*Short Communication*

# Environmental & Health Hazards of Fly Ash & SOx from FBC Power Plant at Khanote

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**Abstract**

Lakhra coal reserves are estimated to about 1328 million tones. Most of mined Coal in Pakistan has been used for power generation in addition to some other uses. Lakhra coal (lignite) reserves are very high in sulphur content, moisture and ash that not only cause environmental pollution but also cause operational problems. In order to avoid environmental & operational problems, clean coal technology (FBC technology) has been used globally because of its merits. In FBC power plant, sulphure is captured by using limestone. In Pakistan, 3x50MW power plant was installed at Khanote to utilize the lakhra coal for the first time. The present study is focused on formation of ash & sulphur. In the FBC power plant at khanote, the generation rate of fly ash & bottom ash was 55680 $m^3$/hr and 16550 $m^3$/hr respectively.  Unexpected huge amount of ash causes environmental problem in shape of particulate matter that causes respiratory diseases in the workers. It also affects nearby villages by polluting agricultural land, cattles & habitants. The present research not only indentifies the risks on the basis of extensive experimental analysis, but also proposed solution for its proper disposal.

*Keywords:* Sulphur, Fly ash, Fluidized bed combustor, Power plant, Coal, Limestone, Pollution.

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## Introduction

Pakistan has been gifted with huge Coal reserves. Unfortunately, most of the coal reserves are of low quality. For the proper utilization of these coal reserves, appropriate technology must be explored in addition to proper operation of the power plant based on low quality coal.  Lignite (low quality coal) has been used in FBC power plant at khanote for the generation of electricity [1]. Keeping in view the quality of coal, fluidized-bed-combustor (FBC) technology has been the best option because it is safer, environmental friendly and more energy efficient. That is the major reason, that the FBC technology is known as clean coal technology [2-4].

Because of high sulphur contents in the lakhra coal, ash is produced in much higher quantity. In order to avoid environmental problems caused by ash and sulphur, they  must be removed from the coal [5-7]. During the combustion of coal, minor constituents are also oxidized & are converted to sulpher dioxide and sulphur trioxide. To avoid formation of SOx compounds, limestone has been used [8-11]. The feed rate of Coal and limestone is 52 tones/hr & 26 tones/hr respectively [12-15] that makes the ratio 2:1 of coal and limestone.

Fly ash and sulfur had very bad effect on human health. It causes respiratory problems, such as bronchitis; it can irritate nose, throat & lungs. It may cause coughing, wheezing, phlegm & asthma

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attack. Sulphur compounds and ash particles are also very harmful for ecosystem because it causes acid rain that badly affects humans, animals and cultivated area.

The present study is focused on the quantitative analysis of the formation of ash & SOx compounds. The study further explored the major reasons of formation of ash & SOx by analysing the power plant operation & the coal & lime stone samples.

**Experimental**

Samples of coal, limestone, bottom ash, fly ash & re-injection (un-burnt) materials were collected from the FBC power plant at Lakhra. The samples were analysed by using specific method described in relevent tests in the laboratories of FBC Power Plant at Lakhra and Chemical Engineering Department, Mehran University of Engineering & Technology, Jamshoro in addition to quality control laboratories at Dadabhay , Essa and Zealpak cement Factories.

Lakhra coal used at FBC power plant at khanote contains high percentage of sulphur. Limestone has been used to capture the sulphur. During the combustion of coal with lime stone, following reactions take place:

$$S + O_2 \longrightarrow SO_2$$
$$CaCO_3 \longrightarrow CaO + CO_2$$
$$SO_2 + 1/2\, O_2 + CaO \longrightarrow CaSO_4$$
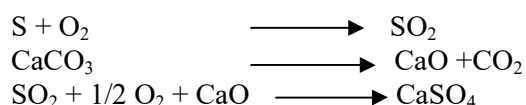
***Coal analysis***
*Proximate analysis*

Proximate analyses have been carried out on the compound basis. This analysis supplies readily meaningful information for coals use in steam generators. Proximate analysis determines the mass percentage of the compound i.e. moisture, volatile matter, ash and fixed carbon. Experimental work was carried out on the basis of the following methods.

