International Journal of Engineering Research and Science & Technology

IJERST

ISSN : 2319-5991
Vol. 2, No. 3
August 2013

www.ijerst.com

Email: editorijerst@gmail.com or editor@ijerst.com

International Journal of Engineering Research and Science & Technology

ISSN 2319-5991 www.ijerst.com
Vol. 2, No. 3, August 2013

Research Paper

EFFECT OF COAL WASHING ON FIRESIDE DEPOSITION AND HEAT TRANSFER PERFORMANCE IN PF FIRED FURNACES

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The physical and chemical characterization of coal ash together with temperature decide the emissivity and thermal conductivity of ash deposits and in turn the heat flux trend across the deposits. The amount of ash content in coal and ash loading per unit volume of the furnace decides the incidental radiation heat flux falling on the water wall heat transfer surfaces. Due to combined effects of organics and inorganics of coal, the furnace design, aerodynamics, etc., the pattern of deposition, rate of thickness build up and heat transfer reductions could vary in different zones of boiler furnace. In addition to that, due to the process of accretion, sintering, cracking, falling and redeposition characteristics specific to the coal and the furnace design, the heat flux reduction pattern can be of different types. In the present study an attempt has been made to find the effect of coal washing on fireside deposition vis a vis change in heat transfer performance in pulverized fuel fired furnaces using a pilot scale test facility.

Keywords: Fireside deposition, Heat flux reduction, Coal washing

INTRODUCTION

In our hydrocarbon economy, carbon plays such an important role that its relative scarcity will come as a surprise. It accounts for only 0.04% of total mass of earth and mere 0.02% of carbon in the earth's crust. To a depth of 5 km, carbon occurs in a form that can react with oxygen, rest being in the form of carbonates, carbon-di-oxide, etc. Most of this reactive carbon occurs in concentrated form in the fossil fuels as peat, lignite, coal, oil and natural gas and the known reserves of coal represent by far the largest proportion of carbon.

"Boiler are tailor made to the fuel" with the main boiler furnace and other heat transfer equipment as well as the peripheral equipment selected and sized depending upon various fuel characteristics. Amongst the characteristics, mineral matter in coal and ash formed from the minerals after combustion, have the maximum impact on the

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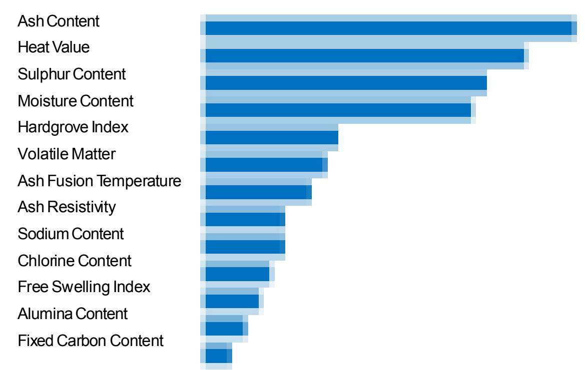
design and operational costs as given in Figure 1 (Nandakumar *et al*., 1988).

Figure 1: Relative Importance of Coal Parameters on Power Plant Performance



As the ash content goes up, it has ramifications in many areas, such as sizing of coal and ash handling plants, number of mills, abrasion of mill rollers, erosion of heat transfer surface, furnace size, horizontal pass velocity, size of electrostatic precipitator (ESP) etc.

Conventional indices which are based on ash composition like base to acid ratio, silica ratio, Iron/Calcium ratio as well as based on ash fusion temperatures are being widely used to predict slagging propensity. The applicability of the above formulae for Indian coals are to be verified since they have been formulated for American/ European coals which are different from Indian coals (Bryers, 1992).

The deposit characteristics like thickness, thermal conductivity, emissivity etc. are dynamic phenomena, depending on accretion, sintering, falling, redeposition, etc., happening in the furnace. Though mathematical modeling efforts are being made, due to the above factors which decide the deposition rate and heat transfer the models have remained very much subjective to the coal type or boiler design, etc. (*TERI Energy Data Director and Year Book,* 1990-91)

Pilot scale testing, simulating as much as possible the actual boiler conditions is one of the most widely practiced technique to evaluate the impact of fire side deposition and heat transfer performance. Collection of such heat flux reduction data by installing sensors on water walls of boilers is also practiced.

