Emissions of NOx from Fast Fluidized Bed Combustor Burning Wheat Straw with Coal

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Abstract

Large quantities of biomass residues are produced from the agricultural and wood products industries that could also provide fuel for electricity production and could alleviate the burdens and environmental consequences of waste disposal. Use of biomass in coal-fired power plants results in high efficiencies and fuel diversity. Co-firing biomass and coal is also a viable way to manage the increasing emissions of greenhouse gases and other pollutants from power generating facilities. The effect of operating parameters on the NOx formation and reduction in a fast fluidized bed combustor burning wheat straw and coal are reported in this paper. Combustor is a pilot scale test facility with 6m height and 0.152m diameter at Fluidized Bed Combustion Laboratory University of the Punjab, Lahore. Experimental investigations were done to see the effect of temperature, excess air ratio, total air split ratio etc. on the NOx formation for different fuel blends. Emissions of NOx were found to increase with the increased bed temperature, excess air ratio, Ca/S molar ratio while total air split, higher wheat straw ratio had reducing tendency on the NOx formation.

Introduction

Now a days world is moving towards the green energy options after the environmental concerns of the conventional energy sources. In UK utilization of the fossil fuels will be replaced with renewables by 10% up to 2010 and 20% up to 2020 [1]. According to the power generation plan in Pakistan renewable share will increase from 0.92% in 2005 to 3.5% in 2015 [2]. Among these renewable, sustainable grown biomass is viable replacement option. Biomass is considered as CO2 neutral fuel and CO2 emissions from coal fired power plants can effectively be reduced by co-firing this biomass with coal. In Asia wheat is the commonly cultivated crop and huge amount of wheat straw is available specially in Pakistan.

Wheat straw with the heating value around 17MJ/kg is becoming more attractive for heat and power generation. Combustion is the most effective technology for thermo chemical conversion of biomass [3]. CFB technology offer great fuel flexibility and can be utilized for co combustion in an economical way [4]. About 1200 CFBC plants with installed capacity of 65GWth are in operation worldwide [5]. Super critical power plants are also being built based on the CFBC technology [6]. Existing CFBC plants can be operated on co-combustion with minor modifications etc. in the feeding system [4]. Along with reduction of CO2, biomass also reduces NOx, SO2 and CO emissions in co-combustion with coal [7-9].

Gaseous emissions from co-firing seems to be the function of operating conditions in cyclonic fluidized bed combustor [10]. The objective of the present study is to investigate the significance of operating conditions like bed temperature, excess air ratio, Ca/S molar ratio, superficial gas velocity, solid circulation rate and primary air split ratio on the destruction and formation of NOx in FFBC burning coal and biomass in different ratios.

Experimental

FFB combustor used in this investigation is shown in Fig.1. The system comprised of a riser of 0.161 m i.d. and 6.2 m height, two high efficiency cyclones in series, an external heat exchanger (EHE) and an L-valve. The whole system was made of stainless steel and insulated with kao wool from outside. Primary air was supplied at the riser bottom through an air distribution plate, while secondary air was injected through opposing injectors located 1.83m above the primary air distribution plate. Both primary and secondary air were supplied by roots blower and controlled via frequency inverter. Solids entrained by the flue gases from the riser were collected by the primary cyclone and fed to the EHE via a dip leg. Solids were returned to the riser through the L-valve at a controlled rate. The coal and wheat straw were supplied from a gravimetric hopper with a screw feeder coupled with variable speed motor. The fuel was pneumatically injected into the combustor (30cm above the air distribution plate). Temperatures around the system were monitored by K-type thermocouples. The temperature in the riser was controlled by adjusting the heat transfer surfaces (i.e. the stainless steel tubes) of the EHE immersed in solids, thus controlling the temperature of the recycling particles. For the experimental runs studied, variations in temperature over the riser height were <50K.

Lakhra coal was used in all the experiments. The coal was reduced to particles with a sauter mean diameter of 0.6mm. Silica sand, having a sauter mean diameter of 120 micron with bulk density of 2500kg/m^3, 0was used as the main circulating material. Wheat straw having a Sauter mean diameter of 175 µm was used. Proximate and ultimate analyses of the fuels are given in Table 1.

Gas concentrations of O2, NO and NO2 were measured using analyzers PEM 9002 and Testo 350.

