STUDY OF BUBBLING FLUIDIZED BED COMBUSTOR BASED ON CO-FIRING BIOMASS & COAL

Mohit Gaba[1]
Assistant Professor
Department of Mechanical Engineering,
Asra College of Engineering & Technology,
Bhawanigarh (148026), India

Hemant Kumar[2]
Assistant Professor
Department of Mechanical Engineering,
Punjabi University,
Patiala (147002), India

ABSTRACT

Energy is vital for the social and economic development of any nation. The demand of energy is increasing rapidly world widely with development of civilization and growing industrialization. The requirement of energy demand is met by fossil fuels or conventional energy sources. But due to the depletion of fossil fuels there is an urgent need to effectively tap the non conventional and renewable energy sources. The investigations take place in a 30 MW power plant named Captive Power Plant, Ambuja Cements Limited, Ropar. It is a mini power plant based on biomass. CPP is the internal unit of Ambuja Cements Limited which a pioneer cement production company of India. CPP generates 30 MW of power running on three units. In the present study the measurements were done with both coal-firing and biomass firing with 30% share. The effect of co-firing on boiler performance was evaluated. The influence of various variables such as temperature, stack emissions, steam and flue gas temperatures was investigated. Temperature distribution along the bed was measured with the help of thermocouple. It was observed that due to high volatile content in the biomass, it burnt in the freeboard. So the higher temperature in the freeboard than bed was observed. The boiler performance was not affected by co-firing. In case of co-firing, the emission of gases was within the permissible limits.

Keywords: Biomass, Fluidized bed, fossil fuels, BFBC, Co - firing

1Introduction

Energy is vital for the social and economic development of any nation. The demand of energy is increasing rapidly world widely with development of civilization and growing industrialization. The requirement of energy demand is met by fossil fuels or conventional energy sources. But due to the depletion of fossil fuels there is a urgent need to effectively tap the non conventional and renewable energy sources. The energy demand of India is expected to grow to 5.6% - 6.4% per year in coming years. Coal is most important fossil fuel in India and accounts for 55% of India's energy need. 30 % of the requirement is met by petroleum products (INCCA, 2010). Biomass contributes some 9 – 14 % to the total energy supplies (Khan et al., 2009). World widely, biomass is the fourth largest energy resource after coal, oil and natural gas. Biomass is a renewable energy source and seen as the most promising energy source. Biomass is a biological material derived from living or recently living organisms. Biomass can be divided into various categories such as agricultural farm residues (e.g. paddy straw, sugar cane trash etc), agro-industrial residues (e.g. paddy husk, coffee husk etc), forests & social forests residues (Arvelakis, 2002). Several solutions and incentives can be used for different kinds of biomass fuels to produce energy. Technological developments over time made possible to burns different kinds of fuels and flexibility to burn different fuels in a boiler. Steam generator design depends on various factors i.e. fuel analysis, the fuel type and available quantity, the required steam conditions or process efficiency and required emissions limit. Cofiring of fuels increases the complexity. It is critical to know what the available options to burn biomass and what the factors to take into account when selecting a combustion technology (Jose and Pascual, 2011). The proper technology must be selected base on the required cost, available fuel, required steam conditions, and emissions to be reached. BFBC technology is more advanced than grate technology. BFBC offers more advantages over other technologies in terms of emissions and performance. Fluidized bed technology allows lower SO_x and NO_x emissions. but in grate unit it would need to introduce auxiliary equipments which increases the capital cost of the boiler. On the basis of above explained reasons BFBC is more suitable for biomass fuels. Grate Units will offer Low performance on fuel flexibility and high maintenance cost than Bubbling fluidized bed combustion unit. Grate units used only when the fuel having high alkali contents or high bed temperature to produce agglomerates. Due to the advantages of BFB units over grate and similarities between their parts it is economical to upgrade grate unit into BFB unit. (Jose and Pascual, 2011).