Considering the above facts, an attempt has been made to study the comparative impacts of ash depositions on heat transfer of a raw coal and a washed coal in a pilot scale test facility.

The scope of the present work is to observe the comparative deposition behavior and impact of cleaning on ash depositions in Slag probe and foul probe installed for ash depositional studies.

AN OVERVIEW OF EXPERIMENTS AND ANALYSIS

Fireside deposition phenomena is influenced by many factors such as proportion of different minerals and their included and excluded nature, time and temperature history experienced furnace aerodynamics, etc. Further, it has been observed that pilot scale simulated experimentation is practiced around the world and it is considered to be a less costly and more reliable technique for relatively evaluating the slagging propensities and heat transfer in different furnace zones (Gupta and Wall, 1993).

Pilot scale experiments have been carried out in Fuel Evaluation Test Facility (FETF) wherein experiments were conducted with two different Indian coal samples which includes one raw and one washed coal.

SALIENT FEATURES AND CAPABILITIES OF FUEL EVALUATION TEST FACILITY

- FETF consists of a furnace a combustion system with the associated air and fuel (coal/ oil) supplying equipment a convection pass containing heat exchangers to cool the flue gas a second pass containing erosion test section followed by a flue gas cleanup system.

- Probes located at conditions simulating actual boiler facilitate evaluation of deposits, heat absorption, emission, etc.

The Furnace

The furnace inner dimensions are 500 mm x 500 mm x 6,000 mm. The furnace and convection pass are castable refractory lined calcium silicate insulation brick. A cross section of the furnace showing the two burners is given in Figure 3. The furnace first pass houses the wall burner, slag/ heat flux panels heat absorbing coils, gas recirculation openings and view ports, thermocouples, photographic and video recording facilities. The furnace is bottom supported.

The radiant section contains three demineralized water cooled panels to simulate water walls. These panels are used for slag deposition and heat transfer studies.

Figure 2: Flow Sheet of Fuel Evaluation Test Facility

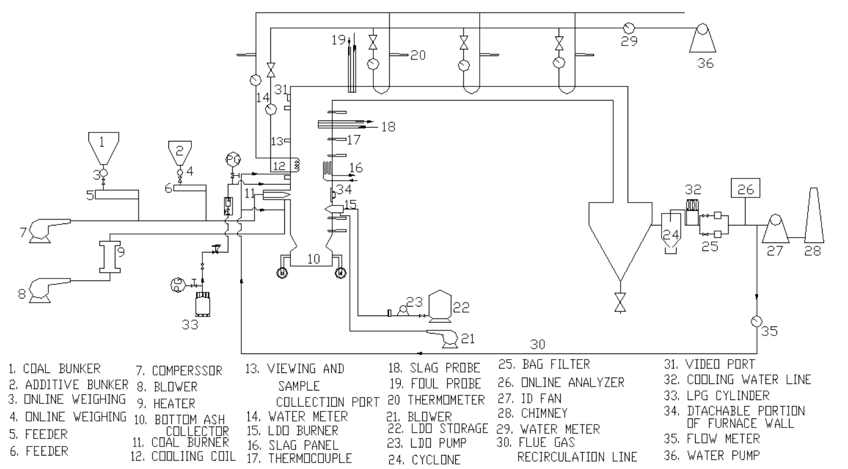
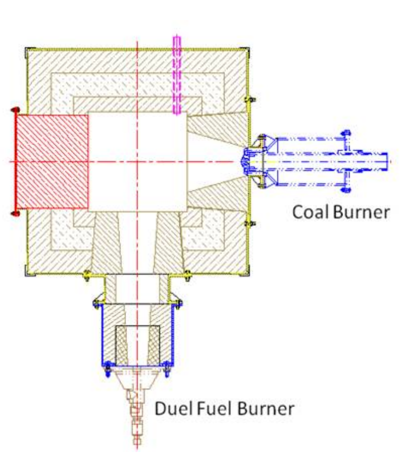


