International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.10 No.2, pp 121-131, 2017

Establishing correct coal quality for achieving optimum boiler efficiency & performance – a case study in the Indian utility industry

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Abstract : This paper outlines a preliminary effort towards efficient and reliable boiler operation, steam generation and the role of correct coal quality for the application which eventually impacts heavily on the economics of power generation. Coal properties can affect the efficiency, reliability and availability of both the boiler and the emissions control units. In this direction, an attempt has been made to study variation in boiler efficiency with coal properties in Indian context by carrying out a case study of 500 MW plant to understand the effect of coal quality on efficiency of boiler. It is concluded that eEstablishing & securing right coal for Boiler is the key to achieving desired efficiency, emission levels and plant life.
Keywords : Coal quality, moisture loss, hydrogen loss, boiler performance, boiler efficiency.

1. Introduction:

Coal continues to be the dominant fuel choice for power generation around the world. While hydraulic fracturing and new drilling techniques have increased natural gas supplies, coal consumption continues to rise, especially in Asia. China and India alone are responsible for nearly all of the growth in global coal consumption since 2000. We know that the emissions characteristics of coal combustion are substantially influenced by the type and processing of coal used; it is also true that the quality of coal affects the profitability of a particular power plant and can facilitate or hinder the plant's ability to meet environmental requirements [1]. The efficiency of converting coal into electricity matters: more efficient power plants use less fuel and emit less climate-damaging pollutants [2]. Being a fossil fuel, it is worthwhile to discuss the effects of its quality and characteristics on the boiler performance. Coal selected for a particular power plant, plays a key role in establishing desired steam parameters, achieving the required combustion efficiency and gross heat rate of the plant. Determining the efficiency of a boiler generating steam for power generation purposes is an important factor in ensuring that operating costs are minimized. This has a direct impact on the cost of the product that is units of electrical power. The efficiency can be defined as the useful output divided by the input, for an industrial boiler it is normally in the range of 80 to 90% and for a utility boiler in between 90 and 94% [3]. Since a very long time, it was held that operational conditions are more important than the nature and properties of coal, but as the problems persisted, boilers were designed to match coal types or, conversely, that coals should be characterized in greater depth to match the operational characteristics of existing boiler plants for optimum boiler performance. Furthermore, there is virtually no published information which clearly draws the relationship between coal quality, technical operational conditions, and the boiler efficiency of steam generators for Indian Coals [4]. Most of the information on related studies resides are with boiler manufacturers who rarely publish their results and findings. In addition, the bulk of this restricted investigational work was formerly based on laboratory and pilot - scale operating conditions. This absence of information suggests the need to further explore combustion performance of coal under full- scale operation. To what extent does coal quality affect boiler efficiency? What are the other factors within the ambit of coal quality that affects the boiler performance? What are the parameters of coal quality that must be adequately represented in the ambit of coal quality vis-à-vis boiler performance? Despite the fact that modern combustion equipment can be designed to accommodate any type of fuel, thus overcoming the ever-increasing problem of the poor qualities and lower grades of coal being mined, it is necessary to establish better evaluation, characterization, and specification of coals than has been the custom in the past. Towards this end, new characterization tests and analyses are already playing a very important and integral role [5]. In light with this fact, an effort has been made in this paper to study boiler efficiency variations with coal properties and or with coal of different characteristics.

2. Coal quality and utility boiler efficiency of Indian Power Industry:

Several codes specify the methodology for boiler efficiency testing. These codes are governed by: BS 2885 (1974), BS 845-1&2 (1987) and ASME PTC 4 (2008) which has been replaced by the advanced version in the form of EN 12952-15 (2004) [3, 6]. The boiler efficiency in the present paper is has been calculated by using EN 12952-15 (2004) standard codes.