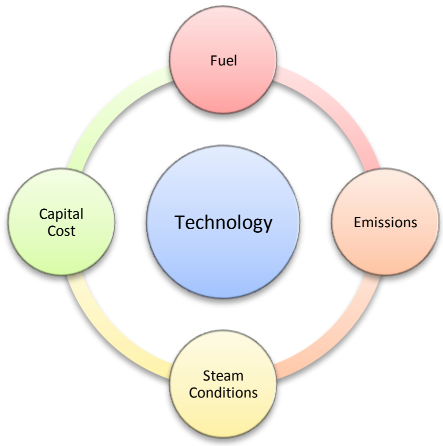

Figure 1 Technology Selection (Pena, 2011)

2. Fluidization and Fluidized Bed Combustors

Fluidization is a process in which solids are caused to behave like a fluid by blowing gas or liquid upwards through the solid-filled reactor. A simple fluidized-bed reactor consists of a chamber containing a bed of inert particles such as sand, supported by a distributor plate. Pressurized air is passed through the distributor plate and the velocity of the air is progressively increased so as to support the entire weight of the bed by the fluid drag on the bed particles due to the upward flowing air. The bed is then said to be incipiently fluidized, and it exhibits fluid-like properties above this particular velocity, called minimum fluidization velocity. This moving mass of solid particles is called a fluidized bed. The turbulence of the bed increases with velocity, above the minimum fluidization velocity.

The advantages of fluidized bed boilers are as follows:

1. The smooth, liquid like flow of particles allows continuous, automatically controlled operation with ease of handling and it is suitable for large-scale operations.
2. The rapid mixing of solids leads to nearly isothermal conditions throughout the combustor; hence the operation can be controlled easily and reliably.

3. Heat and mass transfer rates between gas and particles are high when compared with other modes of contacting.
4. Low-grade fuels such as high ash coal and biomass can be used in the system.
5. Since the bed temperature is kept normally below 1000°C, little atmospheric nitrogen is converted to NOx.
6. In addition, the whole vessel of well mixed solids represents a large thermal flywheel that resists rapid temperature changes, responds slowly to abrupt changes in operating conditions and gives a large margin of safety in avoiding temperature runaways for exothermic reactions.
7. The rate of heat transfer between a fluidized bed and immersed object is high; hence heat transfer with in fluidized beds requires relatively small surface transfer area.

3. Literature related to BFBC

Kaynak et al. compares the combustion performance of peach and apricot stones with coal. A steel bubbling fluidized bed combustor having inside diameter of 102 mm and a height of 900 mm was used for experimentation. The study observed that the volatile matter of peach and apricot stones was released after the biomass is fed in to the furnace and the combustion of volatile matter takes place along the free board. Maximum temperature in the free board obtained by the coal was 100°C which was lower than the peach and apricot stone combustion. It was due to the lower volatile content in coal than peach and apricot stones. Varol et al. studied the effect of secondary air on combustion efficiency and emissions of olive cake and coal. An experimental setup is fabricated of inner diameter 102 mm and a height of 900 mm. It was observed that with increasing the flow rate of secondary air the temperature of free board zone increases. The CO and especially hydrocarbons burns better in freeboard as the secondary air increases. Rao et al. studied the combustion behavior of ground nut shells in a atmospheric fluidized bed combustor under different operating conditions. A fluidized bed combustor of circular cross section with inner diameter 150 mm and height 1000 mm was fabricated with stainless steel. It was observed that the temperature of fluidized bed was increased with increase in the fluidization velocity. It also observed that 35-45% excess air was optimal to reduce carbon losses during the combustion of ground nut shells. The increase in the air velocity decreases the CO emissions.

4. Experience at CPP

Captive Power Plant (CPP) is the internal unit of Ambuja Cements Limited for power generation. Ambuja Cements Limited took a appreciable step to exploit the non conventional energy source, when a 30 MW plant set in Ropar in 2004.

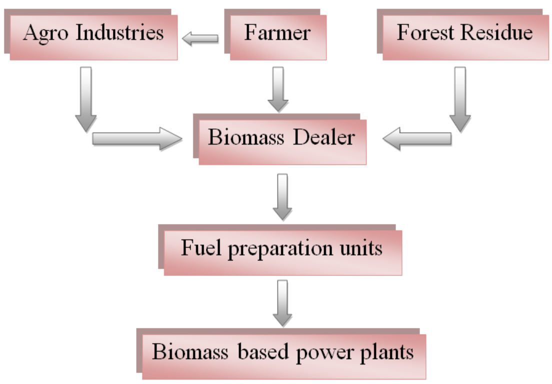

Figure 2: Consortium for collection of Biomass

Consortium for biomass collection from various sources is shown in Fig. 2.

