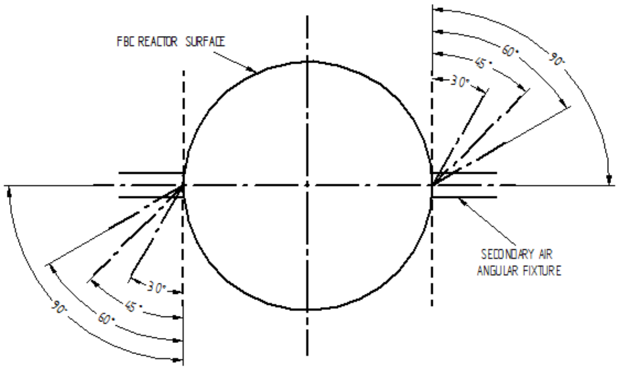

Fig. 2: Schematic Sketch of sectional view A-A for air injection fixtures

The whole experimental set up was allowed to run for 20 to 25 minutes for stable condition and then recorded all the thermocouples T_1 to T_8. Similarly next experiment was conducted by increasing the secondary air injection pressure to 2 bar with the help of valve V_1 for same Sawdust biomass burning and recorded all thermocouple readings and in the similar way conducted the experiments for supplying secondary air with 2.5, 3 and 3.5 bar pressure in the free board region (A-A) of the FBC. The same experimental procedure has been followed for Ricehusk and Baggase biomasses.

3 RESULTS AND DISCUSSIONS

For the discussions, the chemical reactions of bed material with the biomasses and the effect of initial volatile matter and ash content of the biomasses were taken as constant. Also the fluidization velocities of the biomasses were taken constant and single value. It is observed from the Fig.3 and Fig.4, the temperature of the gas and biomass particles within the FBC was increasing along the vertical height of the reactor and it was increasing with more intensity in case of 30^o angle secondary air injection operation in the free board region. With the same trend maximum ranges (for 1.2 bar: 712-981^{o}C to for 3.5 bar: 741-998^{o}C) of temperatures were found while the secondary air injection pressure increases from 1.2 to 3.5 bar as observed in the Fig.1. These were due to the more release of heat by the effect of vorticity created by the 30^o angle air injection at the section A-A of FBC facilitate more residence time to the unburned biomass particles (UBP) for enhancement of burning rate.

