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Cofiring of Coal and Biomass in a Travelling Grate Boiler in India

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Abstract: Concerns regarding the potential global environmental impacts of fossil fuels used in power generation and other energy supplies are increasing worldwide. One of the methods of mitigating these environmental impacts is increasing the fraction of renewable and sustainable energy in the national energy usage. A number of techniques and methods have been proposed for reducing gaseous emissions of NO_x, SO_2 and CO_2 from fossil fuel combustion and for reducing costs associated with these mitigation techniques. Some of the control methods are expensive and therefore increase production costs. Among the less expensive alternatives, cofiring has gained popularity with the electric utilities producers. The present study discusses about the emission characteristics namely NO_X, SO_2, suspended particulate matter and total cost of fuel from a 18.68 MW power plant with a travelling grate boiler, when biomass was cofired with bituminous coal in 3 proportions of 20, 40 and 60%, respectively by mass. Bagasse, wood chips (Julia flora), sugarcane trash and coconut shell are the biomass fuels cofired with coal in this study.

Key words: Cofiring, biomass, emissions, NO_x, SO_2, CO_2

INTRODUCTION

With the present major worldwide agenda to reduce greenhouse gas emissions, the emphasis is on conventional coal-fired utilities to burn renewable fuels such as biomass residues or energy crop-derived biomass fuels as a low-cost option for reducing greenhouse gas emissions. The need for finding new renewable sources of energy together with the necessity of searching new technologies to reduce the negative impact of waste accumulation has led to the possibility of using biomass as an alternate fuel. Most of the industrial sources of pollution come from coal fired power plants which necessitate the need to find ways to decrease the greenhouse gas emissions from these sources. Also, the ratification of the Kyoto Protocol would need countries to implement measures to meet Kyoto standards by 2008. One of the options that need to be considered is the application of cofiring technologies to coal fired power plants.

Cofiring is the simultaneous combustion of a supplementary fuel with a base fuel. Selectively, utilities and independent power producers have used biofuels, particularly wood waste to generate electricity in small stand alone generating stations with less than 50 MWe capacity. In more recent years, utilities have become interested in cofiring biofuels with coal and other fossil fuels, applying wood wastes and other solid forms of biomass to high efficiency, higher capacity generating plants (Ekmann *et al*., 1998; Harding and Adams, 2000; Ross *et al*., 2002; Sami *et al*., 2001; Skodras *et al*., 2002). Initially, cofiring was seen as a means for reducing greenhouse gas emissions from fossil energy generation. Biomass cofiring with coal is proving to be the cheapest method for generating green power in utility plant demonstrations (Battista *et al*., 2000; Changqing *et al*., 2002; Ekmann *et al*., 1998; Hughes and Tillman, 1998; Hus and Tillman, 2000; Leckner, 1999; Tillman, 2000; Gold and Tillman, 1996). Those savings come not only from replacement of coal, but also from displacement of materials being sent to landfill, that ultimately decompose and form both CO_2 and another more powerful greenhouse gas: namely methane.

India is relatively well endowed with both exhaustible and renewable energy resources. Coal, oil and natural gas are the three primary commercial sources of energy. Over the years, there has been a significant change in the pattern of supply and consumption of energy. The share of commercial fuels in the total energy supply in India has risen from 41% in 1970-71 to approximately 70% in 2003-04 (Central Electricity Authority, 2003), despite the dominance of the traditional fuels in the energy sector in

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India. The total domestic primary commercial energy supply in India has risen from 147.05 MTOE (Million Tonnes of Oil Equivalent) in 1970-71 to 248 MTOE in 2003 (Coal Directory of India, 2003-04). There exists a potential for generating about 1500 MW of power from the urban and municipal wastes and about 1000 MW from industrial wastes in the country (Ministry of Nonconventional Energy Sources, 2004-05; Energy Data Directory, 2003-04). The potential for expanding the use of Biomass Energy Technologies (BETs) for energy generation is vast in India and awaits further exploitation. In this context, biomass cofiring and its applicability to Indian power production, will be a great boost to the power producers, environmentalists and all concerned.

The present research carried out, discusses gaseous emissions and particulate matter measured, when a 18.68 MW traveling grate boiler is used to cofire a combination of coal and different types of biomass.

