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# Behaviour of Lakhra Lignite in Atmospheric Fluidized Bed Combustion (AFBC)

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Results of studies carried out on the combustion of Lakhara lignite in Atmospheric Fluidized Bed Combustor (AFBC) are presented. Investigations cover some of the aspects of combustion including ash and environmental monitoring. It has been concluded that AFBC of lignitic coals is safe if sulphur content of coal is less than 4% as there is an optimum limit of addition of $CaCO_3$ as sorbent. It is important for the combustor designer to keep in mind about the burning rates, burn-out times and temperature of char particles which may create some problems during heating.

***Key words:*** Lignitic coals, Combustion, Burning rates, Power generation.

## Introduction

There are over 185 billion tonnes of coal deposits in Pakistan of which largest reserves are in Thar, Sind (Economic Survey, 1998-99). This huge quantity of coal may not be ignored and let dormant for indefinite periods. Presently Lakhra coal fields are the largest productive coal fields of Pakistan as Thar and Sonda-Thatta are not exploited on commercial scale as yet.

Coal inspite of its environmental hazards and threats, is the largest economically feasible source of energy. In USA, China and India, energy is still produced from combustion of coal. Pakistan have two coal based power plants at one is 15MW Sor-Range coal fired power plant at Quetta and other one is three units of 50MW each Atmospheric Fluidized Bed Combustion (AFBC) based power plant at Khanot, Sind using Lakhra lignites for generating power from indigenous coal. However, there are some technical problems for the smooth operation of for power generation. Keeping in view of utilization of indigenous source of coal energy. Some studies were carried out on the combustion of Lakhra lignites. This paper describes the combustion of Lakhra lignites using AFBC of coal which is an established technique for the combustion of mineral coals.

## Experimental

*Material.* Commercial limestone was used and calcined in an oven at 850°C to check its purity for trap of sulphur of coal during combustion. Sand was used as bed material to transmit heat to coal through convection till suitable temperature was achieved. Lakhra lignites were used for these studies.

Ultimate analysis of coal has been carried out of LECO CHN-600 of USA. Proximate estimation were made on Mac-400, LECO, USA. Heating value of Lakhra lignites were determined on PARR Oxygen Adiabatic Bomb Calorimeter of USA. Sulphur was estimated on Sulphur Determinator S-132 LECO of USA. Limestone was calcined in an oven at 850°C for checking its purity. XRF estimations of ash and fly ash were accomplished on 0700 KEVEX, XRF, USA.

*Procedure.* Lakhra lignites and limestone were crushed to-60 mesh. The combustion was accomplished in Fluidized Bed Combustor having inside lining of insulation with an arrangement of air blowing from the bottom as shown in the Fig 1. Two metallic containers were incorporated for supplying coal and limestone separately over the bed. The Fluidized Bed was heated and temperature was maintained at 400°C using natural gas as fuel. The crushed coal and limestone in the ratio 5:2 were allowed to transfer to the Fluidized Bed. Due to combustion of coal, the temperature abruptly raised to 800°C and was maintained by circulating water for avoiding agglomeration and decomposition of $CaSO_4$ formed due to the reaction between sulphur of the coal and limestone. The fly gas was collected from AFBC for 0700 KEVEX, XRE analysis. The analysis of the gases produced during combustion of Lakhrara lignites, in AFBC were also accomplished for oxygen, CO, $CO_2$, $NO_x$, and hydrocarbons.

## Results and Discussion

Table 1 and 2 show that contents of ash, sulphur as well as the moisture and volatile matter are on higher side. These lignites are low grade, friable (brittle), very sensitive to sudden shocks and contain limited (< 4%) amount of lumps i.e. big pieces of 4 inch. Furthermore these lignites also undergo spontaneous combustion and lose heat potential during sudden combustion hence cannot be stored for a longer period. Besides, the washing of these coals is thermally unfavorable technically not possible and economically not feasible since

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sulfur is present in four forms. These lignites are generally used as such with limestone as sorbent. Winkler of Germany made efforts to overcome these drawbacks of lignitic coals and intorduced fluidized bed technique for gasification of coals (Felix 1986). Now the same method is modified for combustion of lignites for power generation. For Lakhra lignites high in ash and sulphur, this method is found useful for power generation. In this method limestone is used as sorbent. This method is known as Atmospheric Fluidized Combustion (AFBC). When limestone comes in contact with lignitic coals, limestone first of all decomposes into calcium oxide and carbon dioxide and the CaO reacts with $SO_2$ of coal produced during combustion in AFBC (see procedure). The reaction mechanism may be suggested (Merick 1984) as under.

