Pak. J. Sci. Ind. Res. 2006 **49**(5) 341-343

Short Communication

Some Studies on the Changes in the Composition of Coal Ash and Bottom/Fly Ash Produced in Atmospheric Fluidized Bed Combustor

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(received October 26, 2004; revised November 16, 2005; accepted November 19, 2005)

Abstract. A study on the ash of Lakhra lignite coal and the bottom/fly ash, obtained from combustion of Lakhra lignites in atmospheric fluidized bed combustor (AFBC) was carried out. It has been observed that the absence of alkali metals was of significant importance, as alkali metals were responsible for agglomeration in the AFBC.

Keywords: atmospheric fluidized bed combustion, coal energy, environmental pollution, coal, Lakhra lignites

The role of mineral coal in the energy consumption of Pakistan is insignificant (Table 1). This needs to be given urgent attention. Annual mining of coal in Pakistan is less than three million ton (Ali, 1995), whereas coal depoints in the country have been estimated to be 185 billion ton (ESP, 1999). The Thar coal-fields are the largest coal deposits in the country, but these have yet to be developed.The Lakhra coal-fields are considered to be the largest fields from the point of view of coal mining. According to a survey report, about 91% of the mined coal is used for burning in brick kilns, while the remainder is used for power generation (ESP, 2000). Based on the indigenous source of coal, only one coal-fired power plant is operating in the country. The analyses of Lakhra coal used in the plant are given in Tables 2 and 3. The three coal-fired power plant units of 50 MW each, situated at Khanot, Sindh, Pakistan, which were based on the Lakhra lignite atmospheric fluidized bed combustion (AFBC), and the 15 MW Sor-Range coal-based power plant at Quetta have since been scrapped.

This paper reports a study carried out on the ash of Lakhra lignites and bottom/fly ash, obtained from atmospheric fluidized bed combustion (AFBC), which are burnt alongwith limestone to trap sulphur. These studies were aimed at determining the alkali metals present, the extent of sulphur fixed, and the utilization of ash for some useful purposes such as insulation bricks, road construction and as a soil conditioner.

The commercial power plants, based on atmospheric fluidized bed combustion of coal, have the necessary quality control facilities to routinely analyse coal and limestone, as supplies of these materials vary considerably in their compositions from lot to lot. The analyses of coal ash and bottom/fly ash, therefore, also show wide veriations. The results reported in the present studies represent only one batch of the supplies obtained from a testing atmospheric fluidized bed combustor. Analyses of these supplies were carried out on standard analytical computerized equipment.

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Table 1. The percentage contribution of various fuels in Pakistan*

Fuels	1996-97	1997-98	1998-99
Oil	48.0	46.8	47.7
Natural gas	29.4	31.3	31.0
Electric	15.4	15.5	14.6
Coal	6.3	5.4	5.7
LPG	0.9	1.0	1.1

* = ESP (2000; 1999); LPG = liquified petroleum gas

Table 2. Ultimate analysis of Lakhra lignites (dry; ash-free basis)

Elements	Percentage
Carbon	58.5 - 72.4
Hydrogen	4.5 - 5.8
Nitrogen	0.9 - 1.4
Sulphur	2.4 - 16.7
Oxygen	14.4 - 22.3

Table 3. Proximate analysis of Lakhra lignites

Constituents	Percentage
Moisture (%)	13.01 - 20.12
Volatile matter (%)	17.49 - 42.8
Ash (%)	28.82 - 37.37
Fixed carbon (%)	12.68 - 31.07
Heating value (MJ/kg)	14.31 - 21.05

The ultimate (elemental) analyses of coal were carried out on CHN-600 (LECO, USA), which have been shown in Table 2. The proximate analysis of coal was done on Mac-400 (LECO, USA), which is shown in Table 3. The sulphur content of coal was determined on sulphur determinator SC-132 (LECO, USA) as shown in Table 2. The heating (calorific) value was determined on the Parr oxygen adiabatic bomb calorimeter (Table 3). Analyis of ash and bottom/fly ash has been given in Table 4.

Table 4. Comparison of ash of Lakhra coal and bottom/fly ash obtained from atmospheric fluidized bed combustion plant

Constituents	Lakhra coal ash (%)	Bottom ash (%)	Fly ash (%)
Silica	32.76	40.30	45.20
Alumina	20.18	25.85	22.30
Iron oxide	30.23	10.00	14.85
Calcium oxide	4.55	10.52	7.33
Magnesium oxide	2.28	2.53	3.03
Sodium oxide	1.18	0.66	0.53
Potassium oxide	0.62	0.10	0.30
Sulphur trioxide	16.9	3.85	3.49

The ultimate (elemental) and proximate analyses of the Lakhra lignite coal showed that sulphur and ash were higher, as compared to good quality coals, such as bituminous, anthracite, and even lignites found in the USA and China. The Pakistani lignites, in general, and the Lakhra lignites in particular, have been noted to be high in sulphur and ash.