2.1 Coal characterization:

Coal is an extremely complex heterogeneous material that is difficult to characterize. That is why several analytical techniques are required for its characterization so as to accurately predict its behavior during conversion processes such as combustion, gasification or liquefaction [7]. Coal quality is defined by various traits and some of the essential terminologies are clarified by Falcon and Ham [5]. Coal grade refers to the amount of impurities or the composition of mineral matter, in the coal, that results in ash content. Rank is the degree of maturation or metamorphism of coal and it is determined by temperature, pressure and time duration. Type signifies the organic composition of coal or the original vegetal matter; it is an indication of coal reactivity. Condition refers to the extent of weathering or abnormality including oxidized coal, coal heated by spontaneous combustion, coal distorted by rock or ground movements. Hence the expression 'quality' is used to refer to a combination of all the term as mentioned above which may be used in various applications. For instance, coal is considered to be of poor quality in the metallurgical industry where as coking coal is considered to be good, whereas coal is considered good for steam generation. The reliability of any study depends on ensuring that both the sampling and analytical techniques are adequately and precisely performed. Techniques for coal analysis can be considered as consisting of two major groups, those that determine the empirical properties and those that focus on the fundamental composition of coal. Empirical properties are verified using methods based on chemical and physical analysis. The conventional analysis methods based on fundamental composition of coal are summarized in Table 1 below.

Table No. 1: List of conventional Analysis for coal [5, 8]

Proximate,%	**Ultimate, %**	**Ash Composition , %, Major Minerals**	**Others**
Moisture	Carbon (C)	Quartz (SiO2)	Calorific Value (kCal/kg)
Volatile Matter	Hydrogen (H)	Pyrite (FeS2)	Swelling Index (CSN)
Ash Content	Oxygen (O) Nitrogen (N)	Calcite (CaCO3)	Hard Grove Index (HGI)
Fixed carbon	Sulphur (S) Phosphorous (P)	Dolomite (MgO) Kaolinte (Al2O3)	Ash Fusion Temperature (AFT, °C)

The proximate and ultimate analysis are those indicted as 'Others' in Table-1 above, are significant in characterizing coal prior to combustion; and they involve the more common laboratory methods such as x-ray, spectroscopy, and atomic absorption. There are known as well as unknown parameters associated with coal during combustion. The known parameters are the proximate, ultimate, calorific value, HGI and ash compositions. The unknowns are petrographic analysis, reactivity, slagging and fouling analysis, etc. All unknowns become known only after the combustion of coal in the boiler furnace and at the cost of boiler performance. Coal fired steam generators therefore can behave differently with different types of coal and their performance depend to a large extent on the quality and type of coal being fired. Sufficient evidence exists to prove that conventional analyses, as defined by ASTM, ISO, and other standards organizations do not reveal the true nature and performance characteristics of coal, i.e. coals of similar proximate and ultimate analyses may exhibit completely different technological behavior [8].

2.2 Indian coal for thermal power plants:

In spite of high relative abundance and availability; the quality of Indian coal is seldom popular in international market because of the inferior quality of ROM (Run-of-Mine) coal and subsequent high cost of preparation needed to attain the quality requirement of internationally traded coals. Most of the Indian coal contains higher percentage of inorganic compound compared to its counter-countries of similar Gondwana origin. The average quality of thermal coal progressively deteriorated due to inferior grades of coal reserves available for opencast mining and also due to high degree of mechanization introduced in large opencast mines [8]. In essence, it can be said that the rapid depletion of the mineable reserves of the good quality coal, change in mining pattern etc. has resulted in lowering of GCV in Indian coals. One of the major characteristics in the quality of presently mined coal is the steady decline in the gross calorific value and increase in ash content that affect the capacity utilization of existing TPS and generation of power. In one of the analysis, it was suggested that state-owned Indian power plants are less efficient than publicly owned power plants in the United States and part of this difference can be explained by differences in the heating value of Indian coal: the heating value of Indian coal is, on average, about 60 percent of the heating value of coal burned in the United States [9]. The problems are exacerbated because of the multiplicity of supply sources. There are very few power plants (except some pit head plants) receiving coal from a single, dedicated source. Most of them are supplied mainly with low grade coals and partly comparatively good grade coal.

The average quality of raw coal presently being used by power stations consists of ash content-30-55%, moisture content-5-9%, sulphur content-0.2-0.7%, volatile matter-20-25% and GCV in between 3000-5000 kCal/kg. Proximate analysis of coals from five different mines is given in Table-2.