Table 1: Ultimate analysis of Biomass fuels

Fuel	Rice Husk	Paddy Rejects	Cow Dug Cake	Cotton stalks	Mustard stalk
Carbon	35	36.54	20.50	41	43
Hydrogen	3	4.12	2.87	4	6
Nitrogen	1.25	0.10	0.10	0.4	0.28
Sulphur	0.18	0.13	0.31	0.1	0.07
Ash	15	14.77	43.88	5	5.1
Oxygen	34.45	34.41	25.59	25	40
GCV	3500	3192	2251	3400	3300

Table 2: Proximate analysis of biomass fuel

Fuel	Paddy Rejects	Cow Dug Cake	Rice Husk
Moisture	9.93	8.75	5.22
Ash	13.43	39.89	14.54
Volatile	65.48	41.63	66.4
Fixed Carbon	11.16	9.73	13.84

It is a mini thermal power plant which uses biomass instead of coal for releasing heat. CPP is the first successful project of HOLCIM group in India. Using biomass instead of coal, provides benefits to the society. It leads to generate employment and sources of income. Consortium for biomass collection from various sources is shown in Fig. 2. Captive Power Plant has three boilers which are used for steam generation. Two boilers have 45 TPH capacities which were commissioned in 2004 and the third boiler having capacity 80 TPH was commissioned in 2008. CPP is a mini thermal power plant based on biomass mixing with coal. But due to the unavailability of biomass, coal is also used as a fuel. The power plant converts the heat generated from the biomass into electric power. Biomass burns and generates heat and the liberated heat goes into the water where it converts the water into superheated steam. The high velocity superheated steam impinges on the turbine to run it. The generator which is coupled with the turbine produces electricity. Different biomass has different calorific values. During the time of feeding biomass into the boiler the calorific values has to be taken into considerations. The fuel which have low calorific value such as wood barks are fed less in percentage to maintain a constant level of net calorific value. The ultimate and proximate analysis of different fuels is shows in tables 1 and table 2 respectively. The ultimate analysis provides the information of the quantity of carbon, hydrogen, nitrogen, sulphur, ash and oxygen. The proximate analysis includes the analysis for moisture, ash, volatile and fixed carbon in the fuel. It is clear from the ultimate and proximate analysis that rice husk has high calorific value than other biomass fuels and it contains a large quantity of volatile matter than other fuels.

Environmental Impact of Captive Power Plant

The need for using non conventional fuels other than fossil fuels cannot be overemphasized on two counts Firstly the non conventional fuels helps in decreasing the rate of depletion of fossils fuels. Secondly the use of non conventional fuels minimizes the degradation of environment and stress associated with mining. Due to unavailability of biomass Captive Power Plant uses 30 % biomass with coal. The data measured from CPP with respect to Coal and Co firing is given in table 3.

Table 3: Flue Gas Emission

Parameters	Coal	Co-firing
O_2 (Percentage by volume)	6.1	7.1
SO_2 (mg/Nm^3)	75	72
NO_x(mg/Nm^3)	18	15
CO (ppm)	5	5
Ash Content (% by volume)	40	30

The table shows that Co firing reduces the emissions of pollutants from flue gases. The emissions of the pollutant from the flue gases are within the permissible limits. The project leads to the production of clean energy which has no bad impact on the environment. Various parameters of CPP are shown in the table 4.

Table 4: Plant Parameters

Plant Parameters	Values
Capacity	30 MW
Type of bed	AFBC
Types of fuel used	Any type of biomass depending upon availability
Feed Rate of fuel	11 T/h
Main steam temperature	495˚C
Feed Water Temperature	172˚C
Area of fluidized bed	41 m^2
Type of distributor	Nozzle Type
Bed Material	Crushed Refractory
Fly ash Collector	ESP
Bed temperature (˚C)	750 – 800˚C
Density of Fuel	100 – 105 Kg/m^3

Figure 3 shows the temperature distribution of coal firing and co-firing along the bed. The plot shows that the temperature of boiler running on coal is much more than the boiler running on co-firing. Biomass has high moisture contents and low calorific value due to which the combustion of biomass produces less heat energy than coal. It is observed that co-firing required more air supply than coal firing. It is because combustion of biomass takes place in freeboard region due to which the furnace area required for combustion is much more than the coal firing (Kumar et al.). For more furnace area more air is supplied. Biomass has low calorific value than coal; the bed temperature in case of biomass remains less than coal combustion. A clear increase in the temperature of bed in case of coal fired boiler is observed. as compared to co-firing boiler. Biomass is a agricultural waste and its quality vary with the variation in moisture due to environmental conditions. Due to these variations the performance of boiler also gets affected. Figure 4 shows the temperature variations in boilers based on coal and co-firing with span of time. It is clear that the boiler based on co-firing having low temperature than the coal firing boiler. Co firing also shows slight fluctuations in the temperature which is caused by the fuel flexibility. A fuel having high moisture content exerts low temperature on combustion.