PLANT DESCRIPTION

A study to measure cofiring emission characteristics is done in a 18.68 MW power plant, situated in Virudachalam district of Tamil Nadu, the southern most state of India. This plant is a cogeneration plant, attached to the sugar mill. The plant has been generating power to meet its own requirements and the rest is being given to the main grid. The boiler is provided with two fuel feeder routes, one each for coal and biomass. Coal feeding is done from a height of 8 m and biomass from a height of 9.8 m above the base. The maximum amount of steam generation from the plant has been kept at 70 tonnes h^{-1} for the tests conducted. The generated steam has a maximum temperature and pressure of 485°C and 65 kg cm^{-2}.

Boiler specifications: The pressure and temperature rating of our boiler is as follows:

- Design pressure of boiler : 51 kg cm^{-2}(g)
- Working pressure of boiler : 42 kg cm^{-2} (g)
- Boiler temperature : 256°C
- Boiler super heater outlet steam temperature : 410 +/- 15°C
- The Total heating surface of our boiler : 3396 m^2.
- The size of the travelling grate is 3842 mm wide × 5664 mm long : 2 No's.
- The speed of the travelling grate : 0.027 rpm to 0.27 rpm.

FUEL CHARACTERIZATION

Bituminous coal, lignite, bagasse, wood chips, sugarcane trash and coconut shell are the fuels used for the tests. The proximate and ultimate analysis were carried out for all the fuels and the results are presented in Table 1. It should be noticed that, in comparison to the primary fuel (coal), biomass contains much less carbon and more oxygen. With regard to the ash content, values for biomass are much lower that for coal. Bituminous coal, which costs Rs. 3000/tonne, was mixed with lignite abundantly available in the state of Tamil Nadu, but inferior quality than bituminous coal. Biomass materials which were required for cofiring tests, were procured from the neighboring areas, whose cost varies from Rs. 700 to Rs. 900 per tonne.

Table 1: Proximate and ultimate analysis of fuels on (%) weight basis

Parameter	Bituminous coal (%)	Wood chips (%)	Sugarcane trash (%)	Coconut shell (%)	Bagasse (%)	Lignite (%)
Moisture	5.55	7.00	4.00	6.50	50.00	48.50
Ash	34.00	0.37	1.75	6.50	1.50	7.00
Carbon	44.14	48.80	49.00	49.75	23.50	29.06
Fixed carbon	34.50	38.11	38.27	38.85	18.35	22.69
Hydrogen	3.23	6.37	5.89	5.80	3.25	2.35
Sulphur	0.59	0.00	0.00	0.05	0.00	0.50
Oxygen	11.58	44.40	43.36	36.70	21.75	12.31
Nitrogen	0.91	0.00	0.00	1.20	0.00	0.28

Fuel handling prior to feeding: The type and extent of the necessary preparation of the biomass fuels depend on the combustion system and the type of biomass. In general, bituminous coal mills are not suitable for biomass. Therefore, separate biomass milling and feeding devices were required. The raw coal, procured was around 165 mm to 185 mm in length. It was milled down to around 20 mm length by the use of crushers. Due to the fibrous structure of the biomass materials used in our tests, it was difficult to determine an exact particle size distribution. The biomass materials were milled to the required dimension of 70 mm length and 15 mm thickness by the use of fibrizers. The biomass was fed in to the boiler by screw feeders.

COFIRING TESTS

Methodology: Cofiring tests were conducted in the plant, with various combinations of biomass fuels in different proportions. The fuels were fed in to the boiler through conveyors which carry about 8-10 tonnes h^{-1} of fuel. The mass of secondary air supplied varies from 14% to 25% of the total air supplied. The temperatures and pressures were measured at various points along the path of flue gases. The gaseous emission tests were conducted at the stack. Emission tests were conducted in two phases. In the first phase, bituminous coal, lignite, bagasse, woodchips, sugarcane trash and coconut shells were fired individually (100%), to generate 70 tonnes h^{-1} of steam. In the second phase of testing, each of the above mentioned biomass fuels, were fired in three proportions namely 20, 40 and 60% by mass with bituminous coal, to generate 70 tonnes h^{-1} of steam.

RESULTS AND DISCUSSION

Following are the results derived from the various tests conducted in a 18.68 MW power plant.

