A study on the slagging and fouling propensity of imported coals blended with Indian coal

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Coal blending excercises are becoming popular in the present day scenario with many of the Indian thermal power plants. Blending of an inferior variety of indigeneous coal with that of high quality imported coal is gaining importance. With the depleting coal reserves in the country leading to deterioration of the indigeneous coal quality and less availability of the high grade coals, it has become imperative on part of the power generation plants to import high quality coals and blend them with inferior variety of indigeneous coal and burn them in the boilers for power generation.

It is challenging to ensure that the resulting coal blend will maintain the required plant output without damaging the boiler and high temperature components.

Combustion of various coalsblends in the boiler lead to a variety of complex thermochemical reactions. The inert residue of coal combustion product which is ash is composed of complex oxides of various minerals. The quantity and the characteristic of the ash is inherent to the particular type of coal combusted. The fusion of this ash in the boiler during combustion may sometime lead to slag forming and fouling problems. This slagging and fouling phenomenon is dependent on a number of factors such as the ash chemical composition, combustion temperature, combustion atmosphere, boiler operating parameters etc., Deposition of coal ash/slag and fouling impedes the heat transfer there by increasing the Flue Gas Exit Temperature (FEGT). Ash deposits due to fouling on convective pass tube banks can block flow passages. Large deposits in the upper furnace or radiant zone dislodge and fall which may cause damages to the lower furnace pressure parts. Extreme ash deposition leads to forced outages and corrosion problems. Keeping the above in view it is important to study the various parameters related with blended coal so as to ascertain the proper blend ratios, operating temperature, boiler conditions and other factors.

In this study 3 types of imported coals and an Indian coal was blended in various proportions and the blended coals were studied for their various paratmeters such as ash fusion temperatures, chemical compositions etc., and by applying certain indices, the behavior of the residual blended coalash for its slagging and fouling propensity have been reported.

Keywords: *Blending of coals, slagging propensity, fouling, boiler slags, pulverized coal firing*

1.0 INTRODUCTION

India is one of the world's largest consumer of energy. The conventional sources of energy are thermal, hydro and nuclear. Non-conventional energy sources are wind, solar, geothermal, tidal and others. The installed capacity in India as on 31.09.2016 (Source: Central Electricity Authority) is about 3.06 GW, in which the thermal power installed capacity is about 2.13GW which is about 70 %. Among the thermal power

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generation, coals of various gradesare used to generate about 1,87,253 MW which is about 87.8 %. Nuclear power generation is about 5,780 MW and Hydro power plants contribute to about 43,112 MW. Solar power including Renewable Energy (RES) sources account to about 44,237 MW. The annual growth rate is envisaged at 6 % and the number of units which have completed design life is about more than 40 %. The expected service life of a power plant is estimated to be 25-30 years.

It is seen that use of fossil fuels such as coal continue to dominate the electricity production through out the world and it is estimated that about 10,000 plus Terra Watt hour power would be generated by the year 2030 worldwide.

Coal a cheapest fuel available abundantly in the world, which is basically composed of hydrocarbons chemically as a major constituent. Coals are being termed as an heterogeneous material having complex chemistry with associated moisture, volatiles, sulpur, and ash. These constitutents vary widely to a large extent from mine to mine and from different geological coal deposit locations worldwide.

Coal is classified into three major types namely anthracite, bituminous, and lignite. How ever there is no clear demarcation between them and coal is also further classified as semi- anthracite, semi-bituminous and sub-bituminous.

Anthracite is the oldest coal from geological perspective. It is a hard coal composed mainly of carbon with little volatile content and practically no moisture. Lignite is the youngest coal from geological perspective. It is a soft coal composed mainly of volatile matter and moisture content with low fixed carbon. Fixed carbon refers to carbon in its free state, not combined with other elements. Volatile matter refers to those combustible constituents of coal that vaporize when coal is heated. (www.researchgate.net). Figure 1 depicts various types of coals.

Coal exclusively used as a fossil fuel in boilers for power generation, metallurgical reduction

processes, and many other such applications or processes which involve enormous heat consumption.
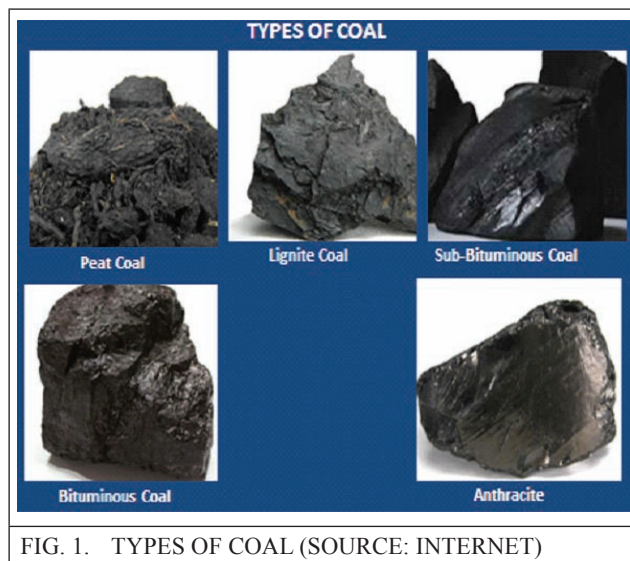

FIG. 1.   TYPES OF COAL (SOURCE: INTERNET)

The operating parameters in the boilers to a large extent depend on the coal chemistry and physics and the boilers for such applications are designed depending on the coal availability, its quality and quantitive parameters in the nature. India depends to a large extent on thermal power stations for power generation and most of the thermal power generation companies depend on coal for fuel in their boilers. India has vast deposits of coal with a lot of inconsistency in the quality and variations in terms of physical, chemical and thermal properties. The coal consumption is also enormous leading to depletion in the coal deposits in the country and the quality of coal is also a concern for boiler operators. With the increase in demand for the power generation and the installation of increased capacity thermal power plants in the country, the demand for coal supply associated with quality is also on the rise.