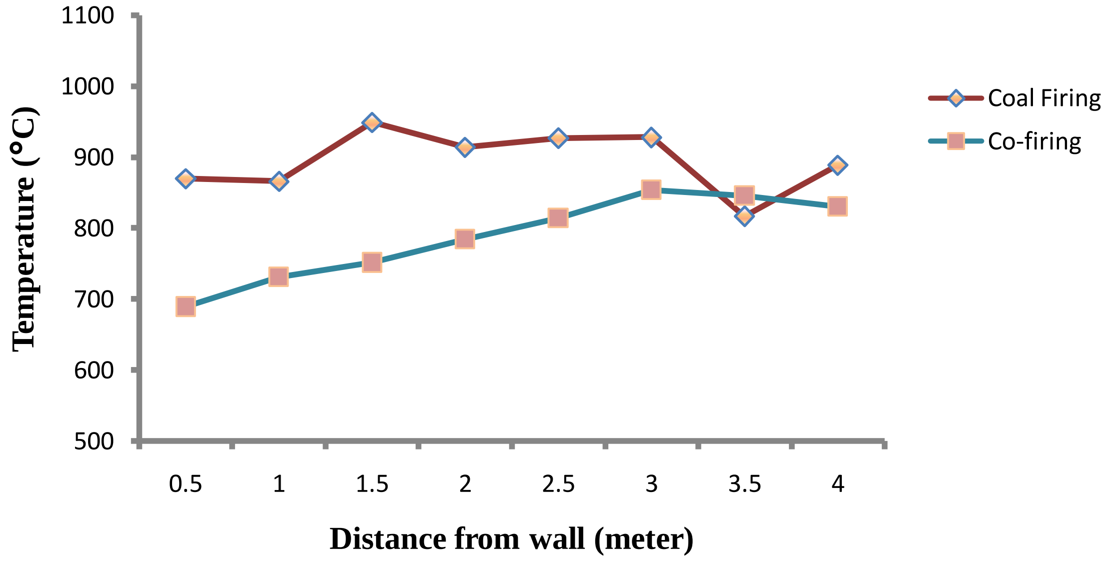

Figure 3: Temperature variations along the bed

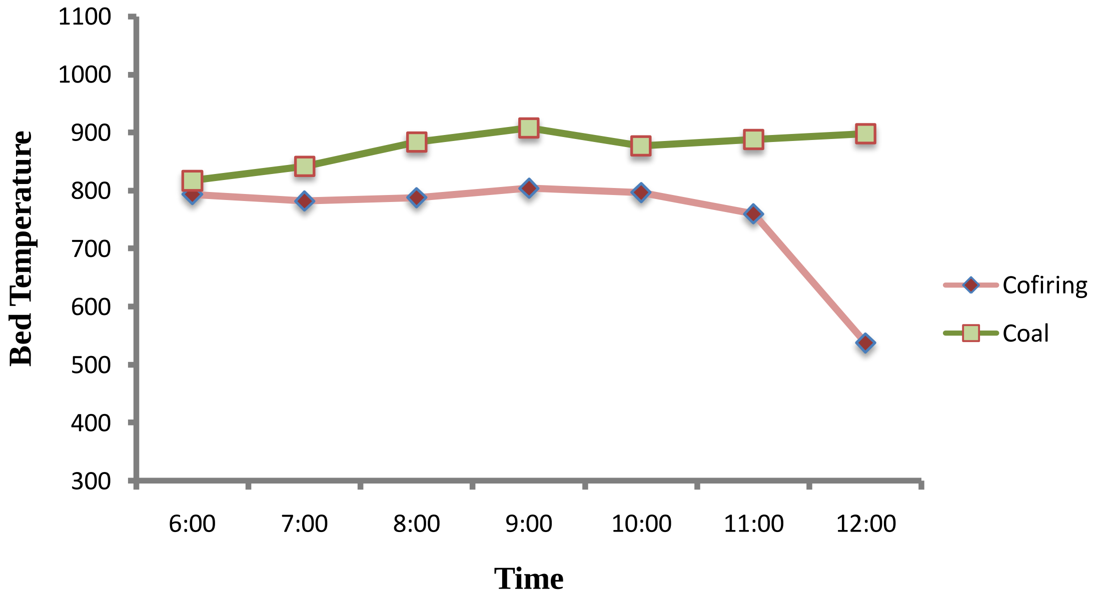

Figure 4 :Bed Temperatures versus Time

The properties of biomass are different from coal. Biomass has high ash content, less carbon and low heat value. As the biomass is a low quality and high volatile fuel it requires a large quantity of air for effective combustion. It is already discussed that biomass combustion take place in freeboard region which required a large furnace area. For more furnace area more air is required for combustion. Oxygen which is present in the air is used for combustion. As co firing required more air for effective combustion the higher supply of air causes to increase the oxygen concentration in the furnace. Figure 5 shows the oxygen concentration in the furnace. It is cleared from the figure that the concentration of oxygen for co firing is much more than the coal firing. Figure 6 shows the plots for the stack emissions for the coal firing and co firing boilers. The emissions in case of coal fired boiler are much more than the co-fired boiler. The biomass composition is different from the coal. Biomass has low sulphur contents, high nitrogen contents, high oxygen, high ash contents, high moisture and high volatile material. During combustion biomass emits fewer pollutants than coal. Due to low quantity of sulphur it produces very low quantity of sulphur gas which is a toxic gas. But in case of coal, it has high value of sulphur due to which it produces higher value of sulphur which harms the environment.