SO_2 Emissions: The cofiring of biomass with coal clearly reduces SO_2 concentrations at high mixing ratios as typified in Fig. 1. It can be seen that from Fig. 1, the SO_2 emission is the lowest for coal : wood combination and for a 40:60 proportion, with a decrease of around 50%, in comparison to 100% bituminous coal only firing. The figure also indicates clearly, the drastic reduction in SO_2 emissions as the biomass proportion is increased. Reductions up to 7-12% are obtained at 60% biomass fractions. This is done mainly to the dilution effect as the biomass contains negligible sulphur. Most forms of biomass contain very small amounts of sulfur. Therefore a biomass based power plant emits very little SO_2. The amount of SO_2 reduction depends on both the percentage of heat obtained from biomass and the sulfur content of the coal. In the earlier studies of cocombustion of coal and waste such as wood waste, sewage sludge and biomass (Changqing *et al*., 2002; Desroches Ducarne *et al*., 1998b; Ekmann *et al*., 1998; Spliethoff *et al*., 1999; Suksankraisorn *et al*., 2004), it has been found that the waste addition resulted in SO_2 reductions because of sulphur retention in the ash.

NO_X emissions: As can be seen, the NO_x emission is the lowest for coal :wood combination for a 40:60 proportion (Fig. 2). The decrease in NO_x emissions is best for the above fuel combination and proportion, with a decrease of around 45% for NO_x, in comparison to 100% bituminous coal only firing. The NO_x emissions, reduces as the percent of biomass is increased during co-firing with coal. This is due to the volatile products present in the biomass particles and the reduction reactions that cause the decrease of NO_x are promoted. The combustion of volatile products surrounding the biomass particles takes place and the reduction reactions that cause the decrease of NO_x are promoted. Studies by researchers Changqing Dong *et al.* (2002), Desroches Ducarne *et al.* (1998a, b), Hein and Bemtgen (1998), Leckner (1999), Mukadi *et al.* (2000) have shown that the decrease of NO_x takes place with the increase of biomass proportion. Mostly, NO_x emissions were dependent on the operating conditions and were not affected by the nitrogen content of the fuel mix. This characteristic is clearly visible in our experiments, as shown in Fig. 2.

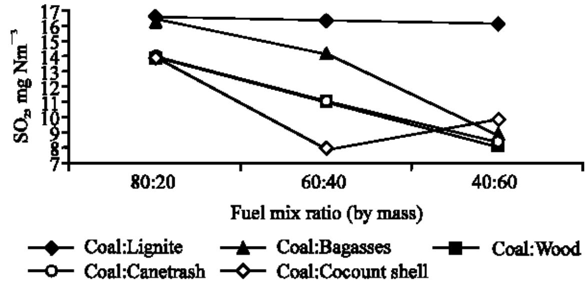

Fig. 1: Variation of stack emissions SO_2 for different cofired fuel combinations and for various proportions of fuel blends. Note: For 100% coal firing, SO_2 value is 16.7 mg Nm^{-3}

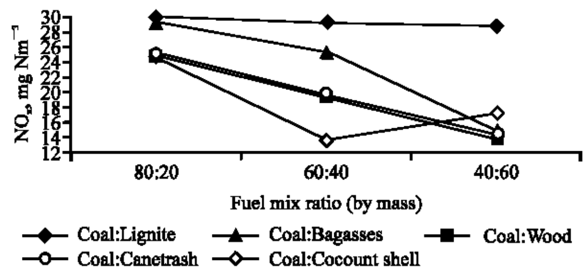

Fig. 2: Variation of stack emission NO_x for different cofired fuel combinations and for various proportions of fuel blends. Note: For 100% coal firing, NO_x value is 30.3 mg Nm^{-3}

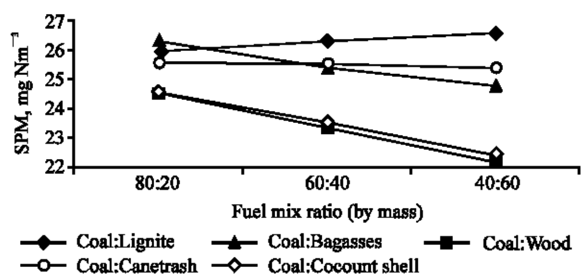

Fig. 3: Variation of stack emission SPM for different cofired fuel combinations and for various proportions of fuel blends. Note: For 100% coal firing, SPM value is 25.7 mg Nm^{-3}

SPM emissions: It can be seen that from Fig. 3 that, the SPM emission is the lowest for coal : wood combination for a 40:60 proportion. The decrease in SPM emissions is best for the above fuel combination and proportion, with a decrease of around 14% for SPM, in comparison to 100% bituminous coal only firing. It is also clear that, the increase in biomass share resulted in a decrease of the concentrations of the particulate matter entrained in flue gas. It was found that our results also matched well