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Table 1. Analysis of fuel samples

Proximate Analysis (%)		
Parameter	**Coal**	**Wheat straw(db)**
Moisture	1.05	-
Fixed Carbon	38.90	10.98
Volatile Matter	43.53	82.12
Ash	16.53	6.9
Ultimate Analysis (%)		
Carbon	68.90	42.95
Hydrogen	9.8	5.35
Nitrogen	0.56	0
Sulfur	4.2	-
Oxygen	16.54	46.99
Heating value (MJ/kg)	25.55	17.98

A. Effect of Wheat straw Ratio

Different blends of wheat straw and coal were combusted in experiments at 20% excess air and bed temperature of 00oC. Results are shown in Fig.2. NOx emissions are mainly from fuel bound nitrogen at low temperatures in fluidized beds [11]. As compared to the coal, wheat straw has lower nitrogen content so co-firing results in reduction of NOx emissions because the decreased net nitrogen contents in the fuel blend. But it was found that NOx reduction is more than that based on the net fuel nitrogen contents. High volatile contents of straw are released earlier and mostly in the form of NH3.

Released NH3 act as reducing agent with NOx to form N2. Also the high volatile content of straw can effectively establish a fuel-rich zone in the flame that can reduce NOx emissions.

B. Effect of Bed Temperature

With the increase in bed temperature, NOx was observed to increase in the co-combustion case. Bed temperature was varied from 780 ^{o}C to 940 ^{o}C by keeping the secondary to primary air ratio constant at 0.35. Results are shown in Fig. 3. With the increase in temperature, NOx increased proportionally. [12] found the similar trends of biomass alone combustion in Bubbling Fluidized Bed Combustor. The results are in agreement with [13-14].

C. Effect of Excess Air Ratio

Excess air was varied from 10% to 25% during the experimental runs by keeping the other parameters constant. Results are shown in Fig. 4. NOx emissions increased with the increase in excess air. Similar behavior was observed by other researchers[10, 12].However [8] observed a decrease in NOx emission by increasing the excess air during combustion of biomass in circulating fluidized bed combustor.

D. Effect of Solid Circulation Rate

By increasing the solid circulation rate, NOx was observed to decrease. Solid circulation rate was varied from 11.42 o 40Kg/m2.sec during the experiments. Results are shown in Fig. 5. By increasing the solid circulation rate voidage in the riser of the combustor was reduced and suspension density increased. So more inventory of char particles ere present which caused the reduction of NO to N^2.

E. Effect of Ca to S Molar

Ca/S molar ratios were varied from 1 to 3 during the experimental runs. By increasing the Ca/S molar ratio, NOx was observed to increase. Results are shown in Fig. 6. It was due to the reason that limestone particles catalyze the oxidation of nitrogen to NO and NO2. So more lime particles in the combustor resulted in more NOx formation. Similar behavior in circulating fluidized bed combustor was reported by [15].

F. Effect of fluidizing velocity

Fluidizing velocity was varied from 5 m/sec to 6.2 m/sec keeping the excess air at 20% and secondary to primary air ratio at 0.35. With the increase in fluidizing velocity, higher emissions of NOx was observed. Results are shown in fig. 7. With increased fluidizing velocity, intense mixing of volatiles and rising gas(mainly oxygen) in the combustor resulted in more oxidation of nitrogen to its oxides. These results are similar to [7, 16] for combustion in circulating fluidized bed. [12] also found the same behavior for biomass combustion in bubbling fluidized beds.

G. Effect of Secondary Air Ratio

Air staging is usual practice in fluidized bed combustion to control NOx. Secondary air to primary air ratio was varied from 0.2 to 0.35 to investigate its effect in co-combustion case by keeping the bed temperature at 800oC and excess air ratio at 20%. Results are shown in Fig. 8. A decrease in NOx emissions was observed with the increase in secondary air ratio. Secondary air was injected at a height of 433mm. However [15] observed an increase in NOx concentration after increasing the secondary to primary air ratio beyond certain value and suggested an optimum value for a circulating fluidized bed combustor to be operated at minimum concentration of NOx.

Conclusion

Co-combustion experiments of coal with wheat straw were performed in fast fluidized bed combustor at different set of operational conditions. Emissions of NOx more lime particles in the combustor resulted in more NOx formation. Similar behavior in circulating fluidized bed combustor was reported by [15]. Figure 6. Emissions of NOx as a function of Ca/S molar ratio were found to decrease by increasing the wheat straw ratio in the fuel blend. Wheat straw having more volatiles produced fuel rich conditions which resulted in NOx reduction. Also the NOx emissions were found to decrease by decreasing the bed temperature, excess air ratio, Ca/S molar ratio and by increasing the solid circulation rate, fluidizing velocity and air split ratio.

