
Erosion in Steam General Tubes in Boiler and ID Fans in Coal Fired FBC Power Plant

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ABSTRACT

The FBC (Fluidized Bed Combustion) is a technique used to make solid particles behave like fluid and grow very fast for the power generation using low grade coal. Due to its merits, first time this technology has been introduced in Pakistan by installing 3x50 MW power plants at Khanote. Fluidized beds have long been used for the combustion of low-quality, difficult fuels and have become a rapidly developing technology for the clean burning of coal. The FBC Power Plant at Khanote has been facing operational and technical problems, resulting frequently shut down of generation units, consequently facing heavy financial losses.

This study reveals that due to the presence of high percentage of silica in the lime stone that are further distributed in the bottom ash, fly ash and re-injection material, the generation tubes in the boiler and wings/blades of ID (Induced Draft) fans were eroded. In addition, filter bags were also ruptured; resulting frequent shut down of power plant units.

Key Words: Steam Generation Tubes, Erosion, Boiler, Coal, Power Plant.

1. INTRODUCTION

Pakistan is rich in coal reserves and it is high time to look for its proper utilization by installing power generation units based on Pakistani coal. Various investigators have worked on this technology for power generation [1-2]. The first FBC power plant has been installed at Khanote based on Lakhra coal [3-4]. Lakhra coal is of low ranking- coal (lignite) containing high percentage of moisture, ash and sulfur. Three power generation units installed at Lakhra coal based power plant generate 150MW electricity, but it has been observed that mostly all these three units are not functional at the same time for parallel operation due to various operational/technical

problems, such as erosion of generation tubes and wings/blades of ID fans, and rupturing of filter bags. The future of indigenous coal utilization for the power generation depends on the success of this plant [5-8]. The requirement of energy has increased rapidly, switching to cheaper coals, normally those with the higher sulfur and high ash contents. This led to significant increase of SO₂ emission in coal combustion [9-12]. Designed specifications of coal and limestone used in power plant at Lakhra are 52 and 26 tones/hour respectively as per stoichiometric calculation [13-15]. But practically it is being observed that less percentage of SO₂ converted into gypsum (CaCO₃).

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In high ash coal fired boilers, fly ash is major concern and the tube failures due to the fly ash erosion are almost 35% of the total tube failures. The amount of ash in coal and its velocity are major factors in the rate of pressure part erosion [16].

Fly ash is the product of high temperature coal combustion and is easily identified by the high proportion of spherical particles in the magnetic fraction of soil/silica.

The objective of this paper is to identify the root cause of erosion of boiler generation tubes and ID fan by investigating the limestone, bottom ash, fly ash and re-injection (un-burnt) material.

2. EXPERIMENTAL WORK

Lakhra coal used at FBC power plant Khanote contains high percentage of sulphur. FBC technology has been considered as the best option to avoid environmental problems caused by the presence of sulphur in coal and is considered as clean coal technology. In FBC clean coal technology, lime stone is added with coal.

In order to study the FBC power plant operational problems, especially, erosion; analysis of limestone had been carried out to find out the root cause of the problem. Additionally, the combustion reaction products, bottom ash, fly ash and re-injection (un-burnt) material analysis

was also carried out by using various standard techniques and equipments [10]. Analysis of the ten samples of each material was taken at different time intervals as shown in Fig. 1.

2.1 COAL ANALYSIS

2.1.1 Proximate Analysis

This type of analysis has 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.

2.1.2 Moisture

Take 1 gram of finally powdered air dried coal sample weighted in a crucible. The crucible was placed inside in an electric hot air oven, maintained at 105-110°C.

The crucible was allowed to remain in oven for 1 hour and then taken out with the help of pair of tongs, cooled in decicator and weighed. Then loss in weight was reported as moisture. The following formula was used as:

$$\text{Percentage of Moisture} = \left(\frac{\text{Loss in Weight}}{\text{Weight of Coal Taken}} \right) \times 100$$



FIG 1. SAMPLES OF COAL, LIMESTONE, BOTTOM ASH, FLY ASH AND UN-BURNT MATERIALS

2.1.3 Volatile Matter

Sample was heated in the absence of oxygen in a standard test up to (954.4°C for 7 minutes). This dried sample of coal left in the crucible was covered with a lid and placed in an electric furnace (Muffle furnace), maintained at 925+20°C. The crucible was taken out of the oven after seven minutes heating; the crucible was cooled first in air then inside a desiccator and weighed again. The loss in weight was calculated by the following formula.

