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Effect of Ash on the Efficiency and Capacity of Coal Fired Thermal Power plants

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This paper reports the effect of ash content in raw coal on the energy performance of coal fired thermal power plants of capacity range 30–500 MW It also gives the extent of capacity reduction in equipment due to firing of coals with higher ash contents.

The effects of variation of ash in coal from 6% (taken as standard) up to 75% (extreme) on component performance are studied and overall unit performance is quantified based on experimental data and performance simulation. When the ash content increases from 6% to 57% and above, the effects on the system (without fuel oil support) are: (a) efficiency of boiler fans drop by 22–27%, (b) drum mills show an increase in SEC of 115% while ball-race mills and bowl mills show an increase in SEC of 30%, (c) ID, FD and PA fans shown an increase in SEC of around 30%, 6–14% and 2–7% respectively, (d) the gross and net overall efficiencies are reduced to 77% and 66% of their original values, (e) ratio of the specific fuel consumption at a given ash content to that at standard ash of 6% increases from 1 to 10, and (f) SFC_{gross} increases from 0.35 to 3.0.

When the ash content of coal goes beyond 57%, limitations in combustion space and flow arise and beyond this the unit has to be operated only at part load. When the ash in coal exceeds 75%, its UHV is reduced to zero.

1.0 INTRODUCTION

The use of low grade, high ash fuel products of coal mines, viz., raw fines, middlings, slurry shales and mine reject dumplings without any processing was prevalent in power stations as early as the 1920s in Eastern Europe. Such high ash fuel products continued to be used late into the 1960s till the onset of cheap fuel oil from the Persian Gulf replaced coal as fuel. However, in India, which has low fuel oil reserves and especially after the Oil Crisis, coal is the base fuel for power generation.

The general experience from the East European stations was that coals with an ash of 55% could be used without any oil support and that up to 70% could be used with fuel oil support[1].

In 1957, the Mitsubishi Heavy Industries Co. Ltd., Japan designed a 0.33 t/h furnace to address two specific questions: (a) What is the limit of high ash coal that can be burned for power plant use? and (b) How to burn high ash pulverized coal efficiently?[2]. They have extensively tested coal of high ash contents and concluded that coals with ash as high as 63% and Useful heating value (UHV) of 6.5 MJ/kg can be burned easily without fuel oil support.

Indian non-coking coals (sub-bituminous and of drift origin) which are the main source of fuel for power generation in India can be broadly classified into three categories: (a) steam coal and rubble, (b) slack coal and washery meddlings, and (c) run of mine coal. These are sub-divided into long flame and non-long flame coals[3]. Most of the coal reserves of around 200 billion tonnes are of low grade variety with low heating value and high ash. Being of drift origin, the minerals and ash are intimately mixed in

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the coal matrix. The top size of Indian run-of-mine coal is 230 mm. In general Indian coals are harder than European, Australian and American coals.

Contamination of coal with ash has been a problem since coal came to be used as a fuel for steam generation and motive power. Coals used in thermal power plants generally contain ash (as received basis) from 8% to as high as 55%. Ash in coal is classified as inherent ash (cannot be reduced by cleaning), associated ash (present in coal seams, lenticels and partings) and adventitious ash (introduced extraneously during cutting) [4]. High ash in coal is occurring mainly because of open cast mining where coal is contaminated with surface mineral impurities (increase in ratio of open cast to underground mining from 26%/74% in 1974–75 to 80%/20% in 2000–01) and poorer seams. Kaolinite particles (generally less than 3 μm) and a-quartz (less than 100 μm) are the most troublesome contaminants in ash.

2.0 EXPERIMENTAL WORK AND PERFORMANCE INDICES

Detailed studies have been undertaken in over thirty coal fired thermal power units spanning around 4 years. Based on field studies conducted in the units and studies at the laboratory, the results of effects of ash on the plant performance are obtained in the form of the following curve fits:

(i) **Curves of Type: Linear:** $Y = A_0 + A_1 X$

(ii) **Curves of Type: Power series:** $Y = A_0 + A_1 X + A_2 X^2$

(iii) **Curves of Type: Non-linear:** $Y = D_0 X^{D1}$

In the above curve fits, X is the independent variable, Y is the dependent variable and $A \& D$ are constants.