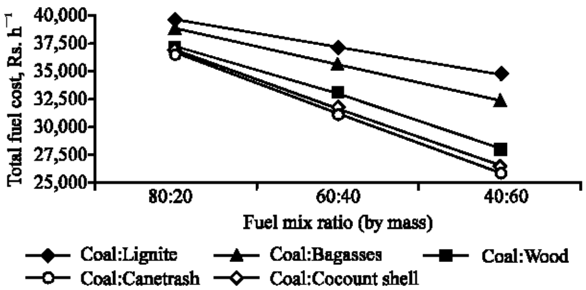

Fig. 4: Variation of total fuel cost of various cofired fuel combinations and for various proportions of fuel blends. Note: For 100% coal firing, total cost is Rs 42, 000 h^{-1}

with the studies conducted by earlier researchers (Mukadi *et al*., 2000; Wolski *et al*., 2004).

Total cost of fuels: The total cost of fuels required to generate 70 tonnes h^{-1} of steam has been found to decrease as shown in Fig. 4. The lowest cost requirements for the fuels, has been found to be for coal and sugarcane trash combination and for a 40:60 proportion, which is Rs. 25,800 h^{-1}, a reduction of around 40% in comparison to coal only firing, which is Rs. 42,000 h^{-1}. The greatest cost is for coal and lignite combination, for 40:60 proportion, which is Rs. 34,685 h^{-1}, a reduction of around 18% from coal only firing.

CONCLUSIONS

The future of coal and biomass blend cofiring in utility boilers looks very bright. Based on the positive results of recent cofiring studies conducted across the globe, coupled with more strict environmental regulations and associated penalties, utilities are seriously considering cofiring locally available biomass fuels with coal in their boilers. In addition, many countries like United States, Denmark, UK have made using a percentage of biomass mandatory for electric utilities.

Cofiring biomass fuels with coal has the capability to reduce both NO_x and SO_2 levels from existing pulverized coal fired power plants. In addition, overall CO_2 emissions can be reduced because biomass is a CO_2 neutral fuel. However, cofiring technology faces some technological problems.

The outcome of the present study can be summarised as follows:

- Within the range of experimental conditions tested, it has been observed that, the optimum proportion of fuels, for cofiring of biomass with coal in view of SO_2, NO_x and SPM is 60% biomass fraction and 40% bituminous coal. Taking in to account, all the earlier parameters for deciding on the optimal fuel combination and proportion and economics of operation, in such a way, that the power producers are benefited largely, it has been found that the coal: wood chips combination for a 40:60 proportion, is the best optimal choice for cofiring for this plant and under the given conditions. The reasons for choosing this fuel blend and proportion, is because wood is available in plenty in the area around the plant site and has better calorific value and the blend has better characteristics as explained earlier. The second best choice, would be coal:coconut shell for a 40:60 proportion.
- This cofiring method of power generation also results in more revenue, when supplied to the main power grid. The Tamil Nadu state Government purchases the power from such producers who use biomass as a fuel along with coal at the rate of Rs.3.15/kW as compared to Rs. 3.00/kW when only coal is used for power generation.

Following are the areas which requires a lot of investigation, to be done to make the cofiring technology commercially viable option for the power producers in India.

- The issue of combustor fouling and corrosion due to the alkaline nature of the biomass ash needs attention. Ash deposits reduce the heat transfer and may also result in severe corrosion at high temperatures. Compared to deposits generated during coal combustion, deposits from biomass materials are denser and more difficult to remove
- The maximum particle size of a given biomass that can be fed to and burned in a given pulverized coal boiler through a given feeding mechanism requires additional studies. However, this issue is a combination of economics and combustion characteristics and more work needs to be done in this area.
- Fundamental combustion studies must be performed, particularly for premixed coal and biomass fuel blends, in order to determine combustion behaviour characteristics in controlled laboratory settings. Interactions between biomass and coal particles is an area in particular need of study.

Despite all the issues and concerns, cofiring technology appears to be a promising one for electric utilities, cofiring has moved from engineering studies to parametric tests to long term demonstrations. Future long term demonstrations, will address many of the issues mentioned above and will help in making the cofiring technology easily available to the industry at an optimal cost.

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