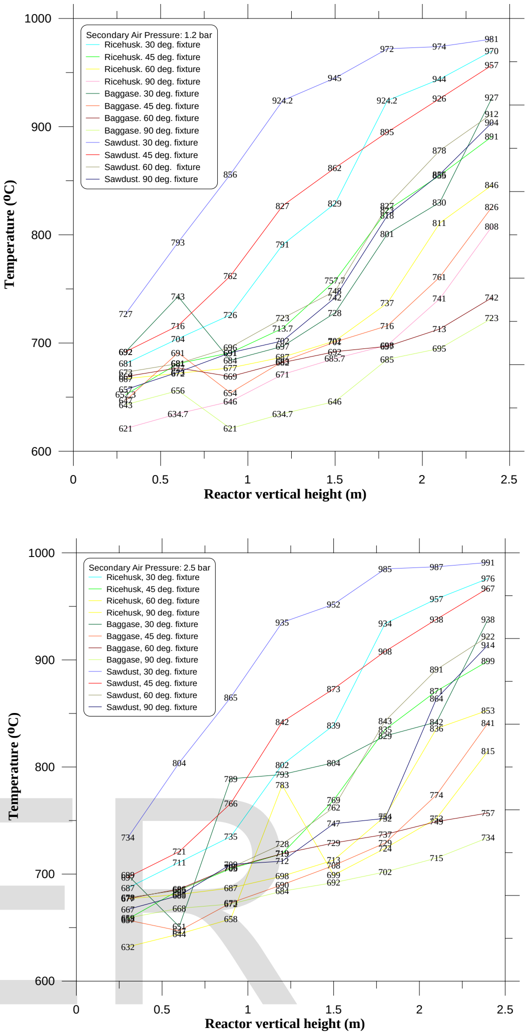

Fig. 3: Effect of secondary air pressure (1.2 and 2.5 bar) on axial temperature

In the similar way the FBC operation with 90^o angle secondary air injection with the pressure from 1.2 to 3.5 bar release least heat with less temperature ranges (for 1.2 bar: 621-723^{o}C to for 3.5 bar: 661-735^{o}C). Therefore the FBC operation with low pressure (1.2 bar) secondary air injection in the freeboard region characterize the vorticity to lower expose of UBP surfaces to the secondary air to release less heat for applications, whereas 3.5 bar operation characterize for highest heat release. The 3.5 bar secondary air injection also increases the heat transfer rate between the bed material and biomass particles for rich burning to release more heat in all the section of the FBC as observed axial temperature profiles in the Fig. 3 and 4. The rich burning of the UBP in the free board region due to vorticity effect as explained above, release more heat, then the density of gases will decrease, so axial buoyancy force will exist to drag UBP and sand particles in the bottom of the FBC and this enhances heat transfer efficiency with more mass flow rates of the fluids within the reactor.It was observed in the experiments, the high pressure (3.5 bar) secondary air injection flush the ash, residue and exhaust gas with high rate as compared to lower pressure (1.2 to 2.5 bar) operations of the FBC and this may help to set streamlined current of the fluidization.

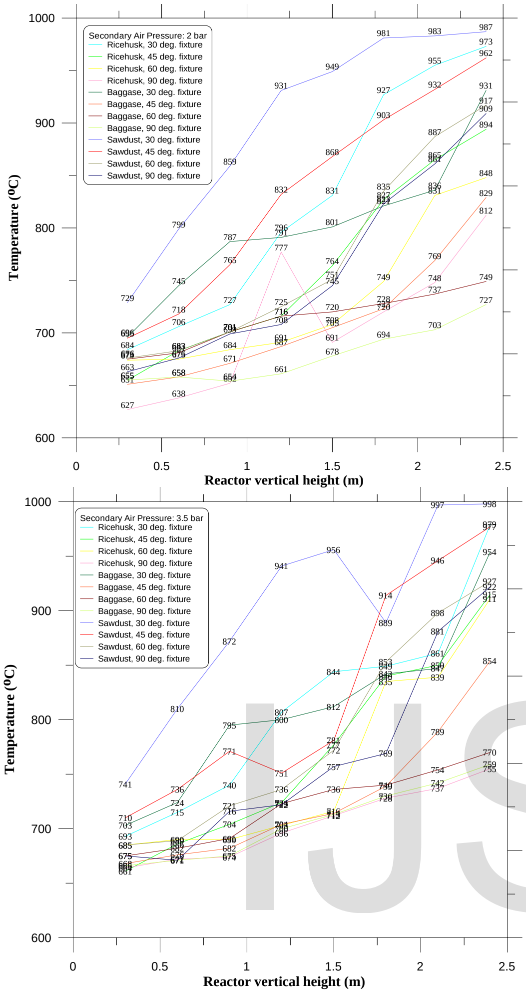

Fig. 4: Effect of secondary air pressure (2 and 3.5 bar) on axial temperature

The characteristic behaviors of the FBC were clearly emphasized, the burning of Sawdust indicating highest temperature profile, whereas for Baggase lowest for all angle fixture of secondary air injection in the free board region. This was due to Sawdust biomass particles has more LHV (19.8 MJ/kg) as compared to Baggase biomass particles (18.12 MJ/kg) as shown in the Table 1, because of this, the Sawdust particles add more heat with the 30° air angle characterized vorticity in the free board region of the FBC.

Baggase particles has more porosity (0.8), volatile matter (71.5%) and less fixed carbon (36%) than the Sawdust (porosity: 0.5, volatile matter: 44.1% and fixed carbon: 16.6%), therefore sudden burning and vaporizing of volatile matter will make Baggase more particles more dense and porosity in the axial fluidization of FBC, in the meanwhile Sawdust more benefitted by the effect of high pressurized vorticity in the free board region to release more heat for highest axial temperature profile. The low moisture content of the Sawdust (10.4%) and lower angle (30°) with high pressure (3.5 bar) secondary air injection in the free board region of the FBC advantages towards rich burning to disintegrate more heat of higher temperature profile. It is observed from the Fig. 3 and 4, as the pressure of the secondary air increases from 1.2 bar to 3.5 bar, the stability of the temperature profile decreases along the vertical height of the FBC reactor and it is pointed more from 1.5m to 2.3m height. This is because the biomass feeding with sudden burning and turbulence added by the vorticity effect of secondary air injection at the freeboard region at A-A section of FBC falls between 1.5 to 2.3 m height.