The indices for quantification of the effects of ash in coal are as follows:

(i) Efficiency is the ratio of the rate of energy output to the rate of energy input to the system/sub-system (boiler, turbine, steam (boiler-turbine interface), generator, auxiliary load) under consideration.

(ii) Specific energy consumption (SEC) is the electrical energy per unit output of the auxiliary equipment.

(iii) Capacity factor (CF) due to electric auxiliary equipment is the instantaneous plant load factor (PLF) corresponding to unity auxiliary load factor (ALF) (100% electrical loading) as: CF = PLF/ALF

(iv) Efficiency ratio (ER) which is the ratio of the efficiency at a given ash to that at standard ash content for the same loading level of coal flow. The ER decreases with increase in ash content of coal.

(v) Specific energy consumption ratio (SECR) which is the ratio of the SEC at a given ash to that at standard ash. As the ash content in coal increases, the SECR decreases.

(vi) The SECR provides the SEC ratio due to increased ash in coal alone. The increased coal flow through the system can be quantified by the SFCR, which is the ratio of the SFC of the unit at a given ash content to that at standard ash.

(vii) To account for the dual effect of increase in coal flow through the system as well as increase in SEC due to quality effects, a SEC index (SECI) defined as: SECI = SECR.SFCR

This index covers both quantity effects (excessive energy consumption due to excessive flow necessitated by reduced efficiency or capacity) and quality effects (excessive energy/poor performance due to wear, erosion, etc.). Hence, it represents the overall behavior of the system which increases with ash content of coal.

3.0 RESULTS AND DISCUSSION

3.1 Heating Value

The data for Belgium high ash mine products[1] are correlated as follows:

$$UHV = 34.937 - 39.173(f_{ash}) - 37.487(f_m)$$

where f_{ash} is the fraction of ash and f_m is the fraction of moisture in coal. The UHV (MJ/kg) is zero at an ash content 79%.

The data for Japanese high ash coals[2] is fitted to a curve as follows:

$$UHV = 35.432 - 35.530(f_{ash}) - 37.982(f_m)$$

The UHV (MJ/kg) is zero at an ash content 89%. The UHV (MJ/kg) for Indian coals is given by[3] as,

$$UHV = 37.202 - 57.684(f_{ash} + f_m)$$

The UHV becomes zero at an ash plus moisture content of 64.4%.

The functional variation of UHV (MJ/kg) with ash is given by Pattanshetti[5] as,

$$UHV = 34.6771 - 42.7688(f_{ash}) - 38.2855(f_m)$$

The UHV is zero when the ash content in coal exceeds 76% (at a moisture of 6%). Though a number of other correlations are in use, this correlation predicts UHV for Indian coals very accurately as it is based on data obtained over several decades.

3.2 Effect on Combustion and Heat Transfer

The effects of ash in coal on combustion and heat transfer are as follows:

(a) **Boiler:** Decreased flame temperature, decreased heat absorption in heat exchangers, increased excess air flow, increased oxygen in flue gas. Increased deposits of ash as slag on the boiler heating surfaces.
(b) **Turbine-generator:** Use of reheater spray and superheater spray reduces specific turbine work. Decrease of turbine efficiency due to low load operation caused by mill and boiler side limitations.
(c) **Auxiliary Steam:** Excessive soot blowing due to higher ash levels in the boiler and air preheater zones.
(d) **Auxiliary Power:** Higher loading and higher power input to induced draft (ID) fans, forced draft (FD) fans and primary air (PA) fans due to requirement of combustion air.