It has become obvious that to meet the growing demand for the quality and quantity of coal, the power plants are looking at coal suppliers outside the country thereby leading to the increase in coal imports during the past decade. Indonesia accounts for over 70 % of India's annual thermal coal import of around 110 million tonnes(mt). Other coal import destinations for India are Australia, South Africa and the US.

Considering the growing needs of imports due to constraints in the availability of domestic coal, CEA in its advisory has told that all the power generating companies, power project developers and power equipment manufacturers that boilers, including auxillaries, should be designed for a 30:70 blend ratio, in which 30% would be imported/ high gross calorific value (GCV) coal, while 70% would be indegeneous coal. Coal quality variations may not be readily accommodated in a plant, and may lead to loos in efficiency It is thus considered prudent that all future coal fired thermal power stations be set up in the country shall be designed to enable the use of higher percentage of imported coal, as may be required (indianpowersector.com)

Indian coals have ash content varies over a wide range from as low as 12% to as high as 55% with an average gross calorific value of about 4800 kcal/kg. Ash content are greatly influenced by the extraneous mineral matter which are contaminated during coal mining. Some of the extraneous minteral matter may be air borne of water borne which have deposited on the coal surface leading to contaminations. Many high ash fuels can be fired successfully in the boilers for power generation. For the purpose of design and to evaluate the quality of fuel, the ash content is determined and to consider the ash content as the basis to express as weight per unit of head input which is expressed as kg ash/MJ which is calculated as:

$$\frac{\text{Ash (\% by weight)}}{\text{HHV(kJ/kg)}} \times 10^3 \qquad \ldots(1)$$

Where HHV is the higher heating value of the fuel. Figure 2 illustrates the coal flow profile in a thermal power plant.

FIG. 2.   COAL FLOW PROFILE IN A THERMAL POWER PLANT SHOWING SLAGGING AND FOULING REGIONS (SOURCE: INTERNET)
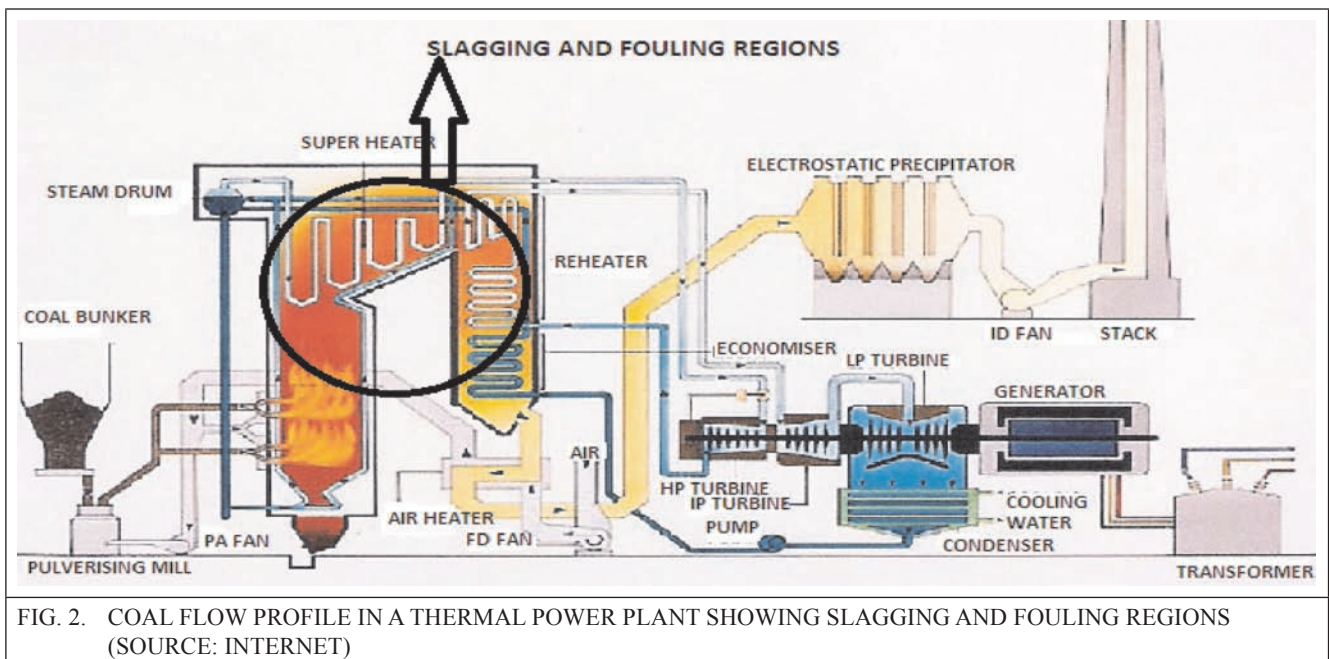
1.1   Slagging

The term 'Slagging' refers to coal ash deposition taking place in the boiler sections where radiative heat transfer is dominant.