Table No. 2: Typical Proximate analysis of various Indian Coal types [9]:

	Bermo	Damodar Valley	Trombay	Umaria Field	Palana
Moisture, %	1.9	4.0	7.2	5.3	41.4
Ash, %	26.6	42.1	27.3	19.8	5.6
Volatile Matter, %	21.1	12.8	20.8	27.1	29.2
Fixed carbon , %	50.4	41.1	44.7	47.8	23.8
GCV (Kcal per kg)	6059.0	4396.0	5353.6	6148.0	3774.8

Consequently, the thermal power stations receive coals of such heterogeneous nature, both in quality and size, that achieving good performance in terms of stability, PLF, maintenance and operating costs, ash disposal, specially GHG emissions become a challenge in day to day operation. Below are the sample of coal quality / proximate analysis of coal as being procured by one of the reputed power producer of this country [10]. Analysis of coal samples collected from all the feeders (in the boiler) in service during operation of the unit in the aforesaid plant during the above mentioned period is given below. The samples were collected just before the raw coal feeders feeding coal to pulverizers from where pulverized coal is transported to boiler furnace with the help of pre-heated primary air through the coal burners. Table-3 shows the analysis report of used composite sample based on different loads of plant.

Table No. 3: Analysis report of coal on TM basis [10]

Sl. No.	Sample type.	Load MW	TM (%)	IM (%)	Ash (%)	VM (%)	FC (%)	GCV (AFB) Kcal/kg
1.	Composite Sample of Feeders	315	10.87	2.67	49.55	18.68	29.10	3250
2	Composite Sample of Feeders	300	10.07	4.67	36.66	23.05	35.62	4177
3	Composite Sample of Feeders	333	10.27	5.27	38.31	23.44	32.98	4130
4	Composite Sample of Feeders	364	9.54	6.30	35.18	28.22	30.30	4407
5	Composite Sample of Feeders	310	8.60	3.78	36.44	23.39	36.39	4369
6	Composite Sample of Feeders	350	6.54	3.40	59.66	14.33	22.61	2467

2.3 Effect of coal quality on boiler efficiency of Indian Power Plants:

Boiler efficiency is a combined result of efficiencies of different components of a boiler. A boiler has many sub systems, which affects the overall boiler efficiency. Couple of efficiencies which finally decide the boiler efficiency is combustion efficiency and thermal efficiency. Apart from these efficiencies, there are some other losses which also play a role while deciding the boiler efficiency and hence need to be considered while calculating the boiler efficiency. These losses include ON-OFF losses, radiation and convection losses, blow down losses etc. In actual practice, two methods are commonly used to calculate overall boiler efficiency, namely direct and indirect method of efficiency calculation. The direct method is based on the actual measured energy output divided by the measured energy input, and the indirect or losses method is based on the sum of the losses subtracted from 100%. Due to the magnitude of losses and practical difficulties with the real time measurement for mass flow and calorific value of the fuel, the indirect method is more accurate and is normally used when assessing the efficiency of operating boilers. By this method, efficiency could be measured easily by measuring all the losses occurring in the boiler. According to this method,

Boiler efficiency $\eta = 100 - (L1+L2+L3+L4+L5+L6+L7+L8)$,

Where, L1 – loss due to dry flue gas, L2 – loss due to hydrogen in fuel, L3 – loss due to moisture in fuel, L4 – loss due to moisture in air, L5 – loss due to CO formation, L6 – loss due to un-burnt fuel in fly ash, L7 – loss due to un-burnt fuel in bottom ash, L8 – loss due to radiation and convection (surface loss). Losses due to moisture in fuel and due to combustion of hydrogen are dependent on the fuel, and cannot be controlled by design.

Boiler inefficiencies were traditionally associated more with inappropriate operating conditions. As a result, not much research was undertaken to investigate variations in coal quality as a credible contributor to these inadequacies. This dilemma has not only led to lack of accessible technical information relating to this subject, but has in the wider context caused serious concerns in the utility and power generation industries due to cost implications associated with inefficient operation. Steam generator performance is greatly influenced by the coal/ash properties. When designing a boiler, fuel analysis plays a major role. Boiler furnace design will depend more on fuel characteristics, and further heat transfer surface sizing will depend on furnace outlet temperature. The performance of the boiler and ultimately the entire unit can change considerably if the coal being used is substantially different from that for which the boiler was designed. In recent times, many utility boilers have to burn off coals with worst quality because a rapid increase in electric power generating capacity resulted in shortage of desired coal for pulverized coal fired utility boilers. This resulted in series of operational problems such as unstable combustion and even fire extinction in furnace, high carbon content in fly ash, difficulty in controlling vapor steam characteristics [11].