3.3 Effect on Power Plant Equipment Performance

Ash in coal affects the boiler auxiliary fans [ID, FD and PA], mills (Raymond bowl mills, Drum/tube type ball mills and slow speed large ball and race 'E' mills- for short refered to as bowl mills, drum mills and ball-race mills respectively). It does not affect crushers and coal handling equipment significantly because of the presence of a large percentage of fines. At an ash content of 50%, the SEC of crushers is sometimes even less than its design SEC owing to fines in coal. Similarly the effect of ash on turbine auxiliaries (boiler feed pumps and condensate extraction pumps) and some of the other outlying auxiliaries such as river water plant, water treatment plant, etc. is negligible.

The auxiliary efficiencies (+motor) are given in Table 1. The efficiency of all boiler auxiliary fans (ID, FD and PA) drop by 19–23% when the ash content in coal increases from 6% to 50%. This is the coupled effect of offset of the operating point of the fan (head-discharge) from its designed point, higher density of ash particles as compared to air/flue gas and wear/erosion/abrasion effects.

TABLE 1

COEFFICIENTS IN THE CURVE FITS OF EFFICIENCY OF AUXILIARY EQUIPMENT AS A FUNCTION OF ASH CONTENT OF COAL

Sl. No.	Particular of variable X: f_{ash} (0.06–0.75) Y:Efficiency (%)	Constants in curve fits (Type: Non-linear)	
		D_0	D_1
01	Induced draft fans (210 MW units) (33.3–57.0%)	31.302	−0.2129
02	Forced draft fans (210 MW units) (31.7–57.3%)	29.627	−0.2343
03	Primary air fans (210 MW units) (30.9–56.0%)	28.860	−0.2353
04	Induced draft fans (500 MW units) (34.8–56.9%)	32.943	−0.1938
05	Forced draft fans (500 MW units) (32.3–57.3%)	30.331	−0.2258
06	Primary air fans (500 MW units) (30.7–56.6%)	28.621	−0.2486

The analysis of data indicates that for an increase in ash content from 6% to 50%, drum mills are most sensitive (increase in SEC: 73%) followed by ball-race mills and bowl mills (increase in SEC: 20%). Among the boiler fans, ID, FD and PA fans show an increase in SEC of around 18–19%, 4–9% and 2–5% respectively for an increase in ash in coal from 6% to 50%. Though FD and PA fans do not handle ash, contamination from the fan suction and rotary APH lead to increased SEC.

The variable which affects the milling power, i.e., Hardgrove index (HGI) varies between 44 and 80 for an ash range of 6–75% as,

$$HGI = 41.318^{(-0.2327 f_{ash})}$$

3.4 Capacity Drop Caused by Wear/Erosion/ Abrasion Arising from Ash in Coal

Wear/erosion/abrasion effects lead to a decrease of fan efficiencies by 5–6% points. At an ash content of 50%, the improvement in CF (due to improvement in efficiency) of equipment before and after overhaul/replacement is 12% due to limitations from mills, 17% due to ID fans, 10% due to FD fans and 2.5% due to PA fans. The corresponding CF due to wear/erosion/abrasion is by,

$$CF = \mathrm{Min}[\{1 - 0.5(CF_{\text{after overhaul}} - CF_{\text{before overhaul}}) + (\text{design margin})\}, \{1\}]$$

Based on the above CF Equation, CF originating from wear/erosion/abrasion effects alone is 92% due to ID fans, 99% due to PA fans and 94% due to mills. The design margins are 20% for ID and PA fans, 25% for mills and 263% for FD fans for 210 MW units. In the case of FD fans, the CF is unaffected by wear/erosion/abrasion because of the design margin (at the electrical motor) is quite wide.

3.5 Capacity Drop Caused by Slagging and Fouling

The effects of slagging and fouling factors (dimensionless numbers between 0 and 1 with zero indicating no slagging/fouling and 1 indicating very severe slagging/fouling) on boiler efficiency and CF of 210 MW units are given in Table 2. The slagging effects are much more severe than those of fouling. The effects of slagging (independent of ash content in coal) are 20% decrease in boiler water wall loading, 3.5% points decrease in boiler efficiency and capacity reduction of 14%. The effects of fouling (at an ash content in coal of 75%) are high fouling factor, decrease in boiler efficiency by 3% and capacity reduction of 2%.