Figure 3: Combustor Cross Section

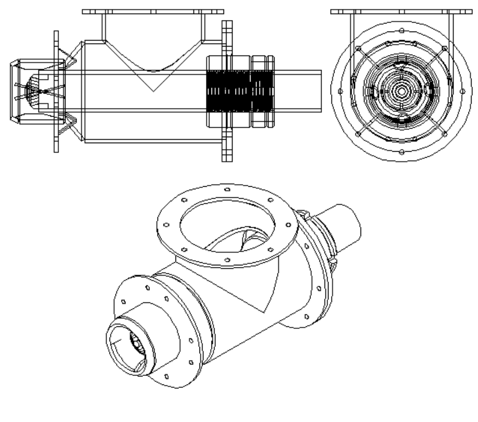


COMBUSTION SYSTEM

There are two wall burners, two each on the consecutive walls. One of the wall burner is duel fuel type and facilitated of firing two different fuels such as gas, light diesel oil, furnace oil. The other wall burner is of swirl type with various tilting angles to facilitate firing different pulverized fuels such as coal, biomass, pet coke, etc.

The coal burner arrangement, as shown in Figure 4, has provision to fire pulverized coal as well as secondary air. The nozzles are arranged with bottom and top-end-air, middle air and over-

Figure 4: Coal Burner



fire air. The burner nozzle is designed in such a way that the fuel-air mixture can flow at any pre-determined velocities representing low, medium and high velocity ranges depending upon the volatile content of coal.

COAL HANDLING SYSTEM

Pulverized coal is prepared and transported in dense phase from an existing system to the bunkers of FETF. There are four microprocessor-controlled loss of weight feeders, each connected to a bunker. The coal flows by gravity to the hopper of the screw feeder. There are two feeders which can feed pulverized fuel at 10-30 kg/h and 8-15 kg/h, respectively with an accuracy of ±1%.

Air Handling System

A separate blower supplies the air required for transport of pulverized coal fed by the feeders to the mixing nozzles. Airflow to the mixing nozzle can be measured and controlled.

The secondary air, supplied by another blower, passes through an electrical heater with air by-pass provision for tempering purposes. Further downstream, separate headers feed the air to the burner.

Second Pass

The second pass has an erosion test section where the flue gas velocity is accelerated by convergence. It is a provision to evaluate the erosion propensity of the fly ash in the future. The fly ash collected can be separately tested as a function of dust loading and impingement angle.

Iso-kinetic sampling of the flue gas, upstream of the erosion test section, facilitates measurement of dust loading as well as further analysis of the size and shape distribution of fly ash.

Flue Gas Clean-up and Handling

An inertial separator, located at the bottom of second pass removes coarser particles in fly ash. The finer particles are removed by twin cyclone located after inertial separator. After passing through the twin cyclone the gases are evacuated by an Induced Draft Fan to the chimney.

Flexibility to reroute flue gases through add on flue gas cleaning test setups such as bag filters has been incorporated in the design.

Fuel Gas Temperature Control

The flue gas temperature at furnace outlet is controllable by varying secondary air temperature heat absorption by water cooled panels gas recirculation and heat input in to the furnace.

The flue gas pass simulates the convection heat transfer zones of the boiler and cooled in a shell and tube heat exchanger by raw water flow. The raw water circuit is also a closed system with spray cooling of the hot raw water in a cooling tower. This facilitates controlling the gas temperatures as that of the boiler.

Emission Monitoring

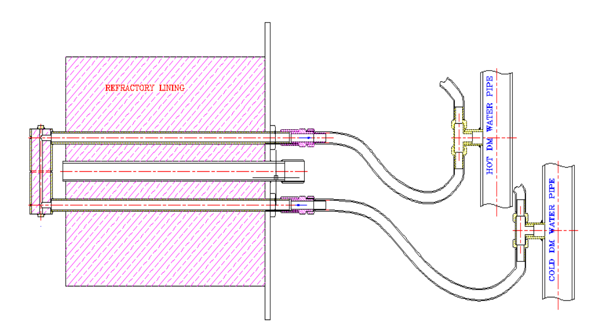
Flue gas is sampled after the cyclones, extracted through heated hoses and conditioned before feeding the gas analyzers in the control room. Oxygen, carbon-di-oxide, carbon monoxide, sulphur oxides and nitrous oxides are monitored and recorded.

