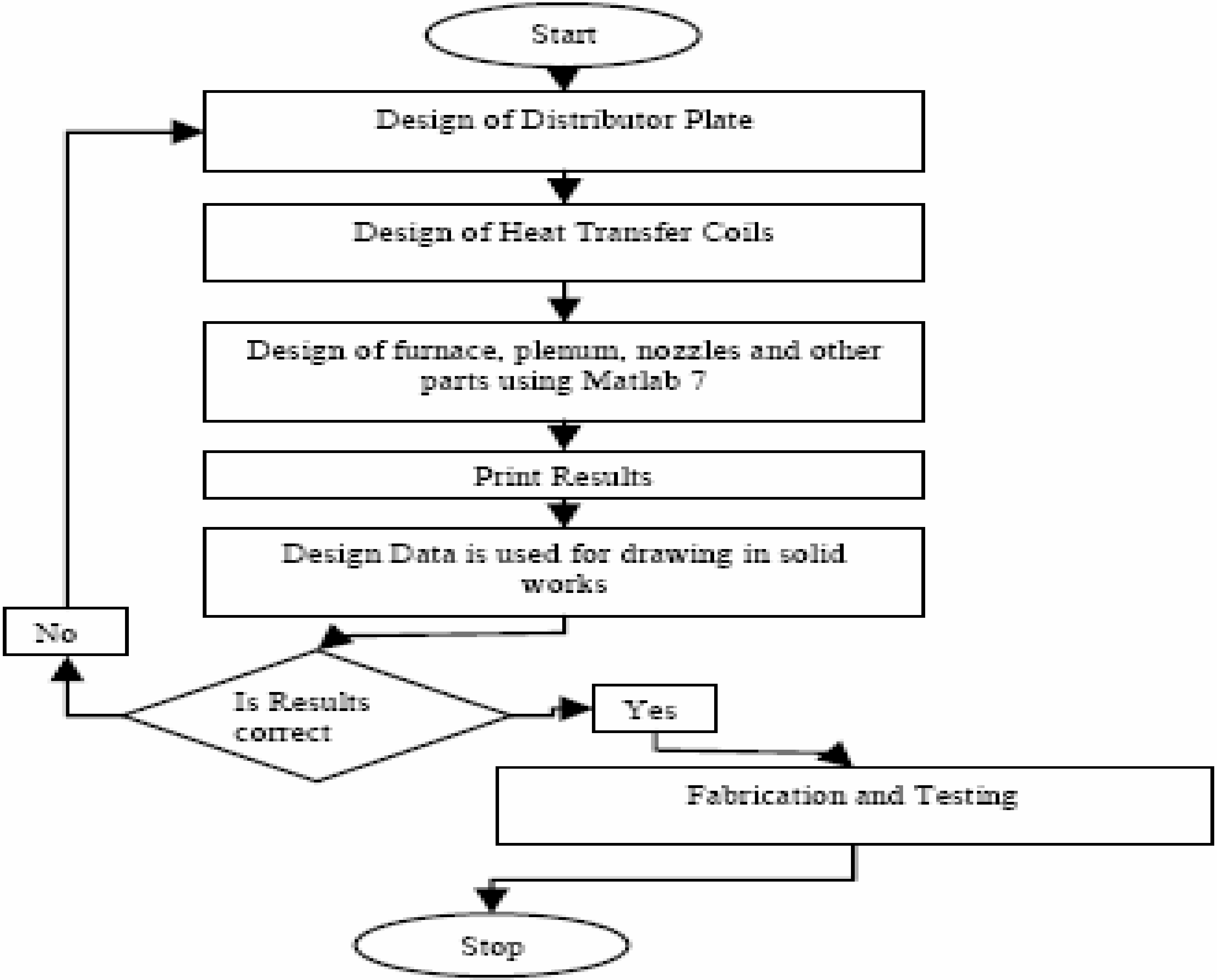
Computer Aided Designing of Circulating Fluidized Bed Combustion Using Biomass

