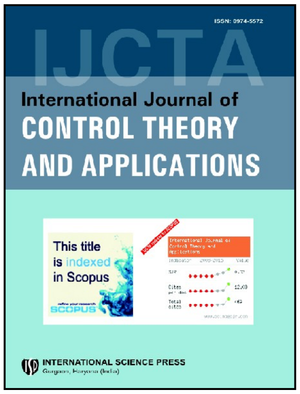

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 10 • 2017

Performance of AFBC and CFBC boilers in thermal power plants

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Abstract: Evaluation of boiler efficiency is a very important aspect in thermal power plants. Gross calorific value (GCV) is one of the influencing parameters in the boiler efficiency evaluation. The range of GCV's for various grades of coal in India is estimated utilizing the Taguchi's approach, which is comparable to the literature data. Efficiency of AFBC and CFBC boilers are evaluated and found that CFBC boiler efficiency can be improved without changing the GCV of coal. This paper presents the requirement of non-destructive testing and maintenance of boiler.

Keywords: AFBC boilers; CFBC boilers; Coal fired boiler; Coal firing rate; Direct method; Efficiency; Indirect method; Gross calorific value.

1. INTRODUCTION

The whole world is in the grip of energy crisis and the increased pollution associated with energy use [1]. The power creation for the year 2016-17 has been set as 1178 Billion dollars Device (BU). That is, the development of around 6.38% over actual creation of 1108 BU for the year 2015-16.[2] Economic growth of a country relies on the power, which is required in transportation, farming as well as in power sectors. A power plant is assembly of systems or subsystems to generate and deliver mechanical or electrical energy. The primary units of a coal-fired thermal power plant are fuel handling system, boiler, turbine and generator and cooling system. The fuel can be in a solid or liquid or gaseous form. Abundantly available coal in India is being used as a solid type of fuel. The pulverized coal in fuel handling system transports to a closed container (bolier), which operates under high pressure and converts chemical energy of fuel to thermal energy [3]. Thermal efficiency reflects on the boiler operation and maintenance. Reduction in the boiler efficiency and evaporation ratio with respect to time is reported due to heat transfer fouling, poor combustion, operation and maintenance [4]. Detoriation in the quality of fuel and water may also lead to poor boiler efficiency [5]. Efficiency is one of the performance parameters useful for proper maintenance of a boiler due to its continuos variation of working parameters.

The boiler efficiency under steady loading conditions will be examined by operating for one hour. It is quoted by the British standards (BS845-1987) as the the percentage of available heat on the basis of its gross calorific value. The German DIN 1942 standard recommends lower calorific value, whereas the ASME PTC-4.1 standard demands higher calorific value. Direct and indirect methods can be employed for boiler efficiency evaluation. In direct method the efficiency is evaluated by dividing the heat output with the fuel power (input) of the boiler, whereas indirect method considers the ratio of sum of major losses to the fuel power input of the boiler, which will be finally substracted from the unity [4].

Atmospheric Fluidized Bed Combustion (AFBC) boilers are most propably found in industries generating heat and power, in which the fluidized air and combustion air use the atmospheric air. Before being exhausted to atmosphere, the combustion gas passes over the super heater of boiler, then economizer, the dust collector, finally air pre-heaters. AFBC allows the bed to operate in between narrow temperature limits which makes it very unique. Feeding of fuel can be done using pneumatic feeding or over bed feeding [6]. Circulating Fluidized Bed Combustion (CFBC) boiler requires less parameters compared to that of the AFBC boiler and even labor required for the maintenance of this boiler is comparatively less. Emissions (NO_2 and SO_2) are very low due to staged combustion. Simple design and excellent performance compared to other boilers [7]. It operates within the temperature range of 880 - 990^{o}C which gets rid of slag formation; even fouling and corrosion are reduced. An ideal combustion atmosphere is maintained which helps the solids to circulate continuously. Wide range of coal and fuels are burnt in CFBC effectively. Cyclone is the major difference between AFBC and CFBC boilers. It collects the un-burnt particles of coal and bed- material from upper part of furnace, the remaining heavier particles are sent to the hopper of cyclone. This is again sent to furnace for recirculation [8]. Recycling of solids is 50 to 100kg of burnt fuel. CFBC boilers designed in such a way that maximum heat exchange takes place. Space utilization of CFBC is better than AFBC boiler. AFBC boilers require 75-100 TPH of steam more than CFBC boiler [9].