Slag Panels and Foul Probes to Observe Heat Flux Reduction Due to Deposits

In the furnace of FETF, there is a demineralized water cooled panel (called as slag panel) just above burner zone. By online computing, multiplying quantity of fluid flow, specific heat of fluid and temperature differential between outlet to inlet and dividing by the projected area, the heat flux at that time is calculated (Q.CpÄT/Area of Panel) and the real time trending is obtained by a Data Acquisition System (DAS). Figure 5 shows the general arrangement of a slag panel. The metal temperature of the panel is maintained as that of boiler by regulating flow before the start of experimental data collection for heat flux reduction. The flow is maintained constant till the heat flux reduction observations are completed.

The radiation and convection zone super heaters are simulated by compressed air cooled bayonet type cooling tubes. Here also the metal temperatures are maintained as in the regular boiler and the experiments start after surface cleaning by blowing compressed air. The heat flux value is calculated online by multiplying the quantity of compressed air with the specific heat of air and the temperature differential between outlet and inlet headers of the bayonet type fouling probe (Q.CpÄT/Area of foul probe).

Figure 5: General arrangement of Slag Panel



Controls and Instrumentation

An integrated controls and instrumentation system incorporating the following features has been provided.

- Primary air flow and pressure control.
- Secondary air flow and pressure control.
- Secondary air temperature control.
- Heat transfer fluid's flow and temperature control.
- Control of metal temperatures of slag panels, slag probe and foul probes at desired set points.
- Auto control of coal feed rates at desired set levels for the volumetric heat inputs being simulated.
- Abnormal conditions of the equipment are hooked to an alarm annunciator for alerting the operator to take corrective action.

The schematic flow diagram of the Fuel Evaluation Test Facility (FETF) is shown in Figure 2 (Project Report, 2006).

Experimental Capabilities of FTEF

FETF has the capabilities to simulate a boiler with respect to combustion aerodynamics, flue gas conditions such as composition, temperature, velocity and turbulence (fluid dynamic aspects) and also metal temperatures of heat absorbing surfaces such as water walls, super heaters, reheaters and economizers.

Combustion Characterization

- Variable heat input rates (0.075 to 0.27 million kcal/h).
- Burns a variety of fuels, e.g., coal, oil.
- Firing modes: wall-fired.
- Blending up to two different coals as well as co-firing of solid and liquid fuels.
- Adjustable secondary air preheat temperatures (40 to 400^{0}C).
- Variable primary velocity.
- Operates at a wide range of stoichiometric ratios
- Study flame stability and carbon loss on a comparative basis.

Deposition and Heat Flux Pattern

- Control of furnace gas exit temperature (800 to 1,200^{0}C).
- Evaluation of heat release pattern of fuels by portable incidental radiation heat flux meters.
- Slagging rates and heat flux reduction rates at different locations from hopper to convection pass entry in radiant zone.
- Flexibility to adjust metal temperatures.
- Fouling rates and heat flux reduction rates in both high and low temperature convection zones by probes with adjustable metal temperature.
- Additives and their impact on slag and foul reduction (slug does or continuous feed) evaluation.

EXPERIMENTAL PERIOD

When the furnace refractory temperature and FOT are stabilized, the experimental observations start. Observations are carried out for a reasonable period, before changing over to the next set of experiments, after deposit removal by compressed air blowing.

Tests in FETF

One raw coal and one washed coal of different characteristics as shown in Table 1 were tested in the FETF. The empirical ratios were calculated and are given in Table 2. Considering that the quantum of ash per million kcal would vary depending on calorific value and ash content, the above values were normalized by multiplying them by ash content per million kcal. Observations were made with two different volumetric heat loading (different heat inputs) namely near about 100% and near about 70-80% load of the design rating of FETF. Correspondingly the FOTs ranged above 1,000^{0}C for 100% load and about 800^{0}C for 70-80% load. Due to limitations in coal quantity only either the test with FOT 1,000^{0}C or FOT of about 800^{0}C could be conducted.

Studies were conducted to compare the following:

- Impact of heat flux reduction due to depositions for the two coals.
- Improvement in heat absorption due to washing of coal by testing raw and washed coals.
- Comparison of heat flux reduction trends along the gas flow path, viz., simulated water walls in the burner zone and at furnace exit and on simulated horizontal pass heat transfer surfaces of radiant SH and final super heater, etc.