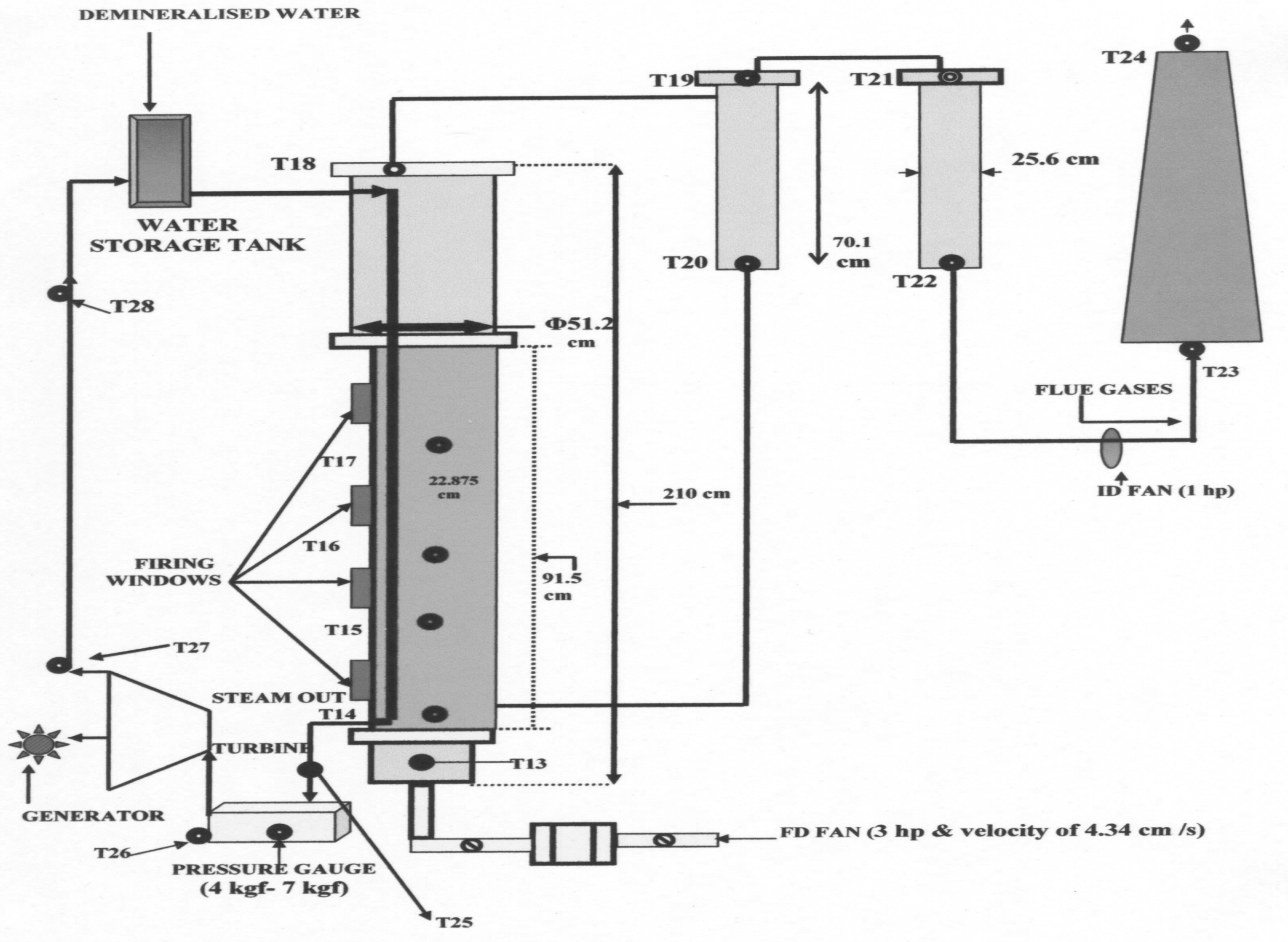
Ravi Inder Singh
Lecturer, Department of Mechanical Engineering
Guru Nanak Dev Engineering College
Ludhiana-141006

For Presentation at the
International Conference on
Advances in Energy Research
Indian Institute of Bombay
December 13-15, 2007

Abstract

- Energy Scenario in Punjab
- Fluidized Bed Combustor
- Types of Fluidized Bed combustor
- Circulating Fluidized Bed Combustor
- Computer Aided Designing of CFBC


Start
Design of Distributor Plate
Design of Heat Transfer Coils
Design of furnace, plenum, nozzles and other parts using Matlab 7
Print Results
Design Data is used for drawing in solid works
No
Is Results correct
Yes
Fabrication and Testing
Stop



DEMINERALISED WATER
WATER STORAGE TANK
T18
T19
T20
T21
T22
T24
70.1 cm
25.6 cm
Φ51.2 cm
T28
T23
FLUE GASES
ID FAN (1 hp)
T17
22.875 cm
210 cm
T16
FIRING WINDOWS
91.5 cm
T15
T27
STEAM OUT
T14
TURBINE
T13
GENERATOR
T26
PRESSURE GAUGE
(4 kgf- 7 kgf)
FD FAN (3 hp & velocity of 4.34 cm /s)
T25

The design of distributor plates comprises of following steps:

1. Determination of pressure drop across the distributor plates using equation

$$\Delta P = \Delta P_s = H(1-\alpha)\rho_s \frac{g}{g_c}$$

2. Determination of Reynolds number using $\mathrm{Re}_t = d_t u_o \rho_g / \mu$ for the total flow approaching the plate and select the corresponding value of C_d.