This study presents the range of GCV's for various grades of coal available in India, utilizing the concept of Taguchi's design of experiments. It demonstrates the possibility of enhancing the efficiency of CFBC boiler without changing the GCV of coal. It recommends the requirement of NDT and maintenance of boilers.

2. GROSS CALORIFIC VALUE (GCV) EVALUATION

There are many fuels in India but not as abundant as coal. Hence coal is being used as fuel for both AFBC and CFBC boilers. Wide varieties of coals (viz., lignite, bituminous, anthracite, peat, moss, and sub-bituminous) in India have different calorific values. The fuel having more calorific value will provide better efficiency. When a volume of fuel is completely oxidized, the energy liberated is defined as the heating value or calorific value of the fuel [10]. The gross calorific value (GCV) can be evaluated from [10]

$$GCV = 339\ \%C + 1427\ (\%H - \%O/8) + 22\ \%S \tag{1}$$

To obtain GCV, equation (1) requires the rates of C, H, O and S in 100kgs of energy. Sulphur is is regarded as minimal. Calorific value or warming value in the laboratory is measured by using either blast calorimeter or junkers gas calorimeter.

In order to examine the adequacy of equation (1), the calorific value of fossil fuel containing 88%C and 4.2% H2 is workedout to be 35825.4 kJ/kg, whereas the measured value is 34194.3 kJ/kg [10]. Different grades of coal are available in India. Designer prefers high calorific value of the coal to be used as fuel in boilers.

Taguchi's approach [11-14] is followed here to estimate the expected range of GCV from the chemical composition. The assignment levels of process parameters (% Carbon, % Hydrogen, % Oxygen, % Sulphur) are arranged in such a way that the data will fit the L_9 orthogonal array as per the Taguchi's approach. The minimum number of experiments as per Taguchi: $N_{taguchi}$ = 1+ Number of factors × (Number of levels – 1) = 1+ 4(3–1) = 9.

The output response (i.e., GCV value) is estimated from the chemical analysis for the assigned process parameters as per L_9 orthogonal array. Mean values of the output response are evaluated for the level settings. To study the sensitiveness of change in output response, the sum of the squares of deviation of each of the mean value from the grand mean is evaluated. Percentage contribution is obtained by dividing the sum of squares of the each process parameter with the total sum of squares. Iit is found that the % of carbon is contributing more on the GCV value when compared to those of hydrogen, oxygen and sulphur. There is a possibility to estimate the minimum and maximum output responses for which the process parameters can be identified by means of the additive law [14]. Table 1 gives the details on the grades of coal in India and their chemical composition. The expected range of GCV for the grades of coal in Table 1 is comparable with the reported range.

Table 1
The expected range of GCV values for the variation in chemical compositions of different grades of coal in India

Grades of coal	*% Carbon*	*% Hydrogen*	*% Oxygen*	*% Sulphur*	*Expected range of GCV (kJ/kg)*
Anthracite	92.1-98	3-4	2.5	0.6-0.7	35070-38678 (32500-34000)*
Bituminous	65-85	3-4	5-15	0.7-4.0	21175-33945 (17000-23250)*
Peat	50-60	5-7	30-40	0.1-0.4	16593-24986 (13800-20500)*
Semi anthracite	85-98	5-6	3.5	0.6-1.0	35343-41177 (26700-32500)*

* The calorific value of a fuel in Parenthesis is reported in *http://thecartech.com/subjects/engine/fuel_calorific_value.htm*

3. BOILER EFFICIENCY BY DIRECT METHOD

Direct method also known as input-output method compares the energy gain of the working fluid (water and steam) to the energy content of the fuel, which requires only the heat output (steam) and heat input (fuel) to evaluate the boiler efficiency, η [15, 16].