$$CaO+SO_2+½O_2 \rightarrow CaSO_4 ............(1)$$

Two routes are suggested for the formation of $CaSO_4$, one is as under:

$$2SO_2+O_2+NO_x \rightarrow 2SO_3 + NO_x ...........(2)$$

Here nitrogen oxides ($NO_x$) act as catalyst for the oxidation of $SO_2$ to sulphur trioxide ($SO_3$). The sulphur trioxide thus combine with CaO forming $CaSO_4$.

$$CaO+ SO_3 \rightarrow Ca\,SO_4 ...........(3)$$

In the second route $SO_3$ combines with water vapour produced during combustion of coal forming sulfuric acid. ($H_2SO_4$).

$$SO_3 + H_2O \rightarrow H_2\,SO_4 ...........(4)$$

The sulfuric acid so produced reacts with CaO or $CaCO_3$ form $CaSO_4$ and water.

$$CaO + H_2SO_4 \rightarrow CaSO_4 + H_2O ...........(5)$$

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4+CO_2 + H_2O ...........(6)$$

The ash of AFBC is collected as fly ash through the cyclones and bag house. Table 3 includes the estimations of flue gases produced during combustion of Lakhra lignites in AFBC when temperature reaches to 800°C. It shows that there is no alkali metals. The agglomeration of ash is not observed. Environmental monitoring of emissions of AFBC shows reduction in sulphur dioxide and $NO_x$ contents in flue gases. The presence of $SO_2$, $NO_x$, CO and hydrocarbon are found respectively as 750, 255, 165 and 36 ppm.

In AFBC, natural gas is used for heating the fluidized bed. As soon the temperature reaches to 400-410, coal and lime stone in definite ratio are transferred to fluidized bed. The coal is ignited in the temperature range 300-400°C and lead to form carbon oxides (CO, $CO_2$), nitrogen ($NO_x$) and sulphur ($SO_x$).

$$Coal + O_2 \rightarrow CO + CO_2 + NO_x + SO_x ...........(7)$$

$$2CO + O_2 \rightarrow CO_2 ...........(8)$$

$$SO_x + O_2 \rightarrow SO_2 + SO_3 ..........(9)$$

$$S + O_2 \rightarrow SO_2 ..........(10)$$

**Table 1**

Ultimate (elemental) analysis of coal on moisture-ash free basis

| Element | Percentage |
|---|---|
| Carbon | 46.5 |
| Hydrogen | 6.9 |
| Nitrogen | 0.7 |
| Sulphur | 7.9 |
| Oxygen | 38.0 |

**Table 2**

Proximate analysis of coal

| Constituents | Percentage |
|---|---|
| Moisture | 21.1 |
| Volatile matter | 28.2 |
| Ash | 25.6 |
| Fixed carbon | 25.1 |
| Heating value (Btu/lb) | 7920 |

**Table 3**

Analysis of flue gases produced during combustion of Lakhra lignite in AFBC

| Flue gases | Quantity |
|---|---|
| Oxygen | 4.52% |
| Carbon dioxide | 14.62% |
| Sulphur dioxide | 750 ppm |
| Oxides of nitrogen | 255 ppm |
| Carbon monoxide | 165 ppm |
| Hydrocarbon | 36 ppm |

Due to combustion of coal the temperature of AFBC abruptly rises to 800°C and this temperature is maintained to minimize the chances of fusion of ash and agglomeration and to increase the quantity of fly ash which is collected through cyclones and bag house. Table-4 includes the comparative data obtained from the 0700 KEVEX, XRF analysis of ash of Lakhra lignites and fly ash from AFBC. Elimination of oxides of sodium and potassium and decrease in the percentage of other minerals helps in avioiding agglomeration and decomposition of $CaSO_4$ at 800°C. It also creates less environmental problems. The percentage of sulphur trioxide indicated in the analysis of ash and fly ash are given as 8.63 and 16.8 respectively. The increase in sulphur trioxide in fly ash compared to coal ash indicates the formation of calcium sulphate. The weight percent of calcium oxide in calcium sulphate is 41.18 and in fly ash (25.6 % see Table) percent of calcium oxide required for the formation of calcium sulphate should be 11.76. For the formation of $CaSO_4$, 16.8% of $SO_3$ looks like sufficient as indicated in Table 4. In other words limestone feed is enough to capture sulphur of coal. On the