3.6 Capacity Factors due to Auxiliaries

The capacity reduction of equipment can be quantified by calculating the instantaneous PLF corresponding to 100% electrical loading of the auxiliary. The design corresponding to standard ash (i.e., 6%) provides 20% margin (in electrical motor power) for ID fans, FD fans and PA fans at 100% Maximum continuous rating (MCR) (i.e. unity PLF). For mills, the design margin is 25% and for FD fans it is 263%. However, the auxiliaries get loaded and reach their full electrical capacity at a plant load much below the 100% MCR rating.

TABLE 2

COEFFICIENTS IN THE CURVE FITS FOR SLAGGING AND FOULING CHARACTERISTICS OF COAL AND ASH

Sl. No.	Particular of variable	Constants in curve fits Type: Linear	
		A_0	A_1
01	X: Weight of Fe_2O_3 in ash (5–23%) Y: Slagging factor (0–1.0)	−0.278	0.0556
02	X: Slagging factor (0–1.0) Y: Decrease in boiler efficiency of 210 MW units (1.0–3.5% points)	1.0	2.5326
03	X: Slagging factor (0–1.0) Y: CF of 210 MW units due to slagging (0.85–1.0)	1.0	−0.1412
04	X: f_{ash} (0.06–0.75) Y: Fouling factor (0–1)	−0.0819	1.4753
05	X: f_{ash} (0.06–0.75) Y: Decrease in boiler efficiency of 210 MW due to fouling (1.0-3.0% points)	0.832	2.8223
06	X: f_{ash} (0.50–0.75) Y: CF of 210 MW units due to fouling (0.97–1.0)	1.0042	−0.0367

The reasons for this could be electrical (drop in voltage, lagging power factor or system frequency), fuel quality (ash), mechanical (wear/erosion/abrasion of components), etc. The electrical effects have been found to be practically negligible. In specific plants, electrical problems arising temporarily are generally rectified. Hence, the drop in CF is the composite effect of ash in coal and wear/erosion/abrasion. Half of the decrease/drop in the CF can be subtracted from the CF (including design margin) to obtain the effect of ash in coal alone. Half of the value is considered because of the average between two overhauls/replacement.

The capacity limitations arise out of two counts-up to an ash content of 57%, the limitations in motor capacity, i.e., if the motor was oversized, the limitations could be overcome. Plant operators partially overcome this limitation by relaxation in mill fineness or invoking the spare mill. The constants for the CF auxiliary equipment up to an ash content of 57% are given in Table 3. The CF at an ash content of 57% is 85% due to the boiler fans, 84% due to Raymond bowl mills and drum type ball mills, 71%

due to slow speed large ball and race mills and 88% due to ash slurry pumps.

TABLE 3

COEFFICIENTS IN THE CURVE FITS FOR CAPACITY FACTOR LIMITATIONS FROM AUXILIARY EQUIPMENT DUE TO ASH IN COAL

Sl. No.	Particular of variable X: f_{ash} ((0.06–0.57) Y: CR due to auxiliary	Constants in curve fits (Type: Linear)	
		A_0	A_1
01	Induced draft fans (210 MW units) (0.85–1.0)	1.2103	−0.6308
02	Primary air fans (210 MW units) (0.85–1.0)	1.2438	−0.6884
03	Raymond bowl mills (210 MW units) (0.84–1.0)	1.2979	−0.7982
04	Drum type ball mills (210 MW units) (0.84–1.0)	1.2930	−0.7865
05	Slow speed large ball and race 'E' mills (210 MW units) (0.71–1.0)	1.3132	−1.0541
06	Coal vapor fans (110 MW units) (0.85–1.0)	1.3679	−0.8919
07	Ash slurry pumps (210 MW units) (0.88–1.0)	1.2122	−0.5696
	X: f_{ash} ((0.06–0.57) Y: CF of composite units		
		A_0	A_1
01	Y: CF for units below 210 MW (0.83–1.00)	1.021	−0.3232
02	Y: CF for units of 210 MW (0.84–1.00)	1.018	−0.2965
03	Y: CF for units of 500 MW (0.95–1.00)	1.006	−0.0941
	X: f_{ash} ((0.57–0.75) Y: CF of composite units		
04	Y: CF for units below 210 MW (0.31–0.84)	2.4967	−2.9122
05	Y: CF for units of 210 MW (0.26–0.85)	2.6974	−3.2439
06	Y: CF for units of 500 MW (0.40–0.96)	2.6716	−3.0162