*(a) Moisture content*

1 gram of finelly powdered air dried coal sample was taken & weigh in a crucible. The crucible was placed inside an electric hot air oven,

maintained at 105-110°C. The crucible was allowed to remain in oven for 1 hr. and then taken out with the help of pair of tongs, cooled in decicator and weighed. Then loss in weight was reported as moisture (on percentage) basis. The following formula was used to calculate the percentage of moisture.

% age of moisture = (loss in wt. / wt. of coal taken) x 100.

*(b) Volatile matter*

Sample was heated in the absence of oxygen in a standard test up to 954.4°C for 07 minutes. The dried sample of coal left in the crucible was covered with a lid and placed in an electric furnace (Muffle furnace), maintained at $925 \pm 20$°C. The crucible was taken out of the oven after seven minutes heating. The crucible was cooled first in air then inside a decicator and weighted again. The loss in weight calculated by the following formula.

$$\%\,age\,of\,volatile\,matter = \frac{loss\,in\,wt: due\,to\,removed\,of\,volatile\,matter \times 100}{wt: of\,coal\,taken}$$

*(c) Ash*

The residual coal in the crucible obtained after removal of volatile matter was heated without a lid in a muffle furnace at $700 \pm 50$°C for 30 min. The crucible was taken out, cooled first in air, then in decicator and weighed. Heating, cooling and weighing is reported till a constant weight is obtained. The residue was recorded as ash contents on percentage basis. The following formula was used to calculate the percentage of ash.

$$\%\,age\,of\,ash = \frac{wt: of\,ash\,left \times 100}{wt: of\,coal\,taken}$$

*(d) Fixed carbon*

Fixed carbon is elemental carbon that exists in coal. In proximate analysis its determination was approximated by assuming it to be the difference between the original sample and the sum of volatile matter moisture and ash, the formula used for the estimation of fixed carbon was as follows.

% age of fixed carbon = 100 - % age of (moisture + ash +volatile matter)

*Ultimate analysis*

The ultimate analysis of coal was carried out for precise chemical determination. These include carbon, hydrogen, nitrogen oxygen and sulfur in an elemental form in addition to Ash. The details of the test are described in the following text.

*(a)  Carbon and hydrogen*

0.2 grams of accurately weighed coal sample was burnt in presence of oxygen in a combustion apparatus. Carbon and hydrogen of coal were converted into $CO_2$ and $H_2O$ respectively. The gaseous products of combustion were absorbed respectively in KOH and $CaCl_2$ tubes of known weights. The increase in weights of these tubes is then determined. The formulas for determination of carbon and Hydrogen percentages were as  follows.

$$\% \text{age of N} = \frac{\text{increase in wt : of kOH in tube} \times 12\ \times 100}{\text{wt : of coal sample taken} \times 44}$$

$$\% \text{age of H} = \frac{\text{increase in wt : of } CaCl_2 \text{ in tube} \times 2\ \times 100}{\text{wt : of coal sample taken} \times 18}$$

*(b)  Nitrogen*

1 gram of accurately weighed powdered coal was heated with concentrated sulfuric acid along with potassium sulfate $K_2SO_4$ *(catalyst)* in a long necked flask *(kjeldihas flask)*. As the solution becomes clear, it was treated with excess KOH and liberated ammonia was distilled over and absorbed with known volume of standard acid solution. The unused acid was determined by titration with standard NaOH from the volume of acid used by ammonia liberated. The percentage of nitrogen in coal has been calculated by the following formula:

$$\% \text{age of N} = \frac{\text{volume of acid used} \times \text{normality} \times 14}{\text{wt : of coal taken} \times 44}$$

*(c)  Sulphur*

It is determined from the washings obtained from the taken mass sample of coal used in a bomb calorimeter for determination of calorific value. During this determination sulphur was converted into sulphates. The washings are treated with barium chloride solution. The precipitated barium sulphate was, filtered washed and heated to constant weight. The following formula was used for the determination of Sulphur.

$$\% \text{age of S in coal} = \frac{\text{wt : } BaSO_4 \text{ contained} \times 32 \times 100}{233 \times \text{wt : of coal sample taken in bomb}}$$

*(d)  Ash*

The ash percentage was determined by the same method used in proximate analysis.