$$\eta = \frac{steam\ flow\ rate \times (steam\ enthalpy - feed\ water\ enthalpy)}{fuel\ firing\ rate \times gross\ calorific\ value} \times \frac{Q \times (h_g - h_f)}{q \times GCV_f} \tag{2}$$

Here , GCV_f is the gross calorific value of the coal; Q is the steam flow rate (kg/hr); q is the fuel firing rate (kg/hr); h_g and h_f are the steam enthalpy and feed water enthalpy respectively. The direct method helps the plant engineers to quickly evaluate the boiler efficiency. It requires few parameters for evaluation and less instrumentation for monitoring. However, it is unable to hint the plane operators why the efficiency of the system is lower. It should be noted that heat losses are not taken into account while evaluating the efficiency by the direct method. Hence it is not possible to find various losses responsible for various efficiency levels. The steam is highly wet due to water carryover, which may mislead the evaporation rate and efficiency [4].

4. BOILER EFFICIENCY BY INDIRECT METHOD

The boiler efficiency in the heat loss method or indirect method is evaluated by considering the sum of percentages of various heat losses and substracting from 100 [17]. For evaluation of boiler efficiency, the input parameters required are: gross calorific value of fuel (GCV_f), gross calorific value of fly ash (GCV_{fly}), gross calorific value of bottom ash (GCV_{bottom}), Specific heat of flue gas (C_p), specific heat of super heated steam (C_v), flue gas temperature (T_f), ambient temperature (T_a), mass of dry flue gas (m), moisture present in the fuel (M), mass of total ash generated (M_a), actual air supplied (AAS), humidity factor (HF), hydrogen in fuel (H_2), carbon monoxide in flue gas (CO), Carbon content in fuel (C) and carbondioxide content in flue gas (CO_2). Theoritical air fuel ratio (AFR) and excess air supplied (EAS) are to be found prior to the boiler losses estimation [15].

Heat losses are due to dry flue gas, water formed due to H_2 in fuel, moisture in fuel, moisture in air, incomplete combustion, radiation, convection, unburnt carbon in fly ash and bottom ash. Though there are different standards available for calculating the efficiency of boiler, the present study considers ASME standard (i.e., ASME PTC-4-1, in which PTC stands for power test code). Table 2 gives theoretical air required, theoretical CO_2, excess air supplied, actual air requirement, actual mass of dry flue gas for the grades of coal in India. Table 3 gives various heat losses in AFBC boiler for different grades of coal. Table 4 gives various heat losses in CFBC boiler. Table 5 gives comparison of the coal firing rates and the efficiency of AFBC and CFBC boilers considering different grades of coal. CFBC boiler's efficiency is found to be higher than that of the AFBC boiler. For the measured steam temperature and pressure, enthalpies at super heater inlet and outlet can be estimated using steam tables with proper interpolation or using the the online software package [18]. The boiler efficiency can be evaluated quickly by the direct method.

Table 2
Basic input for boiler efficiency evaluation by heat loss method

Grades of coal	*Theoritical air required (kg/kg of coal)*	*Theoritical CO_2 (%)*	*Excess air required (%)*	*Actual air required (kg/kg of coal)*
Anthracite	12.2	19.2	26.0	15.4
Bituminous	4.8	19.3	26.7	6.0
Peat	6.9	19.4	27.6	8.8
Semi anthracite	12.4	18.2	19.2	14.8

Table 3
Various heat losses in AFBC boiler for different grades of coal in India

Heat Loss (%) due to	*Anthracite*	*Bituminous*	*Peat*	*Semi anthracite*
dry flue gas	8.06 - 7.3	10.93 – 5.65	14.58 - 9.80	12.15 – 10.43
H_2 in fuel	2.6 – 2.3	5.13 – 2.65	11.2 – 7.5	4.01 – 3.4
moisture in fuel	1.2 – 1.1	3.37 – 1.74	3.07 – 2.06	1.2 – 1.03
moisture in air	0.07 – 0.06	0.187 – 0.096	0.17 – 0.114	6.6 – 5.7
unburnt fuel in fly ash	0.07 – 0.06	0.2 - 0.10	0.18 – 0.122	0.07 – 0.06
unburnt fuel in bottom ash	1.6 – 1.45	4.5 – 2.32	4.09 – 2.75	1.6– 1.37
radiation and convection	2	2	2	2