When the ash content exceeds 57%, heating value of coal deteriorates so much that the requirement of coal exceeds the maximum flow capacity of the mills and poses limitations to the plant load. Even if the electric motor drives are rated to any capacity, the mill will not be able to provide coal to maintain 100% MCR because the heat energy supplied will be insufficient.

Among the outlying/station auxiliaries of coal fired stations, ash handling plant and coal handling plant do not pose any capacity limitations due to ash in coal up to 50%. There is some drop in CF for ash contents in the range of 50–57%. When the ash content increases above 57%, the CF drops severely.

3.7 Overall Capacity Reduction

The overall reduction in unit capacity can be obtained by considering the difference between the plant availability factor and the plant load factor and by subtracting the other capacity reducing effects (loading/unloading after outages, equipment limitation, backing down due to low demand, etc.). The CF for the composite plant can also be calculated based on PLF and PAF and partial unavailability as,

$$CF = 1 - [(PAF - PLF) - (\text{plant unavailability due to factors other than coal quality})]$$

The constants for the CF are given in Table 3. It is to be noted that the CFs at ash contents tending towards 75% are not accurate because the UHV of ash tends towards zero.

3.7.1 Ash Contents in Coal below 57%

For an ash content below 57%, the limitations are due to poorer coal quality and consequent limitations on motor capacity. At 57% ash in coal, units up to 210 MW experience a capacity drop of 16% while units of 500 MW experience a capacity drop of only 5%. The capacity drops are lower in the latter because the majority of these are of recent origin and are specifically designed for coals of ash 45–50%. The average age of plants below 210 MW is around 30 years while that of 210 MW and 500 MW units is 18 and 12 years respectively. The ash content in Indian coals has been gradually increasing over the past 30 years and so the earlier plants have been designed for ash contents of 25–30%. The limitations in the 210 MW are due to the fans and mills. In 500 MW units, the limitations are mainly due to the milling plants. This is partially overcome by invoking additional mills into service.

The CF (for 210 MW units at an ash content of 57%) calculated from the various considerations is given in Table 4. Wear/erosion/abrasion results in a drop in CF of 6% for mills, 8% for ID fans and 1% for PA fans. Fouling results in a drop of 1% while slagging results in drop of 15%. The drop in CF owing to composite effects of ash is 15% due to ID and PA fans and 16–29% due to mills. The capacity loss of whole 210 MW units is around 15% at an ash content of 57%.

3.7.2 Ash Contents in Coal above 57%

When the ash in coal exceeds 57%, the capacity is limited by the flow capacity of the system. Units are designed for a SFC of 1.0 kg.kWh^{-1}. For a 210 MW unit, the upper limit of coal flow is 210 th^{-1}. When the ash is in excess of 57%, the heating value is increasingly inadequate to maintain 100% MCR thereby reducing the power output of the unit. The capacity drop in this ash range is very severe. The CFs are 31% for units below 210 MW, 26% for 210 MW units and 40% for 500 MW at an ash content of 75%.

TABLE 4

CAPACITY FACTORS FOR 210 MW UNITS AT AN ASH CONTENT OF 57%

Sl. No.	Particular CF due to:	Wear and erosion effects only	Ash content in coal (57%)	Slagging (not dependent on ash content)	Fouling	Plant as a whole
01	ID fans	0.92	0.85			
02	PA fans	0.99	0.85			
03	Raymond bowl mills	0.94	0.84			
04	Drum type ball mills	0.94	0.84	0.85	0.99	0.85
05	Slow speed large ball and race 'E' mills	0.94	0.71			

In the ash range of 57% and 70%, large quantities of coal will have to be fired and the power output will be decreased considerably because of upper limitations in the coal flow and its decreased UHV. When the ash content exceeds 70% limitations do arise in plants of all capacities. When the coal exceeds 70% and tends towards 76%, the heating value of coal is tends towards zero.