When coal is burned, relatively a small portion of the ash will cause deposition problems. When the ash is passing through the boiler various chemical reactions and physical forces lead to deposition on the heat absorbing surfaces. The process and structure of deposits are variable to a number of factors such as particle composition, shape, size, particle and surface temperatures, gas velocity, flow patterns and other factors. Primarily due to difference in deposition mechanism, 2 types of high temperature ash deposits have been defined: slagging and fouling.

Slagging which is the formation of molten, partially fused or re-solidifed deposit of the coal ash on the furnace walls and other surfaces which are exposed to the radiant heat. Slag deposits may also occur at convective surfaces if the gas temperatures are not reduced sufficiently. Most ash softens at combustion temperatures. The cooling rate determines wether solid, plasitic or liquid at a given location in the furnace. In order to adhere to a clean surface to from a deposit, the ash particle must have a viscosity low enough to wet the surface.

Slag deposits do not form on clean surfaces and a conditioning period is required before significant deposits occur. Over a period of time a base deposit begins to form on the boiler tube surface due to settling of fine ash particles and gradual accumulation of this fine ash particles with very low melting constituents present in the ash. As the base deposit thickens, the temperature outside the deposit increases above the surface temperature of the tube. Eventually more of the ash deposit melting point exceeds thereby leading to the ash deposit to become molten. This process becomes self accelerating with the plasticity nature of the molten slag traps all the eventually impinging ash particles on it. Ultimately the deposit thickens and an equilibrium state is reached wherein the slag begins to flow. The deposits too become heavy and it falls away from the tube sometimes pulling away a portion of the tube material along with the base deposit.

1.2 Fouling

'Fouling' usually takes place in the cooler convective heat transfer sections of the boiler and results from the behavior of components as the gases cool down.

Corrosion occurs when metal from the tube wall reacts with a component from an ash deposit or flue gas, and erosion is due to the impact of hard particles on tube surfaces and tends to occur in the high heat absorbing surfaces such as superheaters, reheaters that are not exposed to radiant heat.

FIG. 3.   BOILER SECTIONS SHOWNING SLAGGING AND FOULING DEPOSIT AREAS
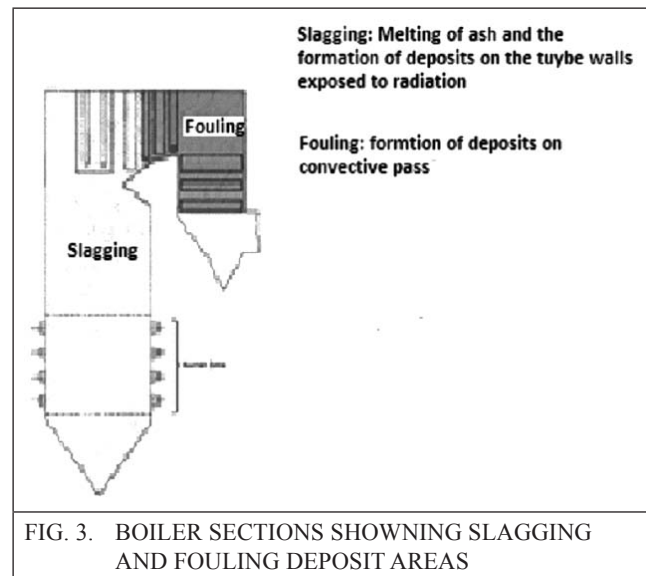
Fouling is usually caused velocity sections of the convective part of the boiler, and is exacerbated bypartial blockage due to fouling deposits. Fouling is caused by vaporization of volatile inorganic elements during coal combustion. As the heat is absorbed and the temperature is lowered at the convection passes inside the boiler, compounds formed by combustion of these elements condense on as particles and heating surfaces forming a glue like substance which initiates deposition. The areas where slagging and foulding are dominant inside a boiler is shown in Figure 3.

1.3 Ash classification

The ash generated from comubstion of coal can be classified as Bituminous & Sub-Bituminous and Lignitic variety depending on the chemical composition. If the presence of Iron Oxide is high compared to the total of Calcium Oxide and Magnesium Oxide, then the coal is classified as Bituminous and Sub- Bituminous variety of ash.

a) $Fe_2O_3 >$ (CaO + MgO) – Bituminous & Sub Bituminous ash.

Whereas if the presence of Iron Oxide is low compared to the total of Calcium Oxide and Magnesium Oxide, then the ash is classified as Lignitic ash.

b) $Fe_2O_3 <$ (CaO + MgO) – Lignitic ash

1.4 IMPORTANCE OF ASH ELEMENTAL ANALYSIS

It is important to assess the chemical constituents of the ash in terms of its qualitative and quantitative aspects. The composition of the ash to a very large extent help prediction of the behaviour of the particular ash at hight temperature in boilers and thereby helps to assess its slagging and fouling characteristics. The following parameters help us to predict the ash behaviours in the boilers:

1.4.1 Base/ Acid oxide ratio in ash

Silica(oxide of Silicon),Alumina(oxide of Aluminium) and Titania(oxide of Titanium) are termed as acidic oxides whreas the oxides of oxides of iron, calcium, magnesium, soda and potash are termed as basis oxides.