Table 4
Various heat losses in CFBC boiler for different grades of coal in India

Heat Loss (%) due to	*Anthracite*	*Bituminous*	*Peat*	*Semi anthracite*
dry flue gas	8.06 - 7.3	10.93 – 5.65	14.58 - 9.80	12.15 – 10.43
H_2 in fuel	2.6 – 2.3	5.13 – 2.65	11.2 – 7.5	4.01 – 3.4
moisture in fuel	1.2 – 1.1	3.37 – 1.74	3.07 – 2.06	1.2 – 1.03
moisture in air	0.07 – 0.06	0.187 – 0.096	0.17 – 0.114	6.6 – 5.7
unburnt fuel in fly ash	0.062 – 0.05	1.3 – 0.67	1.18 - 0.79	0.46- 0.39
unburnt fuel in bottom ash	0.058 – 0.06	1.75– 0.905	1.59 - 1.07	0.621 – 0.53
radiation and convection	2	2	2	2

Table 5
Comparision of efficiency and coal firing rates of AFBC and CFBC boilers for different grades of coal in India

Grades of coal	*Coal fired rate (kg/hr)*		*Efficiency (%)*	
	AFBC boiler	*CFBC boiler*	*AFBC boiler*	*CFBC boiler*
Anthracite	2851 - 2538	2797- 2498	84.4 – 85.73	85.95 – 87.13
Bituminous	5408 - 2909	5289 – 2880	73.68 – 85.44	75.33 – 86.289
Peat	9449 - 5440	9235 – 4405	64.71 – 75.65	66.21 – 76.66
Semi anthracite	3301 - 2702	3274 - 2678	72.37 – 76.01	72.95 – 76.52

Table 6
Expenditure of AFBC and CFBC boilers per annum

Grades of coal	*Coal priceper ton ($)*	*Expenditure per annum (Billion $)*	
		AFBC boiler	*CFBC boiler*
Anthracite	59.85	135 - 120	133 – 118
Bituminous	55.85	239 – 129	234 – 128
Peat	82.64	618 – 356	604 – 288
Semi anthracite	59.84	156 - 128	155 - 127

The overall efficiency of a thermal power plant can be calculated by using the formula [16] : $\eta_{overall} = \eta_{boiler} \times \eta_{cycle} \times \eta_{turbine} \times \eta_{generator} \times \eta_{auxiliary}$. For a typical thermal power plant the efficiency values are [19]: $\eta_{boiler} = 0.92$, $\eta_{cycle} = 0.44$, $\eta_{turbine} = 0.95$, $\eta_{generator} = 0.93$, $\eta_{auxiliary} = 0.95$. The overall efficiency of the plant estimated is 0.34. For the present AFBC boiler using the Anthracite as fuel, $\eta_{boiler} = 0.84$ and the overall efficiency of the plant is found to be 0.31, whereas it is 0.3176 in case of CFBC boiler. A marginal enhancement is noticed in the overall efficiency of the plant with CFBC boiler when compared to AFBC boiler. This indicates 32% of the energy in fuel is converted to electricity. The maximum loss of energy is due to heat to work energy conversion in the cycle. For fuel economy, the Anthracite having lower firing rate (which is inversely proportional to the efficiency) is selected for AFBC and CFBC boilers.

5. ESSENCE OF INSPECTION AND MAINTENANCE

All the above efficiencies are evaluated for the perfect boilers. In this regard, every part has to be inspected regularly. Inspection and maintenance play a crucial role in the boiler performance. Overlook of damage may finally lead to a costly damage. It is mandatory to perform non-destructive testing (NDT) for assessing the component life. Rennovations are vital for safe operation of the boiler by minimizing the down-time and carrying out the inspection.

Various non-destructive testing methods are being adopted to assess the health conditions of boilers. Their selection is based on the type of the component, the type of the defect and the accessibility of the part. The major components of the AFBC boiler are water wall panels, steam drum, mud drum, economizers, evaporators, bed coils, air heater, air box, raisers and down comers, ducting, piping, feed water tank, DE-aerator and blow down tank [20].