3.8 Gross Effects of Ash in Coal on Power Plant Performance

Since the Maximum continuous ratings (MCRs) of the units range from 30 MW up to 500 MW and the units are loaded between 60 to 100% of their MCR, unit size and plant load factor is also a variable to which the system performance is sensitive. The design efficiencies (provided by manufacturers) and operating efficiencies (based on field efficiency tests) of the various units ranging from 30 MW to 500 MW and operating under their normal operating conditions (with high ash: 30–50%) have been curve fitted as functions of the unit size and presented in Table 5. There is a difference of 4.8–6.4% between the design and operating efficiencies (gross and net).

TABLE 5

COEFFICIENTS IN THE CURVE FITS FOR DEPENDENCE GROSS SYSTEM PERFORMANCE ON MCR OF THE PLANT

Sl. No.	Particular	Constants in curve fits D_0	D_1
	Curve fit: Type: Non-linear X: Unit size: MCR (30–500 MW) Y: Efficiency (%) at MCR		
	Design efficiencies (as per equipment manufacturer at 30% ash)		
01	Boiler efficiency (85.5–87.1%)	83.562	0.0067
02	Turbine efficiency (31.0–46.7%)	18.992	0.1445
03	Generator efficiency (98.1–98.7%)	97.510	0.0019
04	Auxiliary efficiency (90.4–94.9%)	85.428	0.0169
05	Steam efficiency (95.8–99.5%)	91.716	0.0130
06	Gross overall efficiency (28.0–39.2%)	18.786	0.1181
07	Net overall efficiency (24.9–35.4%)	16.309	0.1244
	Operating efficiencies (experimental-at operating ash: 35–48%)		
08	Boiler efficiency (79.6–83.9%)	74.852	0.0183
09	Turbine efficiency (30.8–42.1%)	21.198	0.1103
10	Generator efficiency (96.8–98.6%)	94.868	0.0062
11	Auxiliary efficiency (87.4–92.4%)	81.962	0.0192
12	Steam efficiency (91.0–96.0%)	85.334	0.0189
13	Gross overall efficiency (21.7–33.5%)	12.949	0.1525
14	Net overall efficiency (18.5–30.6%)	10.133	0.1775
X: Unit size: MCR (30–500 MW) Y: Design efficiencies at MCR (at standard ash: 6%)			
01	Boiler efficiency (90.0–91.8%)	87.996	0.0067
02	Turbine efficiency (31.0–46.7%)	18.992	0.1445
03	Generator efficiency (98.1–98.7%)	97.510	0.0019
04	Auxiliary efficiency (92.9–97.5%)	87.722	0.0169
05	Steam efficiency (96.3–99.9%)	92.160	0.0130
06	Gross overall efficiency (30.0–41.9%)	20.094	0.1181
07	Net overall efficiency (27.3–38.9%)	17.913	0.1244
X: Unit size: MCR (30–500 MW) Y: Operating efficiencies (at standard ash: 6%)			
08	Boiler efficiency (83.8–88.4%)	78.824	0.0183
09	Turbine efficiency (30.8–42.1%)	21.198	0.1103
10	Generator efficiency (96.8–98.6%)	94.868	0.0062
11	Auxiliary efficiency (89.8–94.9%)	84.163	0.0192
12	Steam efficiency (92.4–97.5%)	86.677	0.0189
13	Gross overall efficiency (23.2–35.8%)	13.851	0.1525
14	Net overall efficiency (20.3–33.6%)	11.130	0.1775
X: Annual load factor (dimensionless: 0–1) Y: ER (efficiency at part load/efficiency at MCR) at standard ash (6%)			
15	Boiler efficiency ratio (0–0.98)	0.9863	0.0413
16	Turbine efficiency ratio (0–0.99)	0.9911	0.0811
17	Generator efficiency ratio (0–0.99)	0.9948	0.0126
18	Auxiliary efficiency ratio (0–0.99)	0.9937	0.0649
19	Steam efficiency ratio (0–0.99)	0.9936	0.1524
20	Gross overall efficiency ratio (0–0.99)	0.9928	0.2874
21	Net overall efficiency ratio (0–0.99)	0.9921	0.3523