The Base/Acid ratio is defined as the sum of oxides of iron, calcium, magnesium, soda and potash divided by the sum of oxides of silicon, aluminium and titanium and this is represented as:

$$\frac{(Fe_2O_3 + CaO + MgO + Na_2O + K_2O)\% \text{ by wt}}{(SiO_2 + Al_2O_3 + TiO_2)} \quad ...(2)$$

The % base is calculated as:

$$\frac{(Fe_2O_3 + CaO + MgO + Na_2O + K_2O) \times 100}{(SiO_2 + Al_2O_3 + TiO_2 + Fe_2O_3 + CaO + MgO + Na_2O + K_2O)} ...(3)$$

The % of acid is calculated as:

$$\frac{(SiO_2 + Al_2O_3 + TiO_2) \times 100}{(SiO_2 + Al_2O_3 + TiO_2 + Fe_2O_3 + CaO + MgO + Na_2O + K_2O)} ...(4)$$

The basic and acidic oxides tend to combine to form compounds that are eutectic in nature or that they tend to flux of lower the melting temperature than their respective melting temperatures individually. The relative proportions of basic and acidic constituents tend to provide an indication on the melting behaviour and viscosity of slags.

Ash generally either acidic or basic in nature has a high melting and fusion temperatures. Generally the basic constituents in an acidic ash tend to flux or reduce the melting temperature and viscosity of the ash. However on the other hand the fusion temperature and ash viscosity are reduced by the relative proportions of the acidic components in the ash. Minimum fusion temperature occur at about 40-45% base constituents in the ash which is about 0.7-0.8 base to acid ratio. The ratio in the range of 0.5-1.2 is generally considered to be having high slagging potential. Studies conducted by Babcok and Wilcox on the relationship of ash composition to ash viscosity provides additional information to the slagging behaviour of the ash in addition to simple acid base ratio calculations. The study indicated that the ash become viscous and flows when it achieves a viscosity to 250 poise and the temperatue at which this occurs is usually termed at $T_{250.}$ The preferred maximum T_{250} temperature is for ash is about 1340°C.

1.4.2 Effect of Iron Oxide in ash

Iron Oxide is mostly existing in pyrite form (FeS_2) has dominating influence on slagging characteristics of coals. Pyrite forms Pyrrhotite (FeS), FeO and metallic iron in the reducing atmosphere has significant low melting point and has a profound effect on the slagging behaviour of the ash.

The iron oxide's presence has a dominating influence on the slagging behaviour of ash. Iron oxide present has been further classified by their mineralogical name depending on its chemical constitutent. They include pyrite (Fe_2S), siderite ($FeCO_3$), haematite (Fe_2O_3), magnetite and ankerite [(Ca, Fe, Mg) CO_3)]. Pyritic form of iron is the major form of oxide in the coal ash. In the oxidation atmosphere, the pyrite form gets disintegrated into Fe_2O_3 and SO_2. However, in the reducing atmosphere, the pyrite gets converted into pyrrhotite (FeS) which is a less oxidized form of iron and at reducing atmospheres the ash melts at a lower temperature compared to the highly oxidized forms.

The fluxing tendency of iron is related to its oxidation state since metallic iron and ferrous iron (FeO) are stong fluing agents as compared to Fe_2O_3 and tend toreduce the reduce the fusion temperature and slag viscosity at a given temperature. The degree of iron oxidation is usually expressed as Ferric percentage which is:

$$\frac{(Fe2O3) \times 100}{(Fe2O3 + 1.11\ FeO + 1.43\ Fe)} \qquad ...(5)$$

1.4.3 Dolomitepercent

It is reported that for lignitic ash with less than 60 % acidic content, the T_{250} is both the function of percentage of bases and the dolomite percent. Dolomite percentage is defined as:

$$\frac{(CaO + MgO) \times 100}{(Fe2O3 + CaO + MgO + Na2O + K2O)} \qquad ...(6)$$

Higher dolomite percent increases the T_{250} temperature since both calcium and magnesium contents tend to increase the viscosity and fusion temperatures of the ash. The increase in other base constituents such as iron, sodium and potassium oxides tend to lower the T_{250} temperature. However in all, it is observed that the silica, alumina, calcia and magnesia indicate higher melting temperature and viscosities whereas the combinations of iron, sodium and potassium act to increase the fluxing tendency and the slagging potential.

1.4.4 Slagging index- Bituminous ash (R_s)

The slagging index of bituminous ash takes into consideration the acid to base ratio and the weight percent of sulphur on dry basis in the coal. While the base to acid ratio gives an indication on the tendency of the ash to form the compounds that melt at low temperatures, the sulphur indicates the presence of iron as pyrite.

The slagging index of bituminous ash (R_s) is calculated as:

$$Rs = \frac{B}{A} \times S \qquad .....(7)$$

Where

B= $CaO + MgO + Fe_2O_3 + Na_2O + K_2O$

A= $SiO_2 + Al_2O_3 + TiO_2$

S=Weight of sulphur on dry coal basis

1.4.5 Iron Calcium

As per the suggested guidline for this index, the iron calcium ratio that is Fe_2O_3/ CaO should be < 0.3

1.4.6 Silica and Silica Alumina ratio

As per the suggested guidline for this index, the Silica (SiO_2) % is specified between 72-80% for low , 65-72 % for medium and 50-65% for high in terms of slagging tendency. The silica to alumina ratio that is SiO_2/Al_2O_3 should be < 2.8.

1.4.7 Soda (Na2O)

As per the suggested guidline the soda (Na_2O) content should be < 2.5 %.

1.4.8 Iron oxide (Fe2O3)

As per the suggested guidline the iron oxide content (Fe_2O_3) content should be < 15 %.