$$\text{Percentage of Volatile Matter} = \frac{\text{Loss in Weight due to Removal of Volatile Matter} \times 100}{\text{Weight of Coal Sample Taken}}$$

2.1.4 Ash

The residual coal in the crucible obtained after volatile method was then heated without a lid in a muffle furnace at (700+50°C) for 1/2 hour. The crucible was then taken out, cooled first in air, then in desiccator and weighed. Heating, cooling and weighing is reported till a constant weight is obtained. The residue was counted as ash on the percentage basis. Thus formula was as:

$$\text{Percentage of Ash} = \frac{\text{Weight of Ash Left} \times 100}{\text{Weight of Coal Sample Taken}}$$

2.1.5 Fixed Carbon

Fixed carbon was an eliminated carbon that existed in coal. In proximate analysis its determination is approximated by assuming it to be the difference between the original sample and the sum of volatile matter moisture and ash, the following formula was used:

$$\text{Percentage of Fixed Carbon} = 100 - (\text{Percentage of (Moisture + Ash + Volatile Matter)})$$

2.1.6 Ultimate Analysis

The ultimate analysis of coal was carried out on the element basis for determination of the chemical. These include carbon, hydrogen, nitrogen oxygen and also sulfur. Ash was also included. The description is given below:

2.1.7 Carbon and Hydrogen

About 0.2 gram of accurately weighed coal sample was burnt in a current of oxygen in a combustion apparatus.

Carbon and hydrogen of coal are converted into CO₂ and H₂O respectively. The gaseous products of combustion were absorbed respectively in KOH and CaCl₂ tubes of known weights. The increase in weights of these tubes was then determined. The reactions are as under:

1. $C + O_2 \rightarrow CO_2$
2. $H_2 + 1/2 O_2 \rightarrow H_2O$
3. $2KOH + CO_2 \rightarrow K_2CO_3 + H_2O$
4. $CaCl_2 + 7H_2O \rightarrow CaCl_2 \cdot 7H_2O$

The formulas for finding percentages of carbon and Hydrogen are:

$$\text{Percentage of C} = \frac{\text{Increase in Weight of KOH in Tube} \times 12 \times 100}{\text{Weight of Coal Sample Taken} \times 44}$$

$$\text{Percentage of H} = \frac{\text{Increase in Weight of CaCl}_2 \text{ in Tube} \times 2 \times 100}{\text{Weight of Coal Sample Taken} \times 18}$$

2.1.8 Nitrogen

1 gram of accurately weighed powdered coal was heated with concentrated sulfuric acid along with potassium sulfate K₂SO₄ (catalyst) in a long necked flask (called kjeldihas flask). After the solution becomes clear, it is treated with excess of KOH and liberated ammonia is distilled over and absorbed. The unused acid was then determined by back titration with standard NaOH. The percentage of nitrogen in coal have been calculated by the following formula:

$$\text{Percentage of N} = \frac{\text{Volume of Acid Used} \times \text{Normality} \times 14}{\text{Weight of Coal Taken}}$$

2.1.9 Sulphur

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

$$\text{Percentage of S in Coal} = \frac{\text{Weight of BaSO}_4 \text{ Contained} \times 32 \times 100}{233 \times \text{Weight of Coal Sample Taken in Bomb}}$$

2.1.10 Ash

The percentage of ash determination was same as it was determined in the proximate analysis.

2.1.11 Oxygen

The percentage of oxygen was determined by the following formula:

$$\text{Percentage of O}_2 = 100 - \text{Percentage of (C+H+O+N+ Ash)}$$

2.2 Limestone Analysis

The limestone that is used as sulphur capturing agent is stored in sheds in the FBC power plant at Lakhra. The samples were taken from sheds, conveyor belt (after crushing) and screw feeder (at the feed point to the reactor). Limestone used at FBC power plant Khanote has been analyzed for the determination of CaCO_3 , SiO_2 , Al_2O_3 and other components. Analysis of the Limestone was carried out by using the following methods:

2.2.1 Loss in Ignition

Weigh about a 0.5g specimen of the prepared sample to the nearest 0.001g into a clean, previously ignited and weighed, covered platinum crucible. Heat slowly at first to avoid loss by decrepitation, finally to constant weight at 1000°C, in the muffle furnace. (Usually 1 hour is sufficient for complete ignition). Cool in a desiccator and report the loss in weight as the loss on ignition.