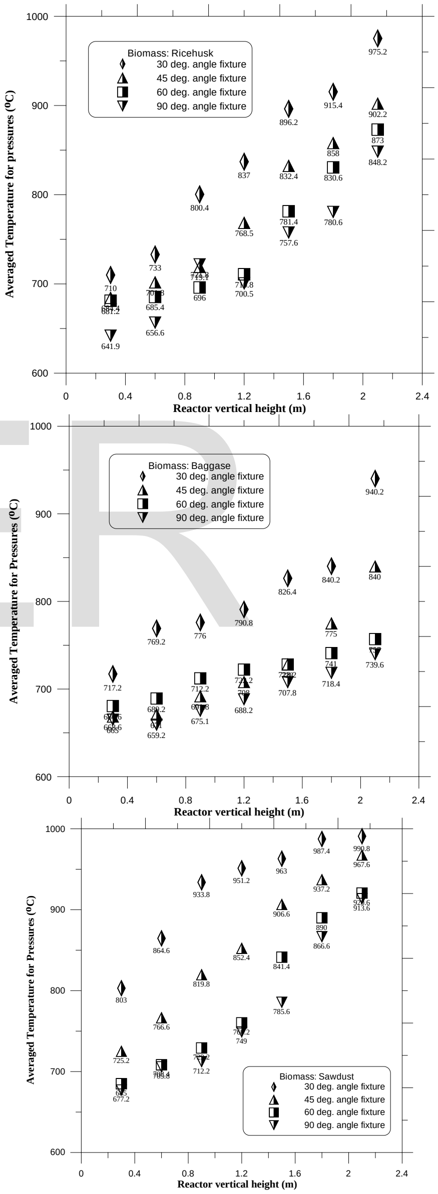

Fig. 4: Effect of secondary air angle injection on averaged axial temperature

It is also observed from the Fig.5, the average temperature profile of pressures between 1.2 and 3.5 bar indicating same effects as explained in the above for any angle (30°, 45°, 60° and 90°) secondary air injection in the free broad region of the

FBC. The operations of FBC with lower angles' (30^o and 45^o) air injection in the free board region creates temperature contours almost linear increasing up to the 1.5 m height and then slow and steady increase in the contours.

4 NOMENCLATURES

H_{mf}: Minimum Fluidization Height of the FBC
Ht: Overall Height of the FBC
H: Expanded or Complete Height of the FBC
U_m: Minimum Fluidization Velocity
Ø: Sphericity of the particle
ε: Porosity of the particle
μ: Dynamic viscosity at the operating temperatures (Approx: 700^oC and 101.32 KPa)
ρ_{sand}: Density of sand particle in Kg/m^3
ρ_{air}: Density of air in Kg/m^3
dp: Mean diameter of the fluid particles in meter
U_t: Terminal velocity of the bed material in m/s
g: Acceleration due gravity of the particles in m/s^2

5 CONCLUSIONS

- The 30^o angle tangential secondary air injection with any pressure between 1.2 and 3.5 bar created optimized vorticity effect to release more heat as compared radial air injection (90^o) in the free board region of the FBC irrespective of any biomasses (Sawdust, Baggase and Rice-husk) burning.

- The high pressure (3.5 bar) secondary air injection operations of FBC were created favorable characterized vorticity and turbulence effects for efficient burning of unburned biomass particles (UBP) and more heat transfer between bed material and biomass particles in the free board region and also to produce streamlined current of the fluidization.

- Sawdust biomass has more benefit with the high pressurized (3.5 bar) vorticity effect in the free board region to release more heat for highest axial temperature profile. Whereas for Baggase lowest for all angle fixture of secondary air injection.

- The low moisture content of the Sawdust (10.4%) and lower angle (30o) with high pressure (3.5 bar) secondary air injection in the free board region of the FBC was advantages towards rich burning to disintegrate more heat of higher temperature profile.

ACKNOLEDGEMENT

A special thanks to esteemed "Vision Group on Science and Technology (VGST)", Government of Karnataka for funding for research equipments through the scheme Karnataka Fund for Infrastructure to develop Science and Technology (K-FIST).

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