Changes in coal property results in efficiency variation and the designer may not be able to demonstrate the guarantees. This can also result in changes in power consumption, load limitations, boiler availability losses due to slagging and fouling, tube failure and plant heat rate reduction. Indo German Energy Programme (IGEN), executed in the year 2006, envisaged to carry out the mapping of Thermal Performance of 85 Pulverized coal fired thermal power generating units situated in different states of India. The identified mapping studies of 85 units ranging in capacity from 100 MW to 500 MW each were completed during the period 2007-09 in 14 Indian States viz Andhra Pradesh, Chhattisgarh, Gujarat, Haryana, Jharkhand, Madhya Pradesh, Karnataka, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal. These units are a part of 45 thermal power stations owned by 17 Power Utilities. The capacities of selected units were considered ranging from 100 MW to 500 MW and totaling 85 in number [12]. Table 3 below depicts the variations in boiler efficiency observed in units of different sizes in the above mentioned study. Test results also point out to the fact that with higher GCV values (than the design coal), generally there is a trend of higher boiler efficiency (than the design) [13]. Combined with this fact and ease of combustion, there had been a trend in the past to use higher rank coals to extract better performance of Boiler. The depletion of high grade coal reserves, changes in transport economics and availability of large variety of domestic and international coals, changes in environmental regulations; results in potential exposure to widely variable types of coal. In recent years, in addition to bituminous coal of good quality as a fuel, there is growing demand for less costly low-rank coals such as sub-bituminous coal and lignite to be applied as a fuel in coal-fired power plants. Table-4 summarizes the boiler efficiency variations in power plants of different capacities.

Table No. 4 – Boiler Efficiency Variations in Power plants studied [12]

Capacity range of units (MW)	**No. of units**	**Average Design Boiler Efficiency (%)**	**Average Operating Boiler Efficiency (%)**	**Average Deviation, (%)**	**Range of Operating Boiler Eff.**
100 - 110	8	86.9	80.5	7.4	78.8 - 82.3
120 -125	9	86.1	80.1	7.0	75.0 - 82.5
140	4	85.9	80.7	6	80.0 - 81.5
195 - 200	5	86	80.8	6.1	73.0 - 85.0
210	49	85.8	81.7	4.8	71.0 - 86.0
250	5	87.2	83.4	4.4	82.7 - 85.6
500	5	87.7	82.3	6.1	79.0 - 84.1

Recent developments in boiler design linked to advanced characterization studies and commercial experience have led to unprecedented use, with maximum effect, of the low-grade, high-ash, high-inertinite coals. In the light of this success, more adequate understanding and better methods of assessment of the coals typical of the Gondwana region are called for, particularly in the light of the price premium for high-grade coal and the more cost-effective lower grade coals on the international markets [5].

3. Case Study on a 500 MW utility boiler:

There are many factors that influence the efficient combustion of coal resulting in optimum boiler efficiency. In general, they can be divided into inherent or intrinsic ones such as the organic and inorganic composition of the coal, its rank or degree of maturity, porosity, exposed surface area, moisture content, degree of weathering or heat-effect, size of particle, state of oxidation, and characteristic initial or ignition temperature, and peak combustion temperature. The second category, the external group, includes factors influencing the combustion process in terms of operating conditions: these include particle size, throughput, environmental temperature, temperature and velocity of the combustion air, the nature of mixing solids and gas, the design and spacing of the burners, and the residence time of the combustible particles in the furnace. Also, boiler Efficiency depends on other factors including operating conditions, Mill performance, Air Ingress, Condition of APH and other heat exchanging surfaces etc. and not only on coal quality. As the external factors are beyond the scope of the present review, only the inherent factors are discussed in this paper. In high capacity pulverized coal fired boilers, the total losses account to about 12 to 14%, i.e. 86 to 88% boiler efficiency. Roughly 50% of the losses can be tuned to the optimum and the other 50% is governed by fuel properties like hydrogen in fuel, moisture in fuel, and ambient air conditions. In the case studies, presented below, authors has made an attempt to study the variation in Boiler Efficiency due to change in coal quality, which will be manifested by changes in Losses in Boiler efficiency due to Hydrogen in Fuel (coal) and Moisture in fuel. Table-5 depicts variation in coal quality received in a typical 500 MW thermal power plant in the eastern part of the country within a period of six months.