1.5 Ash Fusion Temperature(^{o}C)

The determination of Ash Fusion Temperature (AFT) of the ash is of prime importance to assess its high temperature behaviour. The ash fusion test gives an indication of the softening and melting behavior of coal ash at high temperatures in oxidizing atmosphere. Ash fusion temperature is determined by heating a prepared sample of molded ash in a cone form, in a high-temperature furnace to temperatures exceeding 1,000^{o}C in both reducing and oxidizing conditions. Ash fusion point is also one significant parameter as far as ash analysis is concerned.

FIG. 4.   ASH FUSION TEMPERTURE SCHEMATIC
   (SOURCE: INTERNET)
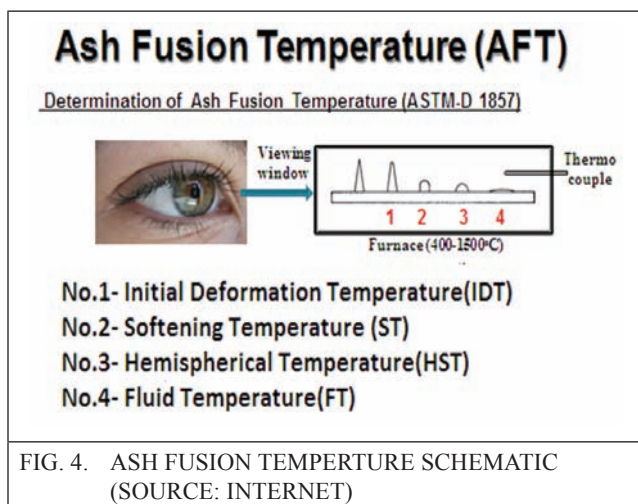
Ash fusion temperatures are determined by viewing a moulded specimen of the coal ash through an observation window in a high-temperature furnace known as the Ash Fusion Temperature Determinator. The ash, in the form of a cone, pyramid or cube, is heated steadily past 1000 °C to as high a temperature as possible, preferably 1,600 °C . The ash fusion determination schematic is represented in Figure 4.

2.0 EXPERIMENTAL

A study was conducted to assess the behaviour of imported coals blended with Indian coals. In the study 2 imported coals designated as 'Imported Coal A' and 'Imported Coal B' obtained from South Africa and indegeneous coal designated as 'Indian Coal' were used for blending studies. The imported and Indian coals which were received in lumps form of size 250- 300 mm was initialled crushed through primary crusher to a size of about 40-50mm and was crushed through secondary crusher to a coal size of about 10-12 mm size. Later this 10-12 mm sized coal sample was further pulverized to 212 microns(ASTM 70 mesh) using laboratory make pulverizer. The coal sample preparation has been carried out following the IS-436(part1/Sec-1)-1964 standard. The individually powdered coal samples were blended in various propotions thoroughly as per the composition presented in Table 1.

TABLE 1	
COAL BLEND COMPOSITION	
Composition (%)	Sample No
10 Imp-A : 90 Indian Coal	1
20 Imp-A : 80 Indian Coal	2
30 Imp-A : 70 Indian Coal	3
50 Imp-A : 50 Indian Coal	4
10 Imp-B : 90 Indian Coal	5
20 Imp-B : 80 Indian Coal	6
30 Imp-B : 70 Indian Coal	7
50 Imp-B : 50 Indian Coal	8
10 (Imp-A -50 + Imp-B 50): 90 Indian Coal	9
20 (Imp-A -50 + Imp-B 50) : 80 Indian Coal	10
30 (Imp-A -50 + Imp-B 50) : 70 Indian Coal	11
50 (Imp-A-50 + Imp-B 50) : 50 Indian Coal	12

The blended coals were then taken up for ash preparation in a LECO make TGA701 Thermogravimetric Analyzer. The lab prepared ash was then analysed for the chemical constitutents by Panalytical make X-Ray Floure scence spectro meter (XRF) and Leica make Energy Dispersive X-Ray Analyzer (EDXRF). The Ash Fusion Temperature was determinded using LECO AF700 Ash Fusion Temperature Determinator (AFTD) as per ASTM D 1857 standard and the oxide phases present in the ash were determined using Panalytical X-Ray Diffracto meter (XRD). The analytical equipment used for the study are shown in Figure 5.