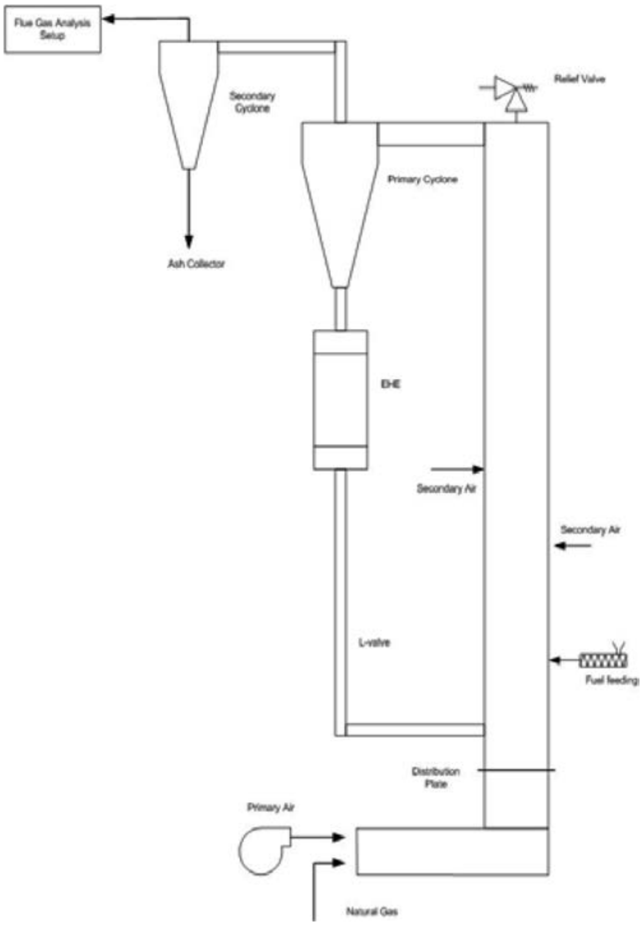

Fig. 1. Fast fluidized bed combustor used in this study

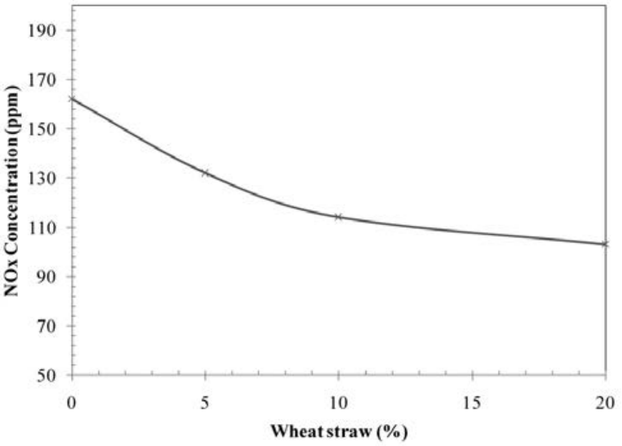

Fig. 2. Emissions of NOx for different coal and wheat straw ratios

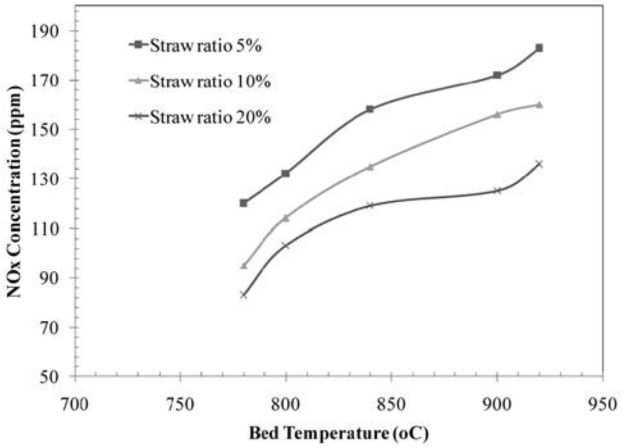

Fig 3. Emissions of NOx as a function of bed temperature

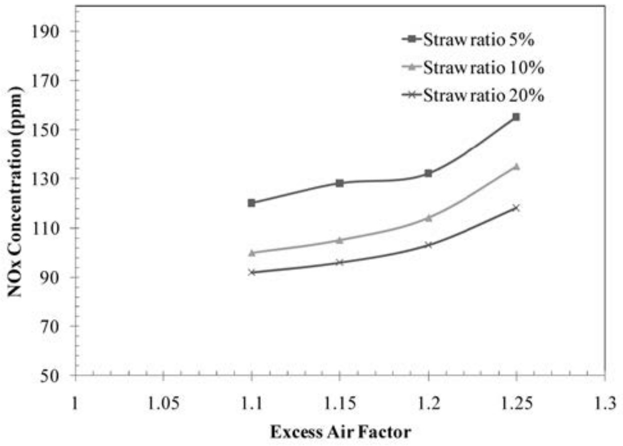

Fig. 4. Emissions of NOx as a function of excess air

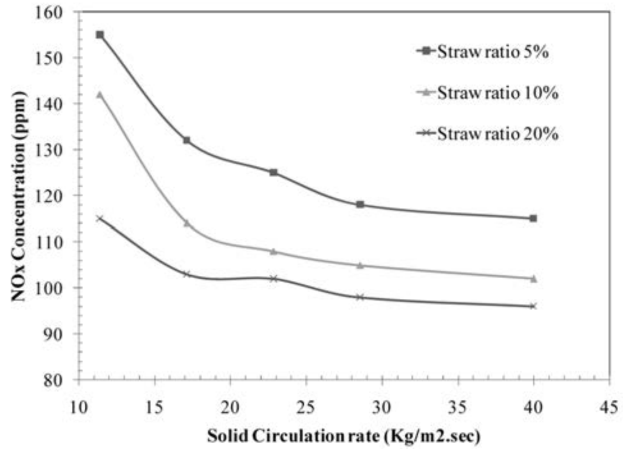

Fig. 5. Emissions of NOx as a function of solid circulation rate