*(e)  Oxygen*

The percentage of oxygen was determined by the following formula:

$$\% \text{age of } O_2 = 100 - \% \text{age of } (C + H + O + N + \text{ash})$$

The analysis was on the basis of elements viz. Carbon, Hydrogen, Nitrogen, Sulphur and Ash.

*Lime stone analysis*

Five lime stone samples were collected from FBC Power Plant. They were analyzed by ASTM C25 - 06 Standard Test Methods for the determination of $CaCO_3$, $SO_2$, MgO, $Al_2O_3$ and other components.

*Analysis of bottom ash, fly ash & re-injection material*

Similarly, five samples of bottom ash, fly ash & re-injection materials were collected from FBC Power Plant at khanote have been analyzed for the determination of Sulphur and calcium oxide compounds by similar techniques in approximate & ultimate analysis.

**Results and Discussion**

In spite of Pakistan having estimated 3,362 million tons of coal reserves; 6th largest in the world, coal has a negligible share in Pakistan's energy mix. The installation of 3x50MW FBC Power plant, khanote was to utilize the indigenous

lignite coal reserves at lakhra coal mines for the generation of electricity to increase the share from coal & to meet the increasing energy demand of the country. Secondly, FBC technology was chosen as it was well established and used all over the world successfully. Also it is known as clean coal technology. In FBC technology, lime stone has been used with coal to remove the sulphur content from the low quality coal, subjected to complete combustion. In order to see whether the sulphur is removed from the lignite coal in the FBC power plant at lakhra, the coal, lime stone, bottom ash, fly ash & un-burnt material were analyzed.

Initially, five coal samples were collected from the sheds at FBC power plant at lakhra. The samples were analyzed for the proximate & ultimate analysis as shown in Table-1 and Table-2. In proximate analysis, it was observed that the calorific value of the samples varies from 3225 to 3336 k.cal/kg. The sulphur contents were between 5.78 & 6.73%. Moisture content ranges between 16.33 & 16.94%. The ash content in the coal samples were found between 30.05 to 31.84%. The volatile matter content in the coal was between 25.54 & 27.15%. The fixed carbon varies between 20.34 & 21.93%

**Table-1.** Proximate Analysis of Coal.

| S. No | Calorific value K/cal/kg | Sulphur % | Moisture % | Ash % | Volatile Matter % | Fixed Carbon % |
|---|---|---|---|---|---|---|
| 1 | 3336 | 6.73 | 16.90 | 30.05 | 26.03 | 21.51 |
| 2 | 3297 | 6.23 | 16.94 | 30.23 | 27.15 | 21.93 |
| 3 | 3315 | 5.78 | 16.45 | 31.84 | 25.54 | 20.34 |
| 4 | 3225 | 6.12 | 16.33 | 30.34 | 26.91 | 21.93 |
| 5 | 3296 | 6.23 | 16.51 | 30.41 | 26.92 | 21.73 |

(Table 2). shows the results of ultimate analysis. The moisture contents were between 16.10 & 17.00%. Ashes were between 24 & 31.20%. Carbon content in the coal samples ranges between 33.04 & 47.17%. Hydrogen percentage in the coal was between 3.09 & 7.54. Nitrogen present in the coal was found to be between 0.70 & 0.92%. The oxygen was between 7.04 & 8.89%.

The most important component from the environmental pollution point of view; sulphur ranges between 4.25 to 5.39%. The results of proximate and ultimate analysis are shown in (Fig. 1 and 2) respectively.