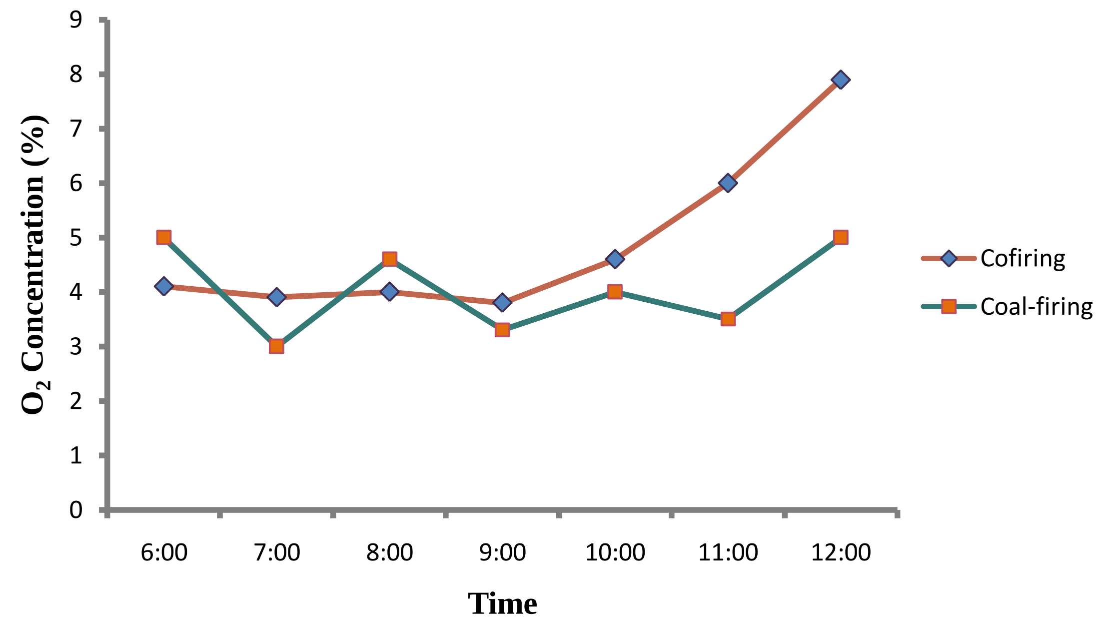

Figure 5: O_2 Concentration versus Time

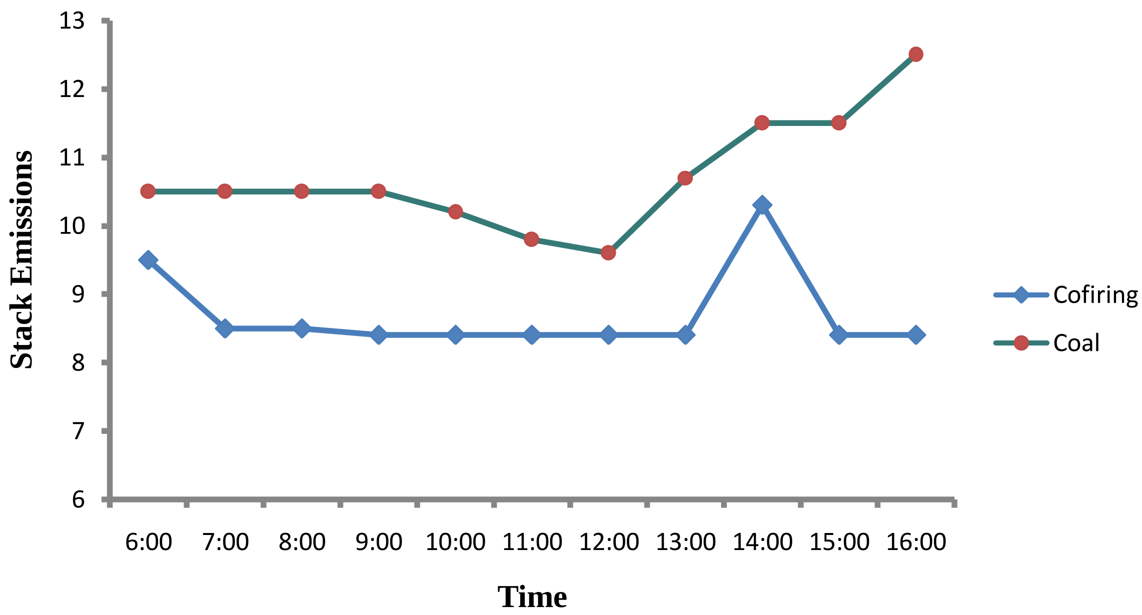

Figure 6: Stack Emissions versus time

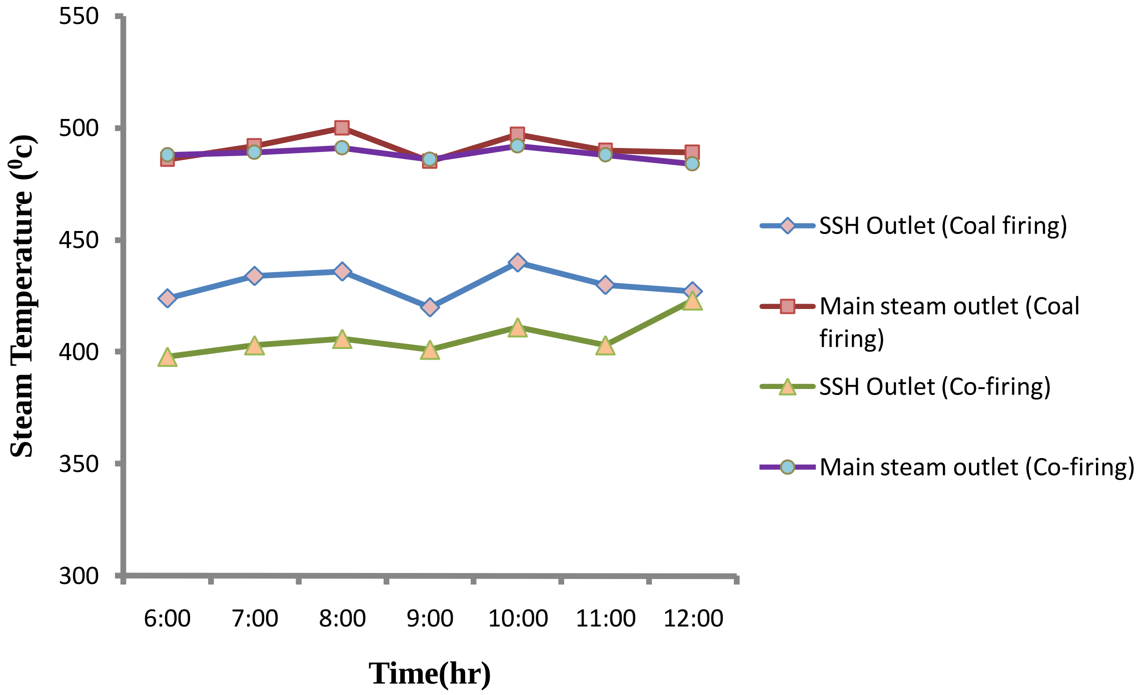

Figure 7 :Steam temperatures versus time

Figure 7. Shows the variations of different steam temperatures at different section of a boiler. Steam temperature has been measured at secondary superheater outlet and main steam outlet. It is cleared from the plots that the co firing and coal firing does not affect the boiler performance. There is slight variation in the
performance of boiler and combustion efficiency.