Table No. 5: Analysis report of coal on TM basis

Sl. No.	Colliery	TM (%)	IM (%)	ASH (%)	VM (%)	FC (%)	GCV (AFB) Kcal/kg
1	Belbad	7.6	5.5	32.1	26.4	36	4630
2	Jambad	7.5	3.3	41.4	25.2	30.1	3995
3	Jamtara	6.5	1.7	44.2	22.8	31.3	3955
4	Jamtara	6.1	1.5	46.2	2.4	30.2	3813
5	Jamtara	6.8	1.8	41.4	23.6	33.2	4185
6	Jamtara	10.34	4.02	44.79	21.14	30.05	3510
7	Jamtara	9.28	3.79	43.96	21.54	30.71	4041
8	Jamtara	13.24	4.5	38.42	21.91	35.17	3895
9	Jamtara	12.62	5.64	41.07	22.64	30.65	3982
10	Jamtara	17.73	5.02	40.65	22.24	32.09	3595
11	Jamtara	12.22	4.28	36	23.29	36.43	4255
12	Jamtara	7.4	2.5	43.88	22.48	31.14	3923
13	Jamtara	10.34	4.02	44.79	21.14	30.05	3510
14	Khottadih	6.8	0.3	46	15.6	38.1	4030
15	Khottadih	6.3	0.3	27.3	17.8	54.6	5760
16	Kustal	6.5	0.5	47.7	15.2	36.6	3862
17	Kustal	6	0.5	48.2	15	36.3	3845
18	Kustal	6.7	1.36	38.59	16.74	43.31	4420
19	Kustal	6.7	1.36	38.59	16.74	43.31	4420
20	Pandaveswar	10.1	7.8	24.6	25.4	42.2	4980
21	Pandaveswar	9.97	7.73	18.68	30.78	42.81	5570

22	Parasia	5.5	3.5	45.5	23.1	27.9	3690
23	Pathardih	7.9	1.35	67.39	12.6	18.66	1930
24	Pathardih	5.48	1.19	44.74	17.45	36.62	3900
25	Salanpur	7.91	2.34	56.99	13.95	26.72	2715
26	Samla	7	4.9	41.9	23.4	29.8	3810
27	Samla	14.18	6.93	41.2	23.39	28.48	3535
28	Sankarpur	6.5	4.6	25.8	30.2	39.4	5350
29	Sankarpur	8.1	6	35.9	25.7	32.4	4210
30	Sankarpur	5.5	3.6	33.8	27	35.6	4750
31	Sankarpur	7.5	6.3	25.4	26.5	41.8	5180
32	Sankarpur	7.2	5.2	24.7	29.9	40.2	5360
33	Sankarpur	6.1	3.8	26.7	30.5	39	5360
34	Sankarpur	9.48	5.71	38.98	24.59	30.72	4012
35	Sankarpur	15.51	6.11	37.86	24.17	31.86	3860
36	Sankarpur	16.67	6.54	34.61	24.39	34.46	4093
37	Sankarpur	13.9	5.68	41.29	25.03	28	3870
38	Sankarpur	11.07	6.27	43.32	22.85	27.56	3580

3.1 Boiler design details:

The unit under consideration is equipped with a boiler of 500 MW capacities. The unit is designed (Maximum Continuous Rating Values) for the following specifications:

Main Steam flow: 1495.2 T/hr.
Main Steam Pressure: 176.7 kg/cm^2 (g).
Reheat Steam Pressure: 40.9 kg/cm^2 (g).
Main Steam /Reheat Steam Temperature at Boiler outlet: 540/540 °C. The boiler unit is designed for the following quality of coal as described in Table-6.