**Table-2.** Ultimate analysis coal.

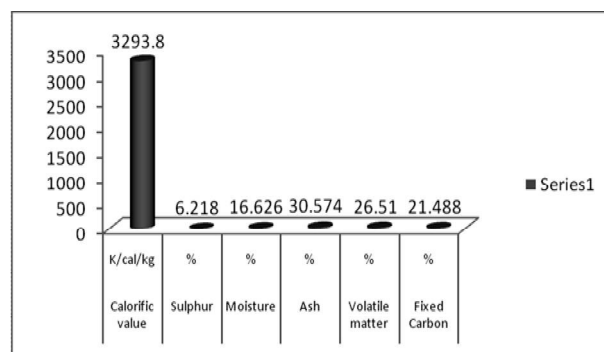| S. No | Moisture % | Ash % | Sulphur % | Carbon % | Hydrogen % | Nitrogen % | Oxygen % |
|---|---|---|---|---|---|---|---|
| 1 | 16.49 | 30.00 | 5.39 | 34.01 | 7.54 | 0.70 | 8.89 |
| 2 | 17.00 | 30.52 | 5.20 | 33.04 | 4.45 | 0.75 | 7.04 |
| 3 | 16.10 | 31.20 | 5.22 | 37.31 | 3.09 | 0.92 | 7.51 |
| 4 | 16.46 | 30.49 | 4.25 | 38.70 | 3.48 | 0.89 | 7.63 |
| 5 | 16.86 | 24.00 | 5.23 | 47.17 | 3.61 | 0.73 | 7.66 |



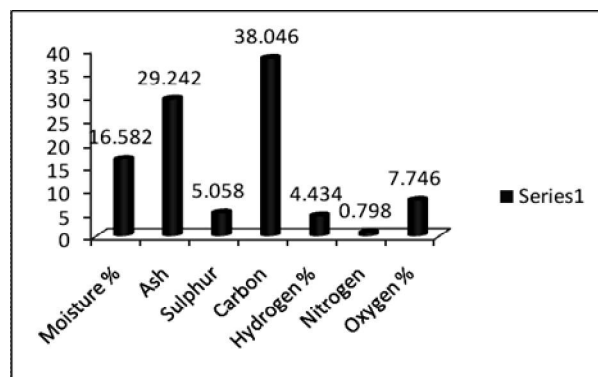**Figure-1.** Proximate analysis of coal.



**Figure-2.** Ultimate analysis coal.

Analysis of limestone has been shown in the Table-3. The compounds of interest in this analysis were $SO_3$ & CaO. It was found that the

$SO_3$ content in the limestone is between 0.15 & 0.19%, whereas the percentage of CaO is between 48.97 & 52.01% as shown in Fig. 3. The analysis of bottom ash result shows the availability of sulphur compounds $SO_3$ ranges between 5.89 to 6.73%. The CaO minimum & maximum range is 10.23 & 11.30. (Table - 4) and is shown in Figure-4. The Fly ash sample contains $SO_3$ in between 12.50-13.50, whereas, CaO is between 22 & 23.30% as shown in Table-5 and Fig.5.

**Table –3.** Limestone analysis.

| S. No | LOI % | SiO₂ % | Al₂O₃ % | Fe₂O₃ % | CaO % | MgO % | SO₃ % |
|---|---|---|---|---|---|---|---|
| 1 | 37.49 | 09.50 | 0.56 | 0.48 | 50.49 | 0.80 | 0.17 |
| 2 | 36.23 | 08.92 | 0.52 | 0.47 | 51.23 | 0.70 | 0.18 |
| 3 | 38.75 | 10.12 | 0.61 | 0.49 | 49.75 | 0.90 | 0.16 |
| 4 | 37.51 | 09.62 | 0.49 | 0.39 | 52.01 | 0.80 | 0.19 |
| 5 | 37.47 | 09.42 | 0.63 | 0.57 | 48.97 | 0.60 | 0.15 |

**Table-4.** Fly ash analysis.

| S. No | LOI % | SiO₂ % | Al₂O₃ % | Fe₂O₃ % | CaO % | MgO % | SO₃ % |
|---|---|---|---|---|---|---|---|
| 1 | 14.50 | 23.89 | 13.4 | 09.00 | 22.00 | 02.50 | 12.50 |
| 2 | 14.40 | 22.93 | 13.20 | 08.70 | 21.20 | 02.40 | 13.00 |
| 3 | 13.90 | 23.22 | 13.10 | 09.10 | 22.40 | 02.90 | 12.90 |
| 4 | 14.70 | 24.12 | 14.00 | 08.23 | 21.50 | 02.80 | 12.70 |
| 5 | 14.20 | 20.30 | 15.20 | 09.50 | 23.30 | 02.70 | 13.50 |