RESULTS AND DISCUSSION

Correlation between percentage heat flux

Table: 1 Analyses of Coal Tested at FETF

Description	Unit	Raw Coal	Washed Coal	Description	Unit	Raw Coal	Washed Coal
Proximate				**Ultimate**			
Moisture	%	2.60	2.80	Carbon	%	43.71	53.76
Ash	%	40.80	31.30	Hydrogen	%	2.13	3.37
VM	%	25.10	26.30	Sulphur	%	0.49	0.72
FC	%	31.50	39.60	Nitrogen	%	0.92	1.04
FC/VM	Ratio	1.25	1.51	Oxygen	%	5.27	3.64
CV	Kcal/kg	4024.00	4986.00	Moisture	%	2.60	2.80
Ash/Mkcal	Kg	101.39	62.78	**Mineral Matter**	%	44.88	34.67
HGI	NO		39.30				
Ash Fusion				**Ash Composition**			
IDT	Deg C	1432.00	1453.00	SiO_2	%	59.30	62.40
ST	Deg C	1563.00	1546.00	Al_2O_3	%	31.50	27.40
HT	Deg C	1577.00	>1600	TiO_2	%	0.80	0.70
FT	Deg C	>1600	1600.00	Fe_2O_3	%	6.40	7.00
				CaO	%	1.20	1.30
				MgO	%	0.30	0.60
				Na_2O	%	0.20	0.20

Table 2: Empirical Ratio Calculated from Ash Composition and Ash Fusion Temperature

S. No.	Description	Unit	Raw Coal	Washed Coal
1	Majumdar	Ratio	11.48	10.07
	Corrected Majumdar	Ratio	1163.78	632.08
2	Base to acid	Ratio	0.09	0.10
	Corrected Base to acid	Ratio	8.97	6.31
3	Silica Alumina	Ratio	1.88	2.28
	Corrected Silica Alumina	Ratio	190.87	142.96
4	Iron Calcium	Ratio	5.33	5.38
	Corrected Iron Calcium	Ratio	540.76	338.02
5	Iron Dolomite	Ratio	4.27	3.68
	Corrected Iron Dolomite	Ratio	432.60	231.28
6	Silica Ratio	Ratio	88.24	87.52
	Silica content corrected to ash/MKcal	Kg	6012.52	3917.21
7	Iron Content Corrected to ash/MKcal	Kg	648.91	439.43
8	Iron to Silica Ratio corrected to ash/Mkcal	Kg	10.94	7.04
9	Slagging temperature (4*IDT+HT/5)	Temp	1145.60	1162.40

reduction due to deposition with empirical indices based on ash composition was not found. The widely used empirical indices like base to acid ratio, silica ratio and iron/calcium ratio did not give a good correlation with respect to slagging and heat flux reduction rate.

Table 3 lists the classified heat flux reduction percentages for the respective tests. The heat flux reduction values are normalized taking the heat flux value observed immediately after soot blowing to be 100% for the respective coals. The empirical ratio for predicting slagging proposed by Mjumdar (1963) which had been considered to be having a better chance for correlating considering the formula development in Indian context was particularly looked into other empirical indices such as iron content, silica content, iron to silica ratio as well as Majumdar Ratio did not give correlation with respect to reduction in heat absorption.

Impact of Coal Washing on Heat Flux Absorptions

The comparative heat flux absorption patterns of raw and washed coals for the burner zone and furnace exit slag panels of FETF at the two different FOTs are given in Figure 6 (a) to (d) and Table 4.

On washing the reduction in heat flux due to deposition in the burner zone has decreased by 10% (from 55% to 455) at FOT of 1,115^{0}C and by 25% at FOT of 860^{0}C. On the contrary, with respect to furnace exit panel, the reduction in heat flux went up from 10% to 36% at FOT of 1,115^{0}C while it was in line with the other trends of improvement at FOT of 853^{0}C as shown by Figures 6 (a) to (d).

The above is again attributable to the changes in proportion of different minerals and their size distribution, before and after washing, resulting in changes of rate of deposition as well as phases of ash formed.