The design and operating efficiencies given in the above Table have been de-coupled to include the effects of ash, unit loading and unit size by three functions as,

$$\eta = [\eta_{\text{standard ash}} : \text{F(MCR)}]$$
$$[\text{ER}_{\text{standard ash}} : \text{F(PLF)}][\text{ER} : \text{F}(f_{\text{ash}})]$$
$$\eta = [D_{01}(\text{MCR})^{D11}][D_{02}(\text{PLF})^{D12}]$$
$$[A_0 + A_1(f_{\text{ash}}) + A_2(f_{\text{ash}})^2]$$

Table 5 gives the constants for efficiencies (at standard ash as a function of the MCR), ER (as function of the PLF) and ER (as a function of the ash content). Using the constants given in the above Table, the design and operating efficiencies can be obtained. These are consistent with the design (manufacturer's data) and experimental efficiencies given in Table 5. It is seen that when the ash content is increased from 6% to 75%, the gross and net overall efficiencies are reduced to 77% and 66% of their original values. Figure 1 gives the efficiency ratios as a function of the fraction of ash in coal.

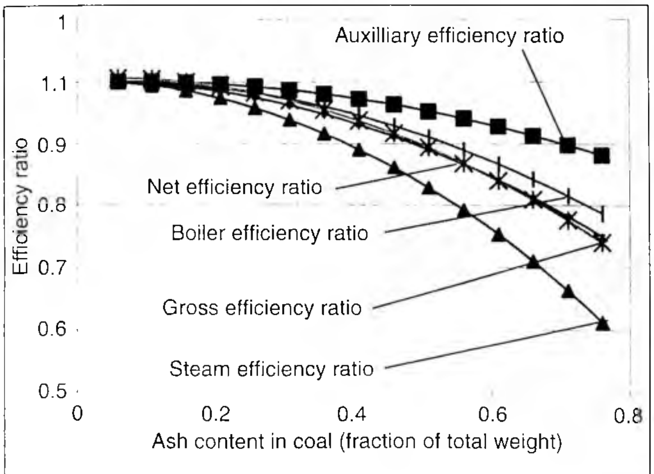

FIG. 1. VARIATION OF EFFICIENCY RATIO WITH ASH CONTENT IN COAL

The SFC is computed as,

$$\text{SFC}_{\text{gross}} = \frac{3.6}{(\eta_{\text{gross}}\ \text{UHV})}$$

$$\text{SFC}_{\text{net}} = \frac{3.6}{(\eta_{\text{net}}\ \text{UHV})}$$

where $\eta(\%)$ and UHV (Pattanshetti, 1996) are both given as functions of ash in coal. A moisture content of 6% is assumed. The gross and net SFCs (operating) are curve fitted as functions of ash content, MCR and PLF as,

$$\text{SFC}_{\text{gross}} = [0.8226 - 3.5477(f_{\text{ash}}) + 33.393(f_{\text{ash}})^2 - 83.321(f_{\text{ash}})^3 + 75.358(f_{\text{ash}})^4] \times [\text{MCR}^{-0.1525}] \times [\text{PLF}^{-0.2874}]$$

$$\text{SFC}_{\text{net}} = [1.0009 - 4.5465(f_{\text{ash}}) + 45.7170(f_{\text{ash}})^2 - 117.590(f_{\text{ash}})^3 + 108.300(f_{\text{ash}})^4] \times [\text{MCR}^{-0.1775}] \times [\text{PLF}^{-0.3523}]$$

The $\text{SFC}_{\text{gross}}$ (operating) varies between 0.35 and 3.0 kg.kWh^{-1} for the whole range of ash content in coal (0.05–0.75), MCR (30–500 MW) and PLF (0.50–0.80). The SFC_{net} varies between 0.37 and 3.2 kg.kWh^{-1} for similar conditions. As the ash fraction exceeds 70% there is a steep fall in the UHV of Indian coals which is responsible for the high SFC at the high ash end. This limits the capacity of the flows through coal, combustion and flue gas circuits thereby limiting the plant load. When the ash content exceeds 75% the UHV approaches zero.