3. Determine velocity of fluid through orifice using

$$u_{or} = C_d \left(\frac{2 g \Delta P_d}{\rho_g}\right)^{1/2}$$

4. Decide N_{or} No. of orifices per unit area of distributor and the corresponding orifice diameter using equation

$$u_o = \frac{\pi}{4} d_{or} . u_{or} . N_{or}$$

Design of Heat Transfer Coil

Heat transfer coil is a device in which energy is transferred from one fluid to another across a good conducting solid wall. The purpose of designing heat transfer coil is the effective transfer of heat energy between the two fluids. For the effective heat transfer it is made of copper metal because of the reason that thermal conductivity of copper is high and the bed material selected is sand, ash, crushed refractory or limestone, with an average size of about 1 mm.

The Design of Heat transfer Coils consist of following steps.

1. Determination of duties required for Heat Exchanger and water flow rate i.e Duty, $D = m \times S_{air} \times \Delta t$.
2. Determine water flow rate, $Q_w = D/(S_w \times \Delta t)$.
3. Calculate water velocity $u_w = Q_w / A_t$
4. Calculate Nusselt Number(Nu) i.e $Nu = 0.023\ (60441.176)^{0.8}(3.54)^{0.4}$.
5. Calculate Heat Transfer coefficient at inner and outer surfaces using $h = Nu \times K_w / d_i$.
6. Check for Archimedies number and Reynolds Number i.e $Ar<26000$ and $Re_{mf}=12.5$.
7. Calculate h_o = 70 % of (h_{max}) where $h_{max} = 35.8 \times \rho_p^{0.2} \times K_a^{0.6} \times d_p^{-0.36}$.

8. Calculate overall heat transfer coefficient in terms of bed to liquid thermal resistance, (1/ UA) by using

$$\frac{1}{UA} = \frac{1}{h_o A_o} + \frac{1}{h_i A_i} + \frac{t}{k A_m}$$

9. Calculate Logarithmic mean temperature difference (LMTD) based on water inlet and outlet temperature and the assumption that the temperature of the bed of the fluidized particle is that of the outlet temperature of the gas namely

200°C.

Thus, (LMTD), $\theta_m = \dfrac{\theta_1 - \theta_2}{\log_e(\theta_1 / \theta_2)}$

10. Calculate thermal resistance which equals (LMTD) /duty.

11. Calculate Tube length, L by Equating (1/ UA) and overall thermal resistance.

Table 1 gives the assumptions assumed for calculation of heat transfer coil and Table 2 gives the assumptions for calculations of pipe length.

Table 1 Gives parameters assumed for calculation of heat transfer coil.

Mass flow of gasses, m	0.5 kg/s
Air inlet temperature, $(\theta_1)_{in}$	$50^{\circ}C$
Air outlet temperature, $(\theta_1)_{out}$	$200^{\circ}C$
Water inlet temperature, $(\theta_2)_{in}$	$20^{\circ}C$
Water outlet temperature, $(\theta_2)_{out}$	$80^{\circ}C$
Tube material	copper
Tube bore, d_i	12 mm
Tube outside diameter, d_o	15 mm
Chosen particle	Silica sand
Particle size, d_p	427 μm
Minimum fluidising velocity at 200°C, U_{mf}	0.25 m/s

Table 2: Physical Properties Assumed for Calculation of Pipe Length

Physical Properties	
Particle density, ρ_p	2640 kg/m^3
Air mean specific heat, S_{air}	1.04 KJ/kgK
Air thermal conductivity at 200°C, K_a	3.87×10^{-2} W/mK
Air density at 1atm, 200°C, ρ_g	0.746kg/m^3
Air viscosity at 200°C, μ_g	2.58×10^{-5}kg/ms
Water viscosity at 50°C, μ_w	544×10^{-6}kg/ms
Water Prandtl number at 50°C, Pr	3.54
Water specific heat, S_w	4.18kJ/kgK
Water thermal conductivity, K_w	643×10^{-6}kW/mK
Copper thermal conductivity, K_{Cu}	380W/mK

Design of components CFBC at TIET Patiala

After designing of distributor plate and heat transfer coil, components of CFBC system need to be designed. These designed components after assembly will help us in setting up an experimental set-up of CFBC system.

1. Average Equivalent Bubble Diameter

$$D_b = 0.43(U_o - U_{mf})^{0.4} (Z + 4(A_o)^{0.5})^{0.8} \quad g^{-0.2}$$

2. Transport Disengaging Height

Hamdullahpur and Mackay(1986) give the transport disengaging height as $TDH = 12D_b$

3. Furnace Construction and Dimensions

For design conditions, the freeboard height is taken to be 20% greater than the TDH,

$$H_{free} = 1.2TDH$$

Now that a range of furnaces sizes have been detrmined for the design conditions, the heat transfer for each of these furnaces must be calculated. Table 3 gives the basic details i.e. names and specifications of some of the components of the experimental CFBC system set-up at TIET Patiala.