**Table 4**

XRF Analysis of lakhra lignite ash and fly ash from AFBC

| Sample No. | Silica oxide % | Aluminium oxide % | Ferric oxide % | Titanium pentoxide % | Phosphorus oxide % | Calcium oxide % | Magnesium oxide % | Sodium oxide % | Potassium oxide % | Sulphur trioxide % |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Fly ash | 21.9 | 9.00 | 6.6 | 0.8 | 0.8 | 43.5 | 0.8 | 0.0 | 0.0 | 16.9 |
| 2. Fly ash | 21.3 | 9.10 | 6.9 | 0.8 | 0.8 | 44.1 | 0.8 | 0.0 | 0.0 | 16.5 |
| 3. Fly ash | 21.7 | 9.00 | 6.6 | 0.8 | 0.8 | 44.0 | 0.8 | 0.0 | 0.0 | 16.8 |
| 4. Lakhra lignite ash | 40.8 | 12.58 | 23.9 | 1.6 | 0.6 | 7.5 | 2.3 | 0.8 | 0.6 | 8.6 |

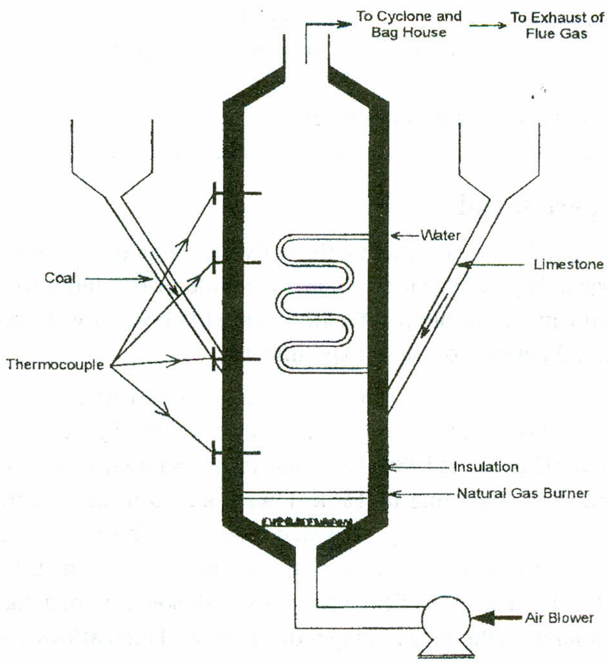


**Fig 1.** Atmospheric fluidized bed combustor.

basis of ash 0.26% of sulphur of capture coal is removed in fly ash. The rest of the sulphur is released either in flue gas (750 ppm-Table 3) or in bed material. As regards the contribution made by volatiles in coal to the performance of fluidized bed combustion system is concerned, it is not well understood yet. Volatiles are important because they account for a large fraction of the calorific value of some coals and much of their heat content is released above the bed (Broghton and Howard 1983) Hence it may be concluded that AFBC is a better technology to use Lakhra lignite for combustion as less environmental problems and better utilization of Pakistani coals. Amongst the benefits of the AFBC there are also some drawbacks which may be recovered easily. There is a possibility of hot sand blasting in the boiler tube which may be punctured or burst. Other possibility is the frequent damage of blowers blade. Forgetting better results, the requirement of lime stone should be calculated on the basis of sulphur content of coal by weight to weight ratio i.e. 3:1, keeping in mind the optimum limit of addition of lime stone in AFBC. Further more it is important for the combustor designer to know about burning rate, burn-out times and temperature of char particles. If char particle is greater than that of which the coal ash or bed inserts melt or becomes soft, then bed choking may occur. If the char particle temperature is low than the rate of oxidation of the char ash hence the rate of heat release by each particle is low and in order to sustain output a very large amount of char must be present in the bed. This raises problmes of control of temperature of bed (Botterill 1975).

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