**Table -5.** Bottom ash analysis.

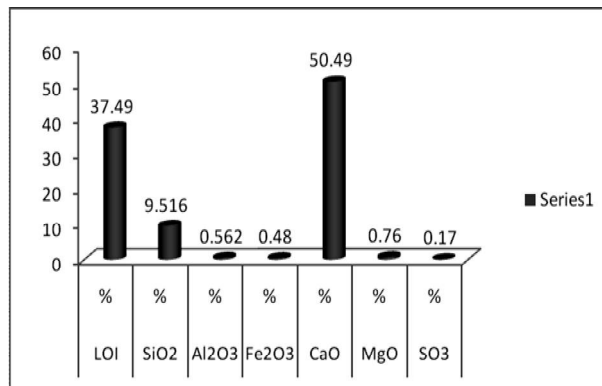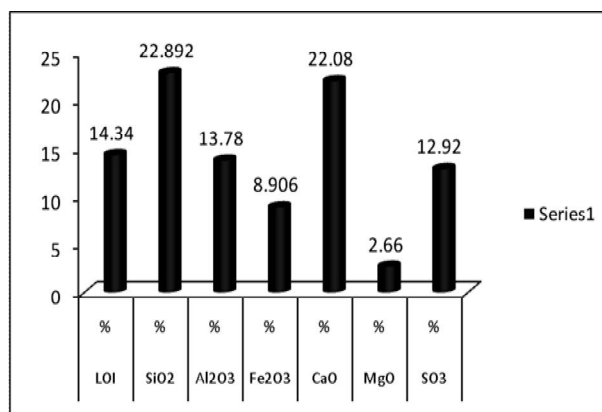| S. No | LOI % | SiO₂ % | Al₂O₃ % | Fe₂O₃ % | CaO % | MgO % | SO₃ % |
|---|---|---|---|---|---|---|---|
| 1 | 06.35 | 33.66 | 16.20 | 25.60 | 10.59 | 0.60 | 05.89 |
| 2 | 07.00 | 34.64 | 16.30 | 24.70 | 10.60 | 0.70 | 06.23 |
| 3 | 06.82 | 33.69 | 16.80 | 24.20 | 11.30 | 0.40 | 06.73 |
| 4 | 06.45 | 34.56 | 16.23 | 25.20 | 11.20 | 0.50 | 06.20 |
| 5 | 07.23 | 32.20 | 16.20 | 24.20 | 10.23 | 0.80 | 06.11 |



**Figure-3.** Lime stone analysis.
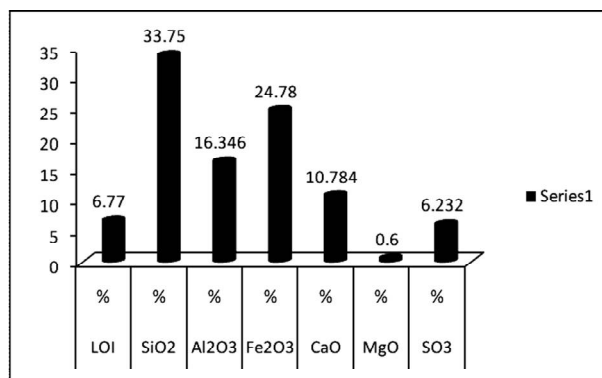


**Figure-4.** Fly ash analysis.



**Figure-5.** Bottom ash analysis.

The re-injection material (*un-burnt material*) contains $SO_3$ in between 2.90 & 3.50%. The percentage of CaO present in the re-injection material was found to be between 5.05 & 6.40% and is shown in Table 6 and in (Fig. 6).

*Table-6.* **Unburnt (Re-Injection) Material Analysis.**

| S. No | LOI % | SiO₂ % | Al₂O₃ % | Fe₂O₃ % | CaO % | MgO % | SO₃ % |
|---|---|---|---|---|---|---|---|
| 1 | 02.38 | 39.50 | 29.35 | 18.40 | 05.05 | 01.48 | 02.90 |
| 2 | 03.54 | 38.40 | 30.20 | 18.10 | 05.60 | 01.31 | 02.70 |
| 3 | 03.24 | 39.20 | 30.60 | 17.90 | 05.80 | 01.92 | 03.10 |
| 4 | 03.37 | 37.90 | 29.40 | 19.20 | 06.40 | 01.21 | 03.00 |
| 5 | 02.77 | 38.90 | 29.40 | 18.30 | 05.90 | 02.34 | 03.50 |