2.2.2 Silica Oxide

Transfer the previously ignited residue quantitatively to a 300 mL porcelain casserole. Carefully slake with about 10 mL of water, and mix to a slurry with a flat end glass stirring rod. Add 5-10 mL of concentrated HCl and digest with gentle heat until solution is complete, carefully breaking up any lumps. Evaporate to dryness and bake the residue on a sand bath or in an oven for 1 hour.

If the MgO content is high (10% or over on the nonvolatile basis), bake at 120°C; if below 10% MgO, bake at 200°C. (The high dehydration temperature is efficient for low MgO, but with high MgO, silica redissolves at temperatures over 120°C). Cool to 40°C or lower, drench with concentrated HCl and allow to stand a few minutes. Then add an equal amount of water, cover the casserole, and heat on the steam or sand bath for about 10 min. Filter through an 11cm filter paper into a 400 mL beaker. Wash the residue thoroughly with HCl (1:10) and then wash twice with hot (about 60-90°C) water. Pour the filtrate back into the same casserole, evaporate to dryness, treat with HCl and water as before, filter through a second filter paper of the above type and wash twice with hot water. Save the filtrate.

Transfer the wet papers to a previously ignited and weighed platinum crucible, char carefully without allowing the paper to flame, and finally ignite in the muffle furnace to constant weight at 1000°C (30 min is usually sufficient). Cool in a desiccator and weigh. Fuse the residue in the crucible with a little Na_2CO_3 (1-2 g), cool the melt, dissolve in 1:1 HCl, and add the solution to the filtrate from silica and insoluble matter.

2.2.3 Alumina

Subtract the Fe_2O_3 from the weight of the $\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$ and calculate the remainder to percentage of Al_2O_3 .

2.2.4 Iron Oxide and Alumina (R_2O_3)

To the acid filtrate from the silica determination, add a few drops of bromine water or concentrated HNO_3 and boil until all traces of bromine or chlorine are gone. Add enough concentrated HCl so as to have a total volume of 10-15 ml of the concentrated acid. Add a few drops of methyl red solution, dilute to 200-250 ml, and heat to boiling. Carefully neutralize with concentrated NH_4OH until the color changes to a distinct yellow. Boil for 1 or 2 min, let settle, and filter into a 600 mL beaker. Wash four times with hot 2% NH_4Cl solution. Save the filtrate.

Place the beaker in which the precipitation was made under the funnel containing the precipitate. Dissolve the precipitate on the paper with about 15 ml of 1:1 HCl; wash

the paper thoroughly with hot water. Heat, neutralize with NH_4OH , and boil as in the first precipitation. Filter (the same paper may be used) and wash four times with hot 2% NH_4Cl solution. Place the paper in a previously ignited and weighed platinum crucible, char without allowing the paper to take fire, and finally ignite 30 min at 1000°C in the muffle. Cool in a desiccator and weigh as R_2O_3 .

2.2.5 Calcium Oxide

Combine the two filtrates from the iron oxide plus alumina determination. Make just acid to methyl red with concentrated HCl , then add 2 mL of the acid in excess. Evaporate to 350 mL, add 20 mL of 10% oxalic acid and boil. To the boiling solution add 1:3 NH_4OH dropwise from a pipet until a precipitate begins to form. Now add the NH_4OH still more slowly, allowing most of the precipitate to form between each addition. Continue until the methyl red just turns yellow. Add 25 mL saturated ammonium oxalate and stir. Let the solution stand and cool for 1 hour.

$$\text{Percentage of CaO} = \frac{(\text{mL KMnO}_4) \times (\text{Normality}) \times 2.804}{\text{Weight of Sample in Grams}}$$

2.2.6 Magnesium Oxide

Acidify the filtrate from the calcium oxalate precipitation and evaporate to about 450 mL. Cool to room temperature. Add 30 mL of a freshly prepared 10% solution of $(\text{NH}_4)_2\text{HPO}_4$. Add a few drops of methyl red, stir vigorously, and add concentrated NH_4OH slowly-especially while the precipitate is still forming-until the solution is alkaline to the methyl red. Now add 10 mL of concentrated NH_4OH for each 100 mL of solution. Stir vigorously a few times at about 15 min intervals. Let settle overnight.