Table No. 6: The data for design coal for the boiler of the unit under consideration

Description	**Unit**	**Value**
Proximate Analysis		
Fixed carbon	%	26
Volatile matter	%	19
Moisture	%	15
Ash	%	40
Grindability Index	HGI	55
Higher Heating Value (HHV)	kcal/kg	3300
Ultimate Analysis		
Carbon	%	29.73
Hydrogen	%	3.70
Sulphur	%	0.50
Nitrogen	%	1.80
Oxygen	%	8.66
Carbonates	%	0.58
Phosphorous	%	0.03
Moisture	%	15.00
Ash		40.00

3.2 Test Results with different coal quality

A series of boiler efficiency tests have been carried out in the unit on different dates with different coals for studying the effect of Boiler efficiency with coal quality within a period short enough to cancel variations due to change in equipment performance levels. Also, as mentioned in Table-7, only change in boiler efficiency due to change in losses due to hydrogen and moisture in fuel has been considered, which are attributable to coal being fired.

Table No. 7: Results of coal analysis for the tests carried out

Sl. no.	Sample type & collection point	Load MW	TM (%)	Ash (%)	VM (%)	FC (%)	GCV (AFB) kcal/kg	Loss or gain boiler efficiency,%
1.	composite sample of feeders in operation	415.0	10.7	29.3	26.7	36.3	4831	3.89
2	composite sample of feeders in operation	369.0	5.0	42.1	16.5	39.0	4137	4.89
3	composite sample of feeders in operation	347.0	9.0	30.5	25.8	36.9	4833	4.11
4	composite sample of feeders in operation	378.0	15.3	13.4	35.6	39.9	5859	3.56
5	composite sample of feeders in operation	352.0	2.6	45.7	20.2	31.5	3740	4.64
6	composite sample of feeders in operation	500.0	3.5	42.7	22.4	31.4	4014	4.68
7	composite sample of feeders in operation	500.0	10.8	38.7	22.3	31.6	4017	3.61

3.3 Calculation of results for the tests mentioned above

Boiler efficiency calculations were carried out for the seven tests mentioned above with different types of coal and the results are hereby given in Table-8.

Table No. 8: Results of the boiler efficiency calculations for the tests

Sl. No	Boiler losses with design coal parameters, %			Boiler losses with test coal parameters, %			Loss or gain in boiler efficiency,%
	Loss due to H_2 in coal	Loss due to moist. in coal	Total	Loss due to H_2 in coal	Loss due to moist. in coal	Total	
1	6.319	2.846	9.165	3.89	1.39	5.27	3.89
2	6.319	2.846	9.165	3.52	0.76	4.28	4.89
3	6.319	2.846	9.165	3.88	1.17	5.05	4.11
4	6.319	2.846	9.165	3.95	1.65	5.60	3.56
5	6.319	2.846	9.165	4.09	0.44	4.53	4.64
6	6.319	2.846	9.165	3.95	0.54	4.49	4.68
7	6.319	2.846	9.165	3.89	1.67	5.55	3.61

A great reduction in boiler loss can be observed from Table-8. As for example, in Test sl. No. 1, total of Loss due to Coal Hydrogen and Loss due to Coal Moisture is 5.27 % as compared to design value of 9.165 %. Thus, there is improvement of 3.89 % in Boiler Efficiency due to change in coal quality which is also well understood from the Fig 1. From the bar chart, one may find the reduction in boiler loss to H_2 as well as due to moisture inherent in coal. In the case of test sl. no. 1, there is reduction in loss due to H2 from the designed value of 6.319% to 3.89%. Similarly losses due to moisture in the coal also are found to be reduced from 2.846 to 1.39.