FIG. 5.   ANALYTICAL EQUIPMENT USED FOR THE
         STUDY
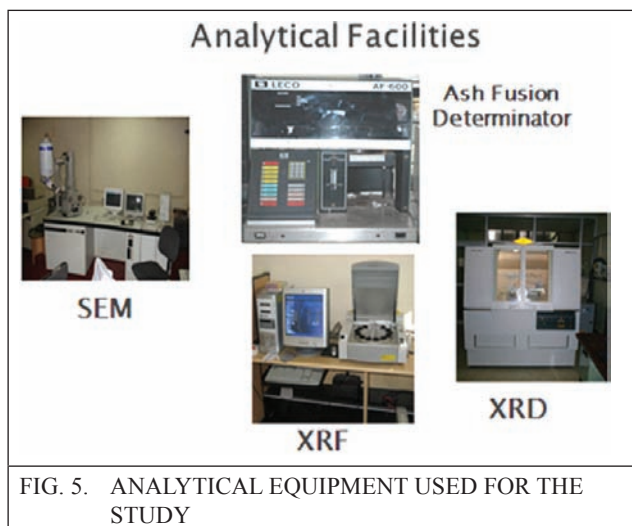
3.0 RESULTS

3.1 Base to Acid ratio

The measured base to acid ratio for the 12 blended coal ash samples were measured to be in the range 0.11 to 0.16. The results are projected in the graph at Figure 6.
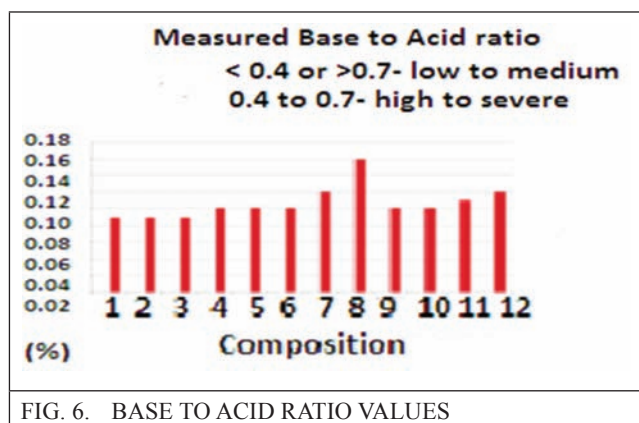

FIG. 6.   BASE TO ACID RATIO VALUES

The results indicated that the values were in the range of low to medium and that the results fall within the accepted range of < 0.4 to > 0.7.

3.2   Iron oxide content in ash

The measured iron oxide content for the blended coal ash samples were measured to be in the range 5.8 to 7.6 %. The results are projected in the graph at Figure 7.
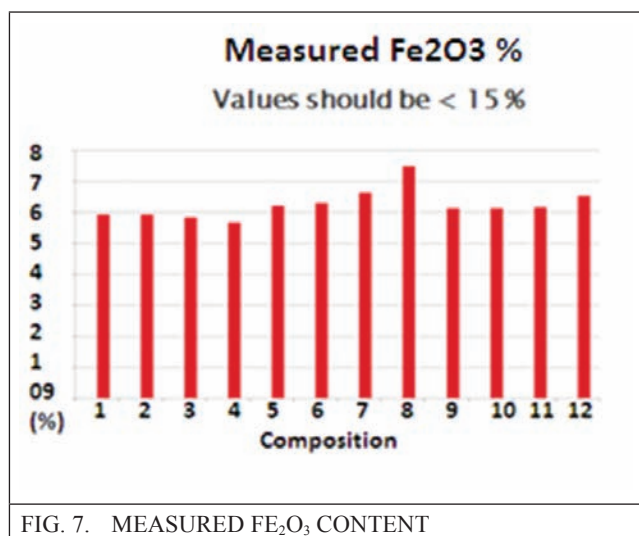

FIG. 7.   MEASURED FE_2O_3 CONTENT

The results indicated that the values were within the acceptable range of < 15 %.

3.3   Dolomite content in ash

The dolomite content for the blended coal ash samples measured varied from 20 to 38 %. The results are projected in the graph at Figure 8.
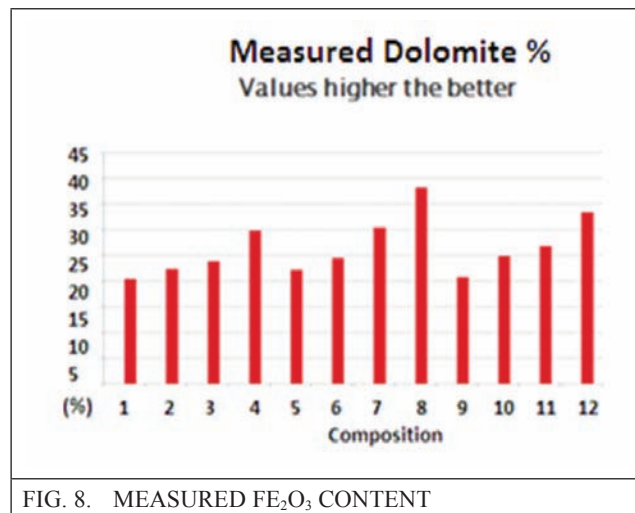

FIG. 8.   MEASURED FE_2O_3 CONTENT

The results indicated that the values were on the higher side for some of the coal blend samples like 4, 7, 8 and 12 which were 30, 30, 38 and 33 % respectively. The higher values of dolomite content is preferred in the coal ash.

3.4   Slagging index- Bituminous ash (R_s)

The slagging index- bituminous ash for blended coal ash samples measured showed values as low as from 0.02 to as high as 0.06. The results are projected in the graph at Figure 9 shows the slagging index of the bituminous ash showed the values within the range of < 0.6 which is very low.
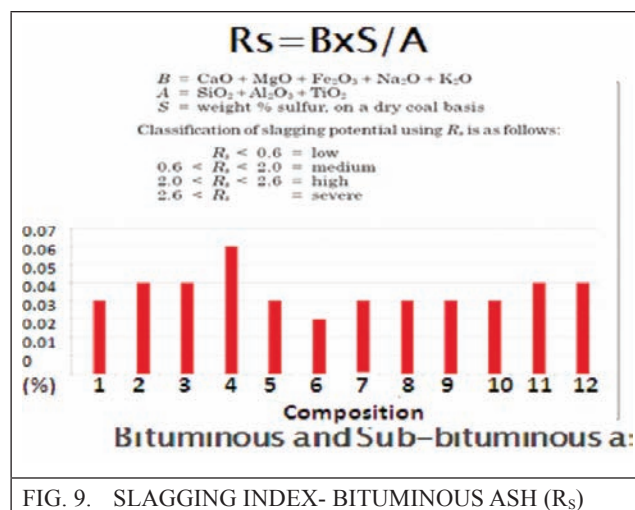