Filter through a tared Gooch crucible, transferring all the precipitate to the crucible with the aid of a rubber policeman. Wash with cool 5% NH_4OH . Ignite in a muffle furnace, starting at 300°C , gradually increasing the heat to 1000°C . Hold at 1000°C for 1 hour. Cool in a desiccator and weigh as $\text{Mg}_2\text{P}_2\text{O}_7$. Calculate the MgO as:

$$\text{Percentage of MgO} = \frac{\text{Weight of Mg}_2\text{P}_2\text{O}_7 \times 36.21}{\text{Weight of Specimen}}$$

3. RESULTS AND DISCUSSION

The raw material used in the FBC boiler is low-grade lignite coal containing high percentage of moisture, ash and sulfur. At the initial stage, lime stone analysis was carried out to find out the presence of SiO_2 , Al_2O_3 , Fe_2O_3 , CaO , MgO , SO_3 , and LOI .

The investigation of lime stone samples shows the presence of silica in the lime stone samples, ranging from 8.92-10.12%. The average silica presence in the lime stone is 9.52%. The detailed results of limestone analysis are shown in Table 1. As per design and operational specifications of the FBC boiler, zero percentage of silica is recommended for proper operation of the boiler [4-5]. The presence of huge amount of silica is non-reactive in the operational conditions of the FBC boiler. As a result, these particles move around in the boiler at high velocity causing erosion of the generation tubes as shown in Fig. 2.

Due to high density of silica particles, the analysis of the bottom ash shows higher percentages of silica ranging between 32.20-35.0%. The average percentage of silica in the bottom ash analysis is 33.37% (Table 2).

The smaller particles of silica were carried through the fly ash that is shown in the results of the analysis of fly ash and its percentage ranges between 20.30-25.23%. The average percentage of silica is 23.61% (Table 3).

Due to vigorous circulation of silica particles at higher velocity, the maximum quantity has been found in re-injection material (Table 4). The silica present in the ten re-injection material samples is in the range of 37.30-39.51%. The average percentage of silica in the re-injection material is 38.54%.

The silica particles accompanying fly ash are generally of smaller size and low density particles. These particles are carried away with fly ash; while passing through the ID fans and causing damage to ID fan blades/wings and erosion occurs as shown in Fig. 3.

It has also been observed that these silica particles have also become the root cause of frequent rupture of filter bags. The filter bags are supposed to separate fly ash particle before emissions are released to the stack.

It can be observed that presence of silica in lime stone have created many problems. The huge amount has been spent for the purchase and crushing of this unwanted material with limestone. The efficiency of the plant has been badly affected. The major components, i.e. FBC boiler, ID fan and filter bag of the power plant has been damaged. Consequently, frequent shut down of the plant occurs.