Average analysis of fly ash, bottom ash and un-burnt material has been shown in Table -7. The data shows the presence of the sulphur compounds on average basis , i.e., 6.25%, 13.13% & 2.94% in fly ash, bottom ash & re-injection material respectively. The average percentage of CaO present in the bottom as, fly ash & un-burnt material is 10.77%, 22.89% & 6.20%, totalling 38% CaO. From the above discussion, it is evident that sulphur is not captured completely by the limestone.
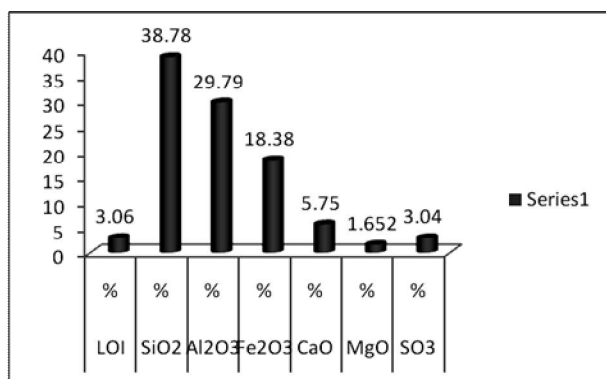


*Figure-6.* **Un-burnt (Re-Injection) material analysis.**

*Table-7.* **Bottom Ash, fly ash & Un-burnt (Re-Injection) Material Analysis.**

| Material | LOI % | SiO₂ % | Al₂O₃ % | Fe₂O₃ % | CaO % | MgO % | SO₃ % |
|---|---|---|---|---|---|---|---|
| Bottom Ash | 06.65 | 33.37 | 16.41 | 24.95 | 10.77 | 0.61 | 06.25 |
| Fly Ash | 14.48 | 23.61 | 14.09 | 09.15 | 22.89 | 02.71 | 13.13 |
| Un-burnt (Re-Injection) Material | 03.10 | 38.54 | 29.00 | 18.32 | 06.20 | 01.91 | 02.94 |
| Total | 24.23 | 95.52 | 59.5 | 52.42 | 39.86 | 5.23 | 22.32 |

## Conclusion

The presence of CaO & sulphur compounds in the ash samples clearly shows that limestone is not being completely consumed for capturing sulphur from coal. That is the major reason; sulphur compounds are present in the fly ash, bottom ash & unburnt material. The proximate & ultimate analysis results of fly ash, bottom ash and re- Injection (un-burnt) material showed unused amount of Calcium Oxide & SO₃, i.e, 39% & 22.32% respectively.

Due to the very small particle sizes of coal and limestone and higher flow rate of air than the required flow rate [12], the residence time for the coal & lime stone had been reduced that not only causes incomplete combustion but also un-burnt particles are coming out with the flue gases.

Coal / limestone ratio as per stoichiometric requirement is 5:1 [12]. But, practically, in FBC power plant 2:1 of caol/limestone had been used, i.e., 150% excess quantity of limestone is being used. The excess amount of limestone not only causes loss of resources but also causes various problems including damage of FBC internal chamber walls, ID Fans [13] that badly affect the efficiency of power plant.

A significant amount of coal and limestone had been wasted that turned into Ash. Ash contains high amount of sulphur compounds and also contains fine particles. The particulate matter is hazardous to humans & cause environmental pollution. To avoid pollutant emissions, encourage sustainable use of natural resources, the efficiency must be optimized by using proper ratio of coal/limestone in proper size as per power palnt specification.

## Recommendation

- Required particles sizes of coal and lime stone (13mm & 6mm respectively) according to design specification of power plant should be used.
- Coal and lime stone ratio should be used 5:1 instead of 2:1, on the basis of Sulphur contents in coal, which will reduce excess amount of ash.

- Regular analysis should be done for the determination of the sulphur compounds and calcium oxide in fly ash, bottom ash and un-burnt samples.
- Lime stone having about 95% $CaCO_3$ should be used.

**Acknowledgement**

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