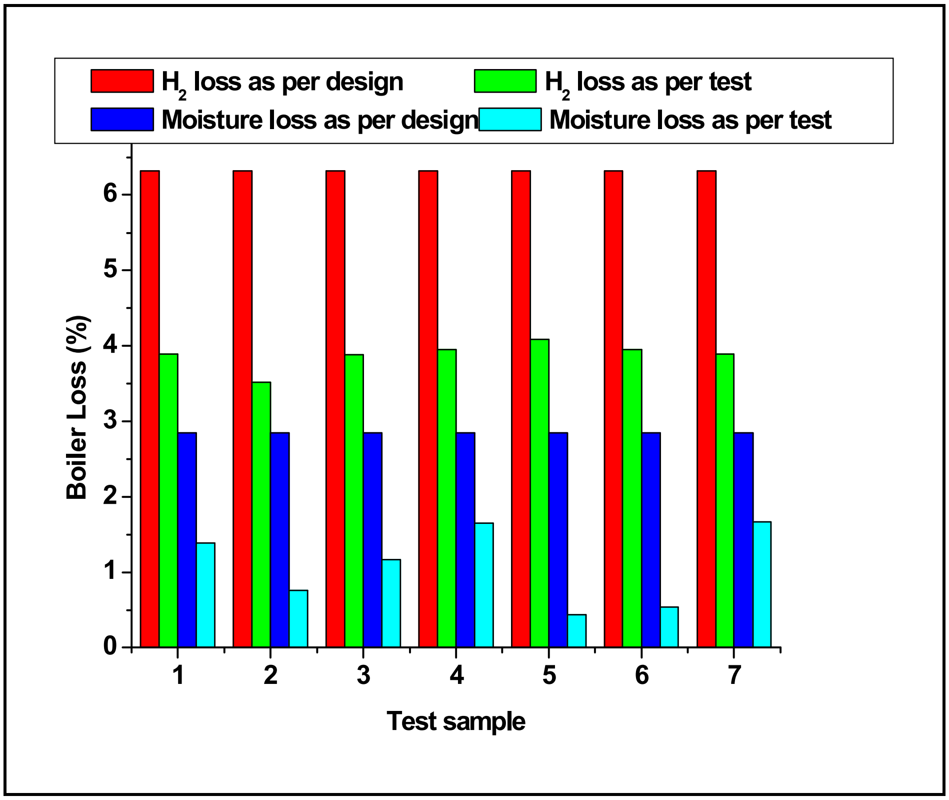

Fig. 1: Reduction in boiler loss as used test samples.

4. Summary and Conclusions

It must be emphasized that the discussion here is not on whether or not coal qualities actually influence boiler performance; past research has reasonably shown that they do. This paper has made a preliminary attempt to study the effect of coal quality on boiler efficiency in a Pulverized coal fired plant, firing coals from various mines. The test results have been compiled for analysis as above. Some of the observations can be summarized as follows: conventional analyses do not reveal the true nature and performance characteristics of coal. As shown above in this paper, two coals having same value of GCV can have different bearings on boiler efficiency. Results of Test no. 6 and Test no. 7 indicate so. While conventional methods allow one to have a quick assessment of coal qualities, on the other hand these yield limited information concerning the actual performance of coal in some cases. That is, alone they may not correctly predict and classify the vital aspects of combustion such as flame stability, rate of combustion, temperature distribution in furnace, burn-out characteristics, blending compatibility, and condition of coal. As a result, additional analysis that involve more fundamental constitution of coal are required in order to fully understand the behavior of different coals using methods such as the petro graphic techniques. More adequate understanding and better methods of assessment of the coals needed for switching from bituminous coal of good quality to less costly low-rank coals such as sub-bituminous coal.

Results of Test no. 7 and Test no. 4 (with higher GCV) indicate that similar boiler performance levels can be achieved with less costly low-rank coals. More work still needs to be done to adequately respond to the question to what extent do coal qualities affect boiler efficiency. In light of the above, it is proposed to undertake further investigation with respect to Indian coal in Indian power plants: We may, in light of the above discussion, draw a conclusion that the first step towards efficient and reliable boiler operation and steam generation is establishing the correct quality coal for the application. All properties and characteristics of the coal must be understood and then used to determine whether the coal is suitable for the specific application. To summarize – "Establishing & securing right coal for Boiler is the key to achieving desired efficiency, emission levels and plant life".

Abbreviations and Acronyms

ARB	As received Basis
ADB	Air Dried basis
AFB	As fired Basis
ASH	Ash content of coal as revealed by Proximate analysis
ASME	American Society for Mechanical Engineers
ASME PTC	ASME Performance Test Codes
ASTM	American Society for Testing and Materials
BS	British standard
FC	Fixed carbon in Coal as revealed by Proximate analysis
GCV	gross calorific value of fuel (kcal/kg)
HGI	Hardgrove Index
ISO	International Organization for Standardization
IM	Inherent Moisture in Coal
kCal	Kilocalories
MW	Megawatt
TM	Total Moisture in Coal as revealed by Proximate analysis
VM	Volatile Matter in Coal as revealed by Proximate analysis

Acknowledgement

The authors thankfully acknowledge the support given by Director, NTPC and Director, CSIR-CMERI to carry our this research work.

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