Table 3: Specifications of Components of CFBC System at TIET

Components/parts	Material/specification
Furnace, cyclone, economizer	Mild steel – 18 gage
Nozzles	Mild steel – tapered drilled
Tubing	Copper
Base plate	Mild steel
Piping	G.I
Insulation	Fireclay
Bed	Silica sand, dolomite
Blower	3hp, air velocity = 30.5m/s, 2.2kW

Design results

1. Distributor plate is fabricated from mild steel (18 gage) sheet. Diameter of the distributor plate is 406 mm. With 14 nozzles, 1 nozzle at the centre, 5 nozzles at the radial distance of 102 mm and remaining 8 nozzles at a radial distance of 203 mm. This distributor plate is fitted at the distance of 51 mm from the bottom of the furnace and welded to the furnace to make a leak proof joint.
2. Table 4 gives the design calculations for heat transfer coils.
3. Furnace is made up of mild steel (18 gage) sheet rolled to form a cylinder. The internal diameter of the cylinder is 406 mm and height is 914 mm. With the plenum at the base, the furnace contains four input windows for feeding fuel at a height of 127 mm, 279 mm, 432 mm, and 559 mm from the bottom of the furnace.

Table 4: Design calculations for Heat Transfer Coil

Duty, D	80 kW
Water flow rate, Q_w	0.4 kg/s
Water velocity, u_w	2.74m/s
Heat transfer coefficient, h_i	13.7 kW/m^{2}K
h_o	0.281kW/m^{2}K
LMTD	150^o k
Tube length, L required	42 m

Exit Gas Composition

Above circulating fluidized bed bolier is run with rice husk and rice straw as fuel. The CO_2 % is 12, O_2 % is 6.9, CO is 100ppm, SO_2 is 48ppm and NO_x is 50 ppm. The CV of combined fuel has taken approx. 15000kJ/kg. With this actual combustion efficiency comes out to be approximately 60%. It is quite low which the fuel is probably due to manually feeding of fuel. With the addition of hopper and automation for fuel addition it will increased

Conclusion

- Circulating fluidized bed boiler based on biomass is designed and fabricated of approximately 80kW with water flow rate 0.4 kg/sec.
- Exit gas composition is also measured which comes within permissible limits set by pollution board.
- Efficiency of boiler is 60 %(approx.) which is quite low.

References

- Arena, U., Chirone, R., D'Amore, M., Miccio, M. and Salatino, P., 1995c, Some Issues in Modelling Bubbling and Circulating Fluidized-Bed Combustors,*Powder Tech*, 82,pp.301.
- Badhai Ionia, 2005, Studies in Techno Economics aspects of power generation from Agriwaste in India*, Phd Thesis,Thapar university,* Patiala.
- Bahillo, A., Cabanillas, De Diego, L, and Adanez, J., 2003, Co-Combustion and Biomass in FB Boilers: Model Validation with Experimental Results from CFB Pilot Plant, *Int. Energy Agency*, Florida.
- Bhattacharya S. and Luong Pham Hoang, 1994, Modeling Heat Transfer in a Circulating Fluidized Bed, *International Journal of Energy Research*, , **Vol. 18**, 1-7.
- Daizo Kunni and Octave Levenspiel; 1991, Fluidization Engineering, Butterworth-Heinemann, USA.
- Davidson, J. F. and Harrison, D., 1963, Fluidized Particles, Cambridge University Press.
- Kumar,D.S,2006,Heat and Mass Transfer, Kataria Publishers ,Ludhiana.
- Fang M., Yang L.and Cheng Shiz, 2004, Experimental study on rice husk combustion in a circulating fluidized bed, *Fuel Processing Technology*, **Vol.85**, 1273-1282.
- Hamdullahpur,F. and Mackay,G.D.M.,1986, Two-phase flow in the freeboard of a fluidized bed, *AIChE* J.,32,2405-2055.
- Mori, S., and Wen, C.Y., Simulation of Fluidised Bed Reactor Performance by Modified Bubble Assemblage Model, *Fluidisation Technology* (Ed. D.L. Keirns), 1, Hemisphere Washington, 179-203, (1975).
- Reddy, G. V. and Mohapatra,1994, S. K., A mathematical model for exit gas composition in a 10 MW fluidized bed coal combustion power plant, *Energy Conversion & Management*, **35,** 12, 1049-1060.

Thank you