Table 3: Relative Heat Absorption Reduction for the two Coals

		% Heat Reduction Due to Deposition					
		FOT above 1000°C			FOT around 850°C		
		FOT°C	Burner	Furnace	FOT°C	Burner	Furnace
Raw Coal (R)	11.48	1.115	55.00	18.00	800	68.00	46.00
Washed Coal (W)	10.07	1115	45.00	36.00	853	43.00	24.00

Table 4: Comparison of Heat Flux Reductions of Raw and Washed Coals

Description	Unit	Burner Zone Panel		Furnace Exit Panel	
		1,115^{0}C	860^{0}C	1,115^{0}C	853^{0}C
Raw (Coal 5)	%	55	68	18	46
Washed (Coal6)	%	45	43	36	24
Differential	%	-10	025	+18	+22

Figure 6(a), 6(b): Comparision of Heat Flux Reduction for Raw and Washed Coals at FOT >1000°C for Burner Zone and Furnace Exit Panels

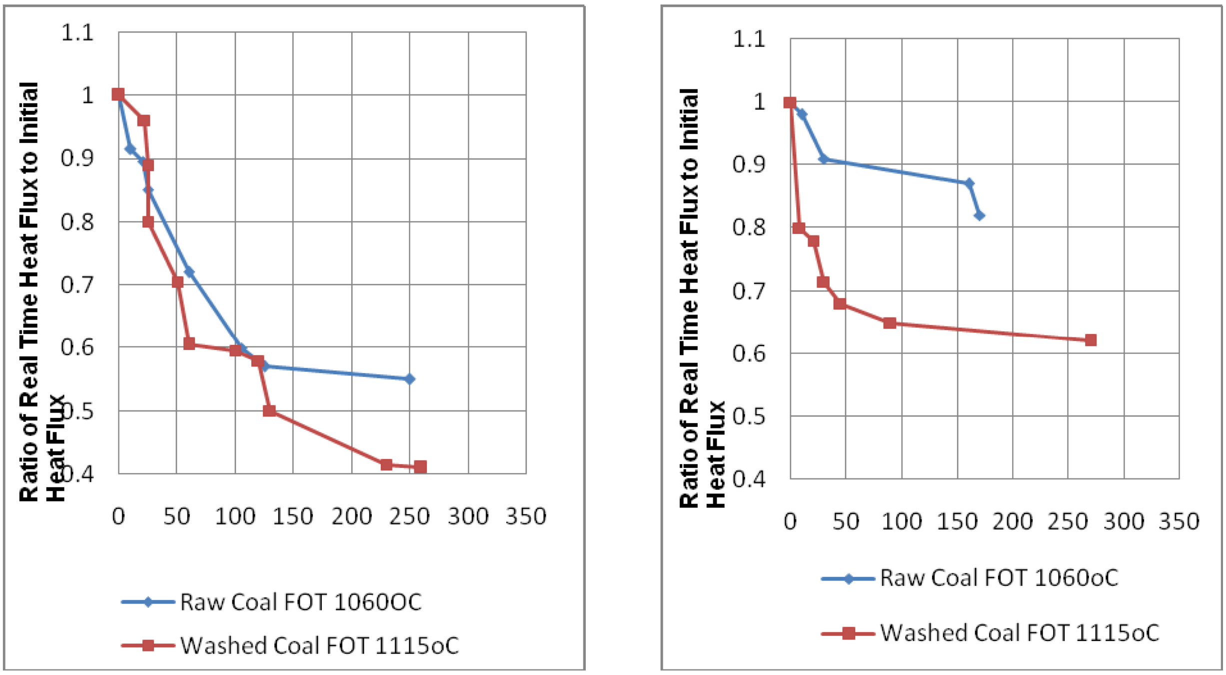
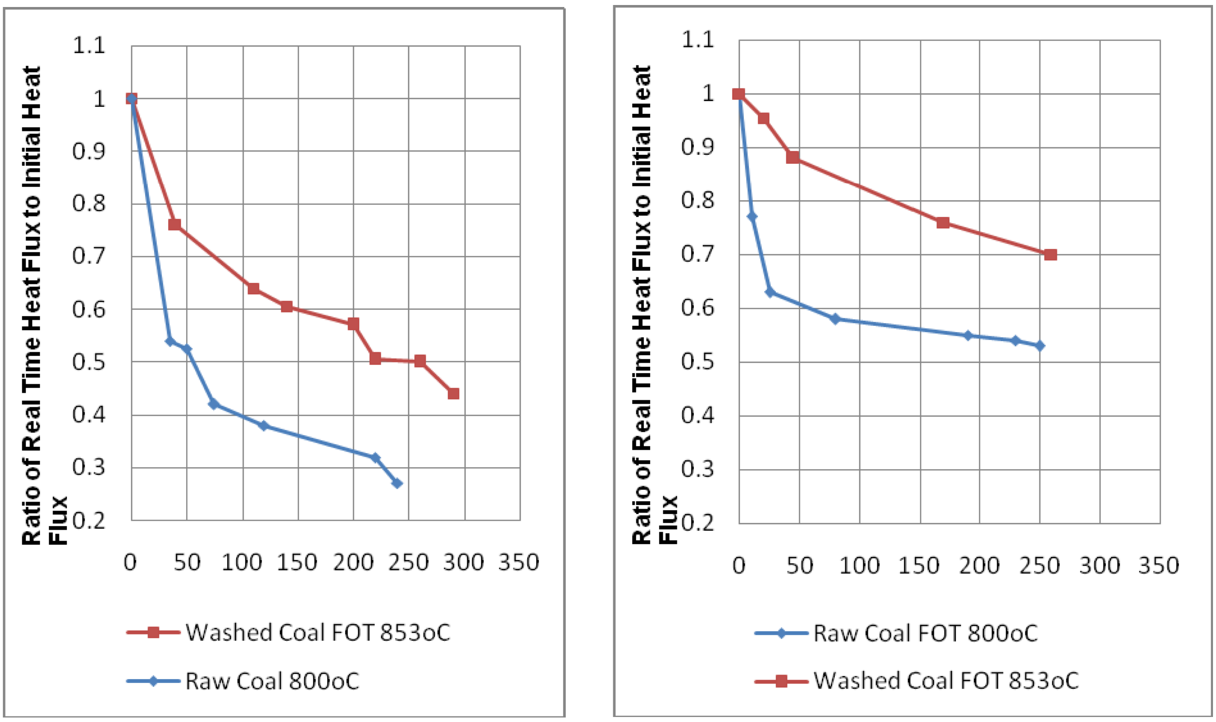