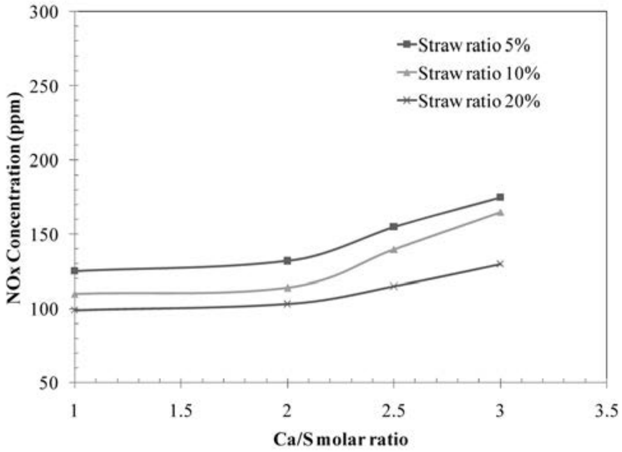

Fig. 6. Emissions of NOx as a function of Ca/S molar ratio

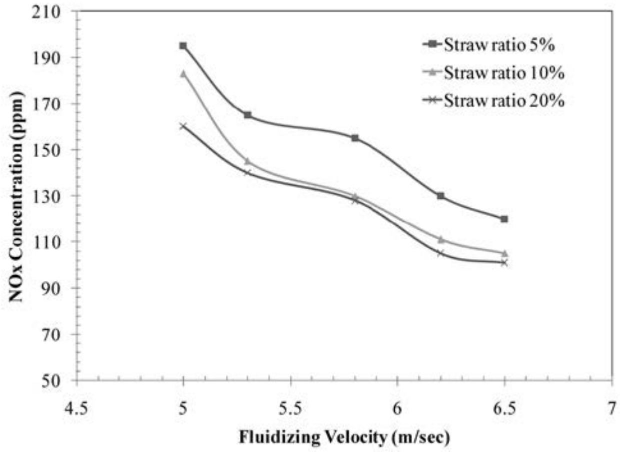

Fig. 7. Emissions of NOx as a function of fluidizing velocity

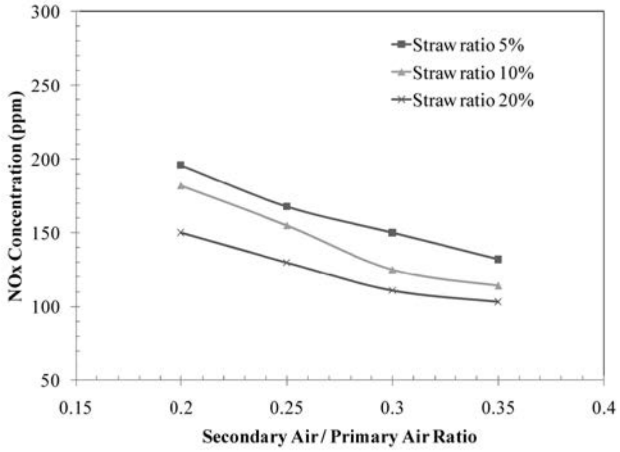

Fig. 8. Emissions of NOx as a function of air split ratio

Thus wheat straw can be utilized as a renewable energy source for heat and power generation, as well as for the reduction of NOx emissions.

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