FIG. 9.   SLAGGING INDEX- BITUMINOUS ASH (R_S)

3.5 Measeured Iron Calcium

The measured iron to calcium ratio for the blended coal ash samples measured varied from as low as 1.7 to as high as 3.6. The results are projected in the graph at Figure 10 indicate that the values are on the higher side. The values should be less than 0.3 % for better slagging resistance of the ash.
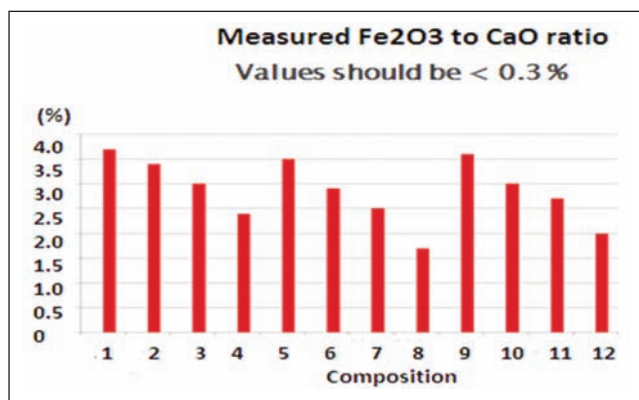

FIG. 10. FE2O3 TO CAO RATIO

3.6 Silica/ Silica Alumina ratio

The silica content is between 55- 60 % indicating high range and high slagging propensity. Silica alumina ratio that is SiO_2/Al_2O_3 should be < 2.8 and the values ranged from 1.85 to 2.0 for the samples indicating that they are in acceptable range. The Figure 11 depicts the values of the alumina silica ratio for the ash samples.
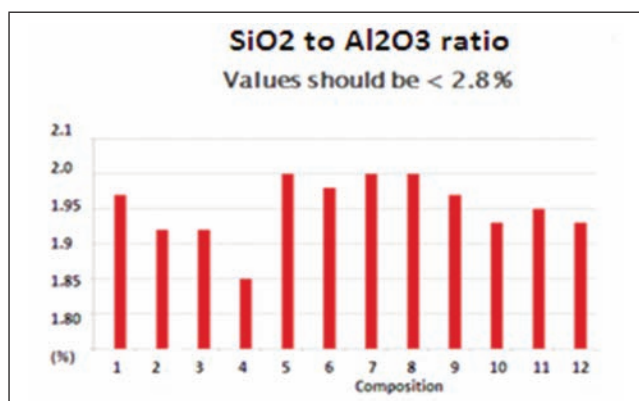

FIG. 11. SILICA ALUMINA RATIO

3.7 Soda (Na2O)

The soda content (Na_2O) in the ash samples varied from as low as 0.01% for sample no. 9 to as high as 0.12% for sample no.12 indicating that the soda content is low and well within the

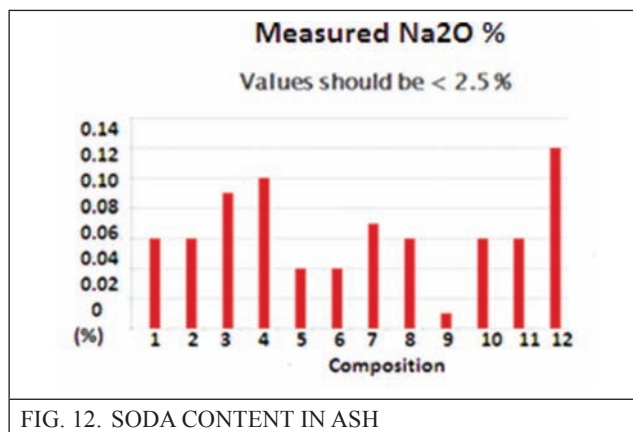stipulated requirement of < 2.5 % and this is depicted in Figure 12.

FIG. 12. SODA CONTENT IN ASH

3.8 Iron oxide (Fe₂O₃)

As per the suggested guidline the iron oxide content (Fe_2O_3) content should be < 15 %.The iron oxide content (Fe_2O_3) in the ash samples varied from as low as 5.7 % for sample no. 4 to as high as 7.5 % for sample no.8 indicating that the iron oxide content is low and well within the stipulated requirement of < 15 % and this is depicted in Figure 13. The ash elemental analysis of the blended coal blend ash samples are shown in Table 2.
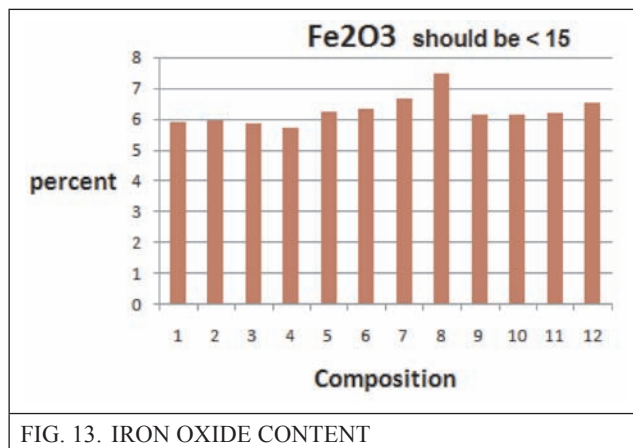