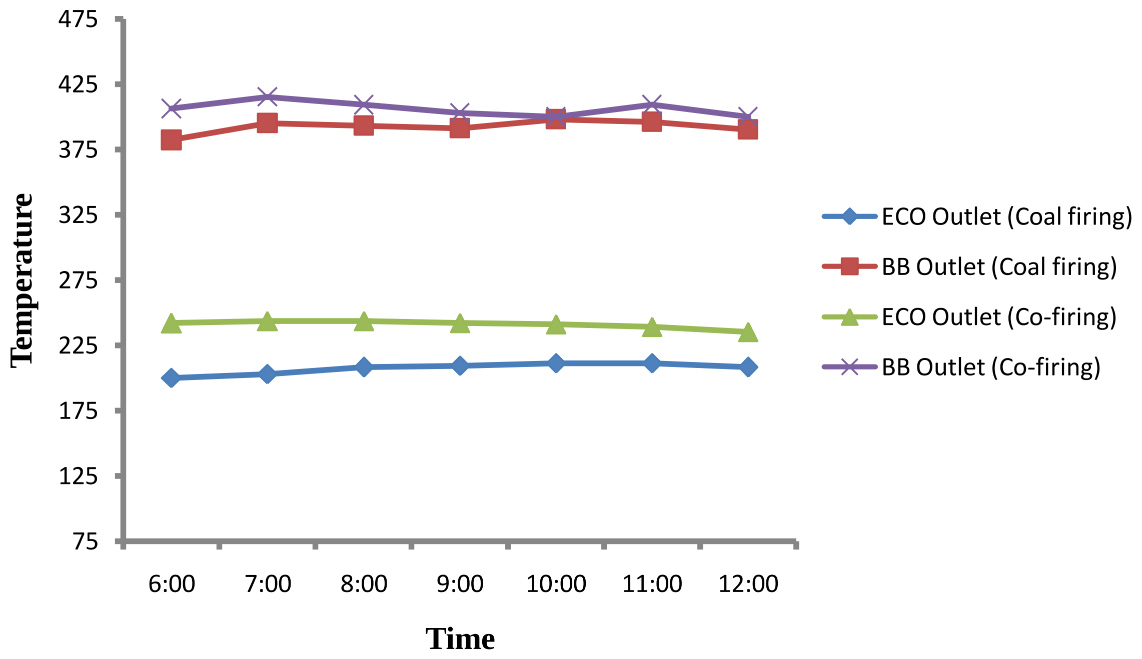

Figure 8: Flue gas temperatures versus time

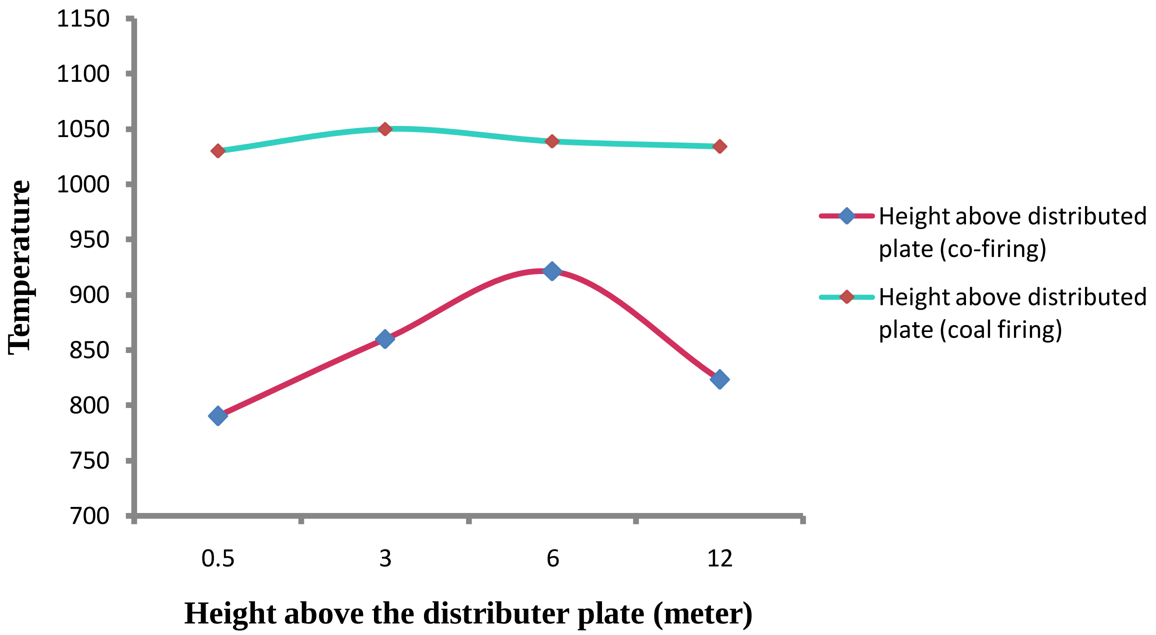

Figure 9 :Temperature along the height of the furnace

At secondary superheater outlet there is a difference in the temperatures of the steam but at main stream outlet the temperature of steam for both the coal and co fired is almost same. Figure 8 shows the flue gas temperature for both the coal firing and the co firing at economizer outlet and convection bank. The heat generated by the combustion of fuel in the furnace is taken by the superheated coils for steam production and the rest is taken over by the flue gases. In case of co firing the furnace temperature is low as compared to coal firing, so the amount of heat which is taken over by flue gases is low in case of co firing. Figure 9 shows the change of temperature profile along the height of the furnace for the combustion of coal and co-firing. The first thermocouple TC1 gives the lowest temperature due to the cooling effect of air. The temperature has increased along the bed height and then decreases along the free board after reaching a maximum value. Due to high volatile matter content the combustions of volatile matter take place in free board region. So the temperature reaches to about 921°C. The bed temperature for the combustion of coal is higher than the bed temperature for co-firing.

5. Conclusions

1. The bed temperature remains lower in case of co-firing than coal due to which low emissions of NO_x and other green house gases are observed.
2. Biomass has less sulphur contents and the coal used at the CPP is also having less sulphur concentrations, so the SO_2 formation remains within the permissible limits.
3. Co-firing required more excess air than coal firing because biomass has high volatile content which burnt in free board region. So the furnace area required for the combustion of biomass remains more than the coal firing.
4. The overall performance of boiler in case of coal firing and co-firing is almost same.

REFERENCES