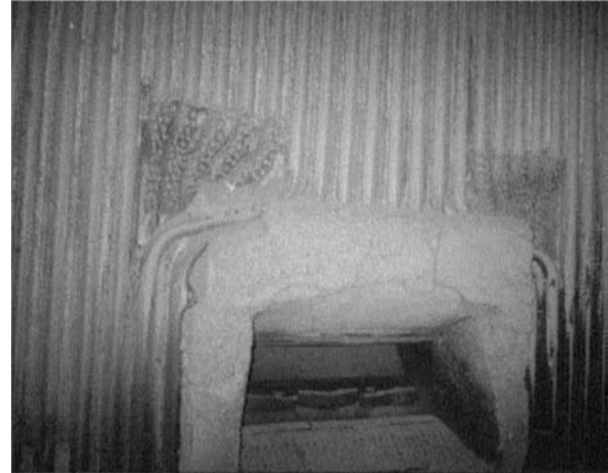


FIG 2. EROSION OF GENERATION TUBES

TABLE 1. LIMESTONE ANALYSIS

No.	LOI (%)	SiO ₂ (%)	Al ₂ O ₃ (%)	Fe ₂ O ₃ (%)	CaO (%)	MgO (%)	SO ₃ (%)
1.	37.49	09.50	00.56	00.48	50.49	00.80	00.17
2.	36.23	08.92	00.52	00.47	51.23	00.70	00.18
3.	38.75	10.12	00.61	00.49	49.75	00.90	00.16
4.	37.51	09.62	00.49	00.39	52.01	00.80	00.19
5.	37.47	09.42	00.63	00.57	48.97	00.60	00.15
6.	36.92	09.34	00.59	00.50	51.60	00.90	00.14
7.	38.06	09.70	00.53	00.46	49.38	00.80	00.20
8.	37.23	09.54	00.63	00.50	51.01	00.70	00.17
9.	37.75	09.50	00.49	00.47	49.97	00.80	00.17
10.	37.43	09.51	00.55	00.45	50.48	00.80	00.18
Average	37.49	09.52	00.56	00.478	51.59	00.78	00.176

TABLE 2. BOTTOM ASH ANALYSIS

No.	LOI (%)	SiO ₂ (%)	Al ₂ O ₃ (%)	Fe ₂ O ₃ (%)	CaO (%)	MgO (%)	SO ₃ (%)
1.	06.35	33.66	16.20	25.60	10.59	00.60	05.89
2.	07.00	34.64	16.30	24.70	10.60	00.70	06.23
3.	06.82	33.69	16.80	24.20	11.30	00.40	06.73
4.	06.45	34.56	16.23	25.20	11.20	00.50	06.20
5.	07.23	32.20	16.20	24.20	10.23	00.80	06.11
6.	06.49	33.11	17.00	24.90	10.23	00.70	07.00
7.	07.13	32.36	16.39	25.30	10.90	00.60	05.9
8.	06.03	33.20	16.38	25.70	11.34	00.70	05.70
9.	06.33	34.55	16.34	24.90	11.39	00.50	06.80
10.	06.74	35.00	16.26	24.80	09.93	00.60	06.00
Average	06.65	33.37	16.41	24.95	10.77	00.61	06.25

7. CONCLUSIONS

From this research study, the following conclusions are made:

- (i) Low quality limestone containing about 10% silica has been used at the power plant.
- (ii) It was concluded that due to the high density particles of silica present in the fly ash that causes pressure part erosion (boilers tubes/ID fans) is the root cause that is also reported by other researchers.
- (iii) Due to noncombustible property, rough shape & higher velocity of silica particles, the generation tubes and wings/blades of ID fans were eroded, and the filter bags were also ruptured, resulting

frequent shut down of the plant, causing heavy financial losses.

- (iv) Due to the presence of silica, the efficiency of the FBC reactor was badly affected.
- (v) It was found that the maximum quantity of silica about 39% in the re-injection material, about 34% in the bottom ash and 24% in fly ash was present.

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TABLE 3. FLY ASH ANALYSIS

No.	LOI (%)	SiO ₂ (%)	Al ₂ O ₃ (%)	Fe ₂ O ₃ (%)	CaO (%)	MgO (%)	SO ₃ (%)
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
6.	15.20	23.50	13.70	09.00	23.40	02.30	13.20
7.	14.50	24.39	14.90	09.30	24.00	02.90	13.50
8.	14.70	24.39	14.90	09.80	23.70	03.50	14.00
9.	13.80	25.23	14.30	09.70	23.40	02.70	12.80
10.	14.90	24.33	14.50	09.20	24.00	02.40	13.20
Average	14.48	23.61	14.09	09.15	22.89	02.71	13.13

TABLE 4. UN-BURNT (RE-INJECTION) MATERIAL ANALYSIS

No.	LOI (%)	SiO ₂ (%)	Al ₂ O ₃ (%)	Fe ₂ O ₃ (%)	CaO (%)	MgO (%)	SO ₃ (%)
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
6.	03.54	37.30	30.20	18.20	05.70	02.39	03.20
7.	03.55	37.32	30.90	19.30	06.70	03.20	02.90
8.	03.00	39.43	30.20	17.90	07.30	02.40	02.80
9.	03.55	39.51	30.80	18.90	08.70	01.38	02.50
10.	02.09	38.21	28.00	17.00	04.90	01.50	02.80
Average	03.10	38.54	29.00	18.32	06.20	01.91	02.94



FIG 3. EROSION OF WINGS OF ID FAN

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