Figure 6(c), 6(d): Comparision of Heat Flux Reduction for Raw and Washed Coals at Around 850°C for Burner Zone and Furnace Exit Panels



However, since the absolute values of heat fluxes are higher in the burner zone and on washing the heat absorption is improving in that zone the net effect on the furnace is likely to be better on use of washed coal.

Heat Flux Reductions Could Progressively Decrease along the Gas Flow Path

Heat flux reduction trends showed that for raw coal, the reduction rates could progressively decrease along the gas flow path as the gas temperatures decreases. For example, the trend as depicted in Table 5 indicated the following changes for Raw Coal.

This clearly indicated that for this coal, progressively, the depositions are becoming lesser and lesser along the gas path.

Table 5 Effect of Temperature Zone along Gas Path on Heat Flux Reduction

S. No.	Observation	% Heat Flux Reduction (240 min)
1	Burner Zone	65%
2	Furnace Exit	55%
3	Radiant SH Zone	20%
4	Convection Zone	10%

CONCLUSION

The studies through experiments in a Pilot Scale test facility reveal that the different coals exhibit a wide range of heat flux reduction phenomena varying with respect to coal, the zone of deposition, viz., below and above burner zones, furnace outlet temperature and also with respect to time. Contrary to the conventional thinking that type of coals taken for studies, being refractory in nature and so would not cause depositions and consequent heat flux reductions, the experiments have revealed that higher degree of depositions are taking place and heat flux reductions are also significant.

Testing of raw and washed coals in Fuel Evaluation Test Facility was found to yield valuable information on the comparative heat flux improvements due to washing. Even though there are no major variations in ash content and composition at lesser FOT of 850^{0}C, about 20% improvement in heat absorption was seen between raw and washed coal. But at FOT of 1000^{0}C, there was a reversal of trend in favor of raw coal. More detailed investigations, comparing high ash raw coals of 40-45% ash content with washed coals of 32% ash content with quantification of the respective changes in mineral content by methods like Computer Controlled Scanning Electron Microscopy (CCSEM), would be more revealing.

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International Journal of Engineering Research and Science & Technology
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Website: www.ijerst.com

ISSN 2319-5991