1. Agraniotis. M., Stamatis P., Kakaras. E, 2010, “Dry lignite cofiring in a greek utility boiler: experimental activities and numerical simulations”, Energy Fuels, 24, pp. 5464-5473.

2. Arvelakis. S., Gehrmann. H., Beckmann. M., Koukios. E.G, 2002, "Effect of leaching on the ash behavior of olive residue during fluidized bed gasification", Biomass and Bioenergy, 22, pp. 55–69.
3. Demires. A, 2005, "Biomass cofiring for boilers associated with environmental impacts", Energy sources, 27, pp. 1385-1396.
4. Gorkem. K., Morali. E.M., Nevin. S, 2010, "Mathematical Modeling of a Bubbling Fluidized Bed Combustor Cofiried with Lignite and Biomass", Combustion Science and Technology, 182, pp. 600-612.
5. Indian Network for Climate Change Assessment (INCCA), India, 2010: Greenhouse gas emissions, Ministry of Environment & Forests, India
6. Kaushal. P., Tobias. P., Hermann. H, 2007, "Model development and validation: Co-combustion of residual char, gases and volatile fuels in the fast fluidized combustion chamber of a dual fluidized bed biomass gasifier", Fuel, 86, 2687-2695.
7. Kaynak. B., Huseyin. T., Aysel A.T, 2005, "Peach and apricot stone combustion in a bubbling fluidized bed", Fuel Processing Technology, 86, pp. 1175-1193.
8. Khan. A.A., Jong W. de, Jansens. P.J., Spliethoff. H, 2009, "Biomass combustion in fluidized bed boilers: Potential problems and remedies", Fuel Processing Technology, 90, pp. 21-50.
9. Kumar. H., Mohapatra. S.K., Singh. R.I, (2015), "Study of a 30 MW Bubbling Fluidized Bed Combustor Based on Co-Firing Biomass and Coal", Sadhana – Indian Academy of Sciences (Article in Press).
1. Jose. P., Pascual. A, 2011, "Bubbling Fluidized Bed (BFB), When to use this technology", Industrial Fluidization SA, pp. 1-12.
2. Rao K.V., Srinivasa. N., Reddy. G.V, 2011, "The Fluidized Bed Combustion of Groundnut Shells for Energy Recovery", Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 33, pp. 833-844.
3. Murat. V., Aysel. A.T, 2007, "Combustion of olive cake and coal in a bubbling fluidized bed with secondary air injection", Fuel, 86, pp. 1430-1438.