FIG. 13. IRON OXIDE CONTENT

3.9 Ash Fusion Temperature(ºC)

The Initial Deformation Ash Fusion Temperature (AFT) of the ash samples is of prime importance to assess its high temperature behaviour and to know the slagging tendency of the given ash. The IDT of the ash samples are depicted in Figure 14.
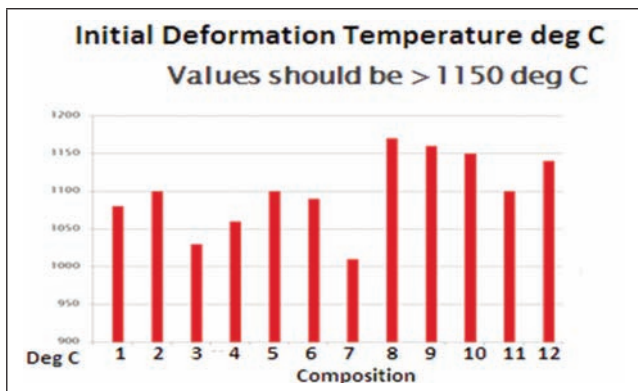
FIG. 14 IDT OF ASH SAMPLES

Coal blending is extremely useful to The IDT of ash samples varied from lower temperature of 1010^0C for sample no. 7 to higher temperature of 1070^0C for sample no. 8 indicating that IDT temperatures are low and not within the specified temperature of minimum of 1150^0C.The other ash fusion temperatures such as IDT, ST, HST and FT are shown in Table 3 and the inference drawn from the study is presented in Table 4

TABLE 2												
ASH ELEMENTAL ANALYSIS (%)												
Oxides	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
SiO_2	60.2	59.6	59.4	58.1	59.9	59.3	58.3	55.9	60.0	58.9	58.8	57.5
Al_2O_3	29.8	30.1	30.1	30.5	29.3	29.1	28.4	27.2	29.6	29.7	29.4	28.9
CaO	1.6	1.7	1.93	2.4	1.80	2.19	2.70	4.32	1.72	2.04	2.30	3.19
MgO	0.2	0.22	0.20	0.42	0.25	0.28	0.65	0.87	0.14	0.31	0.29	0.55
MnO	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01
TiO_2	0.6	0.70	0.73	0.77	0.73	0.75	0.82	1.01	0.70	0.75	0.72	0.85
Na_2O	0.06	0.06	0.09	0.10	0.04	0.04	0.07	0.06	0.01	0.06	0.06	0.12
K_2O	0.9	0.88	0.84	0.76	0.95	0.89	0.94	0.86	0.91	0.88	0.86	0.82
Fe_2O_3	5.9	5.94	5.85	5.68	6.21	6.30	6.64	7.48	6.14	6.13	6.17	6.53
P_2O_5	0.4	0.27	0.28	0.23	0.33	0.32	0.37	0.27	0.34	0.30	0.34	0.25
SO_3	0.4	0.49	0.61	1.09	0.44	0.83	1.08	2.01	0.42	0.91	1.07	1.28

TABLE 3				
ASH FUSION TEMPERATURES (^{o}C)				
Sample Code No.	**IDT**	**ST**	**HST**	**FT**
1	1080	1490	>1500	>1500
2	1100	1470	>1500	>1500
3	1030	1400	>1500	>1500
4	1060	1450	>1500	>1500
5	1100	1450	>1500	>1500
6	1090	1440	1490	>1500
7	1010	1430	1460	>1500
8	1170	1480	>1500	>1500
9	1160	1475	>1500	>1500
10	1150	>1500	>1500	>1500
11	1100	>1500	>1500	>1500
12	1140	1430	1460	1500

TABLE 4			
OBSERVATIONS			
PARAMETER	**GUIDELINES**	**VALUES**	**INFERENCE**
Base/Acid ratio= $(Fe_2O_3+CaO+MgO+Na_2O+K_2O)$ / $(SiO_2+Al_2O_3+TiO_2)$	< 0.4	0.11 to 0.16	Values within range, and low slaggingpropensity
Sulphur slagging = Base/Acid ratio x % Sulphur	< 2.0	0.02 to 0.06	Low values and low slagging propensity
Iron Calcium= Fe_2O_3/CaO	< 0.3	1.7 to 3.6	Higher value, high slagging propensity
Silica Alumina ratio=SiO_2/Al_2O_3	< 2.8	1.85 to 2	Lower limit, acceptable range
Silica (SiO_2) %	72-80% low 50-65% for high	55-60 %	High range and high slagging propensity
Soda (Na_2O)	< 2.5		Lower range
Iron Oxide (Fe_2O_3)	< 15 to 20 %	5.8 to 7.6	Lower range
Initial deformation temperature	> 1150 deg C		Better
Dolomite percentage	33-35% for Blends	20-38%	Higher range

4.0 CONCLUSIONS

1) The acid/ base range indicated low slagging propensity but the owing to lower silica content, the slagging propensity increases.

2) The iron calcium ratio too indicated high slagging propensity owing to the higher values obtained.

3) The initial deformation temperatures for most of the blends indicated 1010 to 1070^{0}C, which too indicated high slagging propensity.

4) Laboratory coal blending study gives an indication about the behaviour of the coal blends during combustion in boilers to some extent

5) Coal blending maximises the use of lower quality of coals which would otherwise be discarded and increases the marketability of new coal source and expands the variety of coal which can be marketed world wide.

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