During the combustion of coal in the atmospheric fluidized bed combustor (AFBC), sulphur changes to SO_2 or SO_3, which is absorbed/fixed in $CaCO_3$ (calcinated in AFBC):

$$CaCO_3 \xrightarrow{\text{heat}} CaO + CO_2$$

The carbon dioxide (CO_2) produced also reacts with carbon of coal to form carbon monoxide (CO), which oxidizes to CO_2 in excess air in the AFBC as below:

$$C + CO_2 \rightarrow 2CO$$

$$2CO + O_2 \rightarrow 2CO_2$$

During the combustion of coal in the AFBC, NO_x forms from the oxidation of nitrogen compounds present in the coal (Ali, 1997). The NO_x acts beneficially as a catalyst for the oxidation of sulphur dioxide (SO_2) to sulphur trioxide (SO_3). It may also be observed that NO_x is not formed in the AFBC from the oxidation of air nitrogen (N_2), as the temperature of the bed is maintained around 800 °C.

$$SO_2 + NO_x \text{ (catalyst)} \rightarrow SO_3$$

Sulphur trioxide (SO_3) reacts with lime or limestone as shown below:

$$CaO + SO_3 \rightarrow CaSO_4$$

Sulphur trioxide (SO_3) may also react with the water vapours, produced during combustion, forming sulphuric acid (H_2SO_4):

$$SO_3 + H_2O \rightarrow H_2SO_4$$

The CaO produced in the AFBC, due to calcination of limestone, reacts with sulphuric acid (H_2SO_4) and produces calcium sulphate ($CaSO_4$):

$$CaO + H_2SO_4 \rightarrow CaSO_4 + H_2O$$

Sulphuric acid (H_2SO_4) also reacts with limestone ($CaCO_3$) forming $CaSO_4$ and CO_2:

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2O + CO_2$$

It has been observed that coals from the same field, even from the same seam in general, and particularly in the case of Lakhra coal, yield different analytical results, as no two samples of the same coal have the same composition. This is quite expected since mineral coal is a very complex mixture of organic and inorganic constituents. Only pure compounds have fixed ratio and the same composition of their constituents. It is, therefore, a range of constituents in the Lakhra coal that have been recorded in Tables 2 and 3. Even at the coal-fired power plant, the exact composition of coal is not maintained as it is practically not possible. Similar is the case with limestone or other materials used in power plants. Large commercial power plants are operated using commercial grade raw materials, after the necessary sizing, etc. Therefore, the ash obtained from Lakhra coal and the bottom/fly ash obtained from the AFBC power plant had no fixed/constant composition. The ash of coal and the ash obtained from AFBC (bottom and fly ash) were compared to the best approximations, so as to assess the fixation of sulphur in limestone in the form of calcium sulphate.

As shown in the Table 4, the percentage of silica in the Lakhra coal increased from 32.76 to 40.30 and 45.20 and alumina from 20.18 to 25.85 and 22.30, respectively, in bottom ash and fly ash, whereas iron content was reduced from 30.23 to 10.00 and 14.85. Calcium oxide increased from 4.55 to 10.52 and 7.33. The percentage of calcium oxide was increased because limestone was added to coal for the fixation of sulphur. Two interpretations can be offerred for the decrease of sulphur trioxide from 16.9 to 3.85 and 3.49, namely the escape of SO_3 to the atmosphere along with the flue gases, or SO_3 may get fixed as calcium sulphate. Gravimetric analysis may indicate the quantity of calcium sulphate formed. Exact quantity of the sulphur fixed in calcium sulphate is yet to be ascertained. However, the negligible quantity of oxides of sodium and potassium present indicated little chances of agglomeration. The deposition of ash on the boiler tube and on the inner walls of the combustion chamber would be least problematic. One of the advantages of the fluidized bed combustion was that the bed temperature is maintained around 800 °C to avoid ash fusion and agglomeration in the AFBC (Gray, 1986).

A detailed study of the fixation of sulphur in limestone is also emphasized from the environmental impact point of view by incorporating monitoring equipment for the flue gases and ash produced in the AFBC. Based on the experience, large-scale combustion of Pakistani lignite for power generation may prove worthwhile. Calcium sulphate produced in the AFBC appears in the bottom/fly ash as shown in the analysis of ash (Table 4). The combustion of Lakhra lignite was problematic as it contained sulphur in the range 2.4-16.7% (Table 2). Samples of ash were, therefore, obtained when good quality of limestone of the coal-feed was used for the maximum trapping of sulphur of coal. It was expected that the ash of the AFBC would be mostly $CaSO_4$, which may be directly applied to soil as soil conditioner.

Application of fertilizer to the soil should be according to the deficiencies of the acidic or basic ingredients. Similar is the case with calcium sulphate. Therefore, it is imperative that calcium sulphate be applied to soils on the recommendation of soil analysts/experts or agriculturists. Soil may be damaged due to unnecessary/over-feeding of fertilizers. Dosage of fertilizers is also important. Therefore, it is recommended that proper and appropriate dose of fertilizer be applied to soils.

The quality control of ash from the AFBC is also very important, as composition of this ash changes from batch to batch as the feed (both coal and limestone) is not of uniform composition. Coal, after mining, also undergoes spontaneous combustion and hence the composition of coal, if not used in a day or two, varies. Similar is the case of limestone composition (purity), which varies from quarry to quarry.

Ash from the AFBC can also be used for brick-making by using high pressure press for moulding. These bricks can be used for insulation as the conductivity of these bricks is very low. Ash from the AFBC can also be used with other materials for building of roads and streets or plastering of roads and streets and pavements. Quality of the calcium sulphate also needs to be checked, otherwise cracks may appear and damage the roads. Since the sorbents (limestone, dolomite, etc.) are used to trap sulphur of the coal, their physical or chemical properties may need to be changed by subjecting to high temperature reactions. The baked broken bricks, if crushed and remoulded, will not give the same results as the originally baked bricks. Their binding property would thus be inevitably damaged.

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