When the ash content exceeds 57% the $\text{SFC}_{\text{gross}}$ (operating) exceeds 1.0 kg.kWh^{-1}. Indian power stations are designed for a maximum flow rate corresponding to a $\text{SFC}_{\text{gross}}$ (operating) of 1.0 kg.kWh^{-1} at 100% MCR. Thus, a unit of 210 MW (at full load) can accommodate a coal flow of 210 th^{-1} and combustion corresponding to it. This limits the ash content of coal to 57% beyond which the unit has to be operated only at part load.

The SFC ratio is computed as,

$$\text{SFCR} = \frac{\text{SFC}_{(\text{at a given ash})}}{\text{SFC}_{(\text{at standard ash: 6\%})}}$$

The effects of MCR and PLF get cancelled and the gross and net SFCRs are curve fitted as functions of the ash content as,

$$\text{SFCR}_{\text{gross}} = [105.73 - 116.88(f_{\text{ash}}) + 46.80(f_{\text{ash}})^2 - 4.9514(f_{\text{ash}})^3 + 1.15(f_{\text{ash}})^4]$$

$$SFCR_{net} = [124.88 - 135.63(f_{ash}) + 52.701(f_{ash})^2 - 5.2205(f_{ash})^3 + 1.1473(f_{ash})^4]$$

Figure 2 shows the SFCR for ash contents from 6% to 75%. The $SFCR_{gross}$ and $SFCR_{net}$ vary between 1 and 10 for the complete range of ash contents in coal (0–0.75).

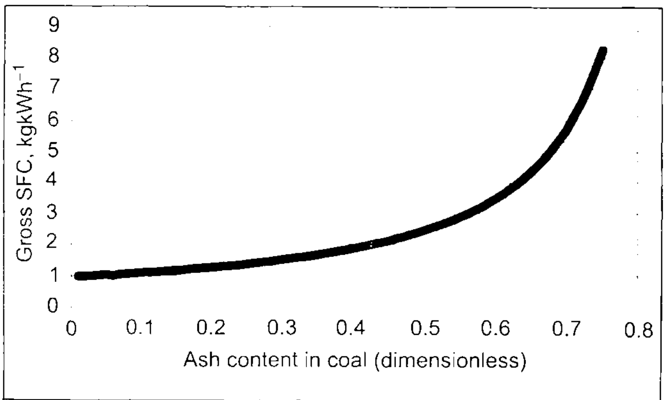

FIG. 2. VARIATION OF GROSS SFC RATIO WITH ASH CONTENT IN COAL

4.0 CONCLUSIONS

The major conclusions of the study is that:

(i) When the ash in coal exceeds 75%, its UHV is reduced to zero.

(ii) When the ash content of coal goes beyond 57%, limitations in combustion space and flow (coal, air and flue gas) arise beyond which the unit has to be operated only at part load.

(iii) The efficiency of all boiler auxiliary fans (ID, FD and PA) drop by 22–27% when the ash content in coal increases from 6% to 57%. Wear/erosion/abrasion effects lead to a decrease of fan efficiencies by 5–6% points at the upper limit of ash in coal.

(iv) The CF at an ash content of 57% is 85% due to the boiler fans, 84% due to Raymond bowl mills and drum type ball mills, 71% due to slow speed large ball and race mills and 88% due to ash slurry pumps. Capacity loss originating from wear/erosion/abrasion effects alone is 8% due to ID fans, 1% due to PA fans and 6% due to mills.

(v) At 57% ash in coal, units up to 210 MW experience a capacity drop of 16% while units of 500 MW experience a capacity drop of only 5%.

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