Figure 1 shows the components of a typical AFBC boiler. Visual testing is done prior to the execution of NDT inspections. Liquid penetrant testing will be carried out for inspection of heat exchangers, tubing and welds, venturi examination, inspection of tube plates. Magnetic particle testing is preferred for cracks defection in pipelines near the turbine as well as the attachments in valves. For characterization of the defects, ultrasonic testing as well as the eddy current testing wherever applicable are recommended [21].

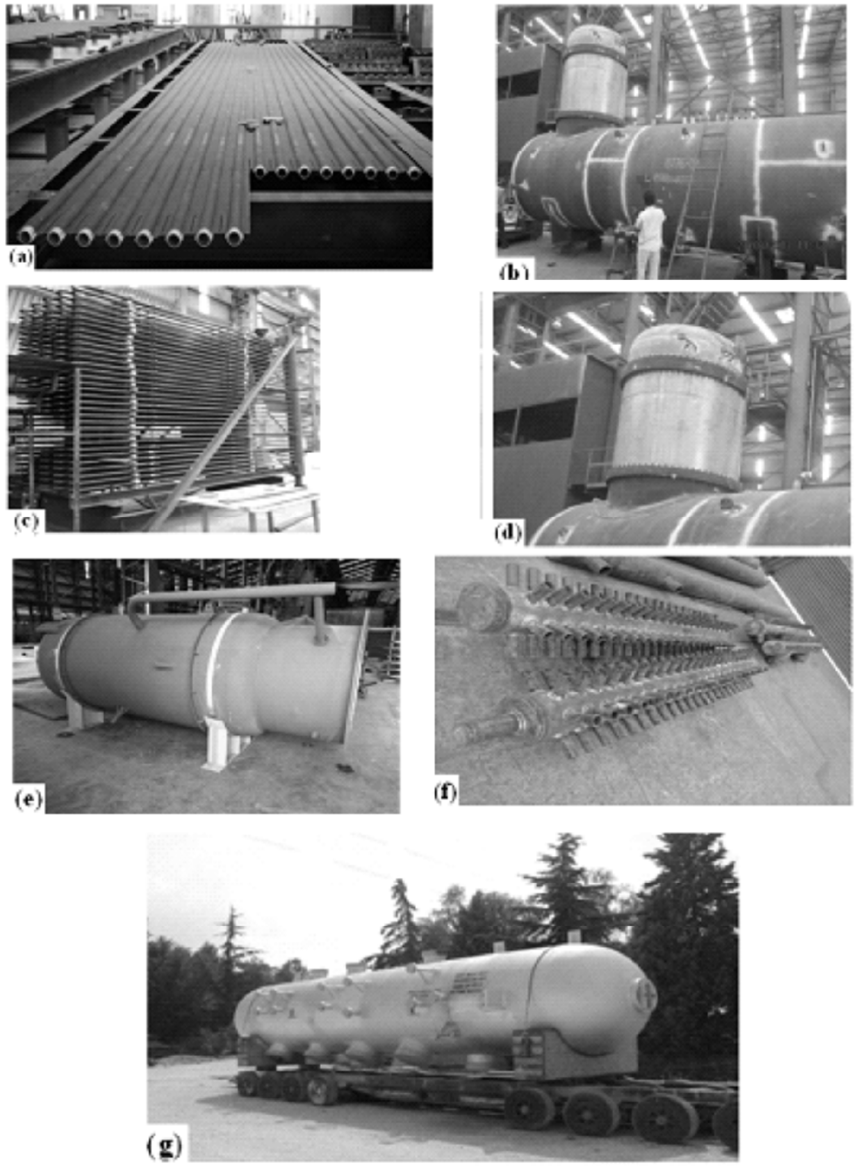

Figure 1: Components of a typical AFBC boiler. (a) Water wall panels; (b) Feed water tank; (c) Super heater, evaporator and economizer; (d) DE aerator to remove oxygen and other dissolved gases from the feed water to steam generating turbines; (e) Blowdown tank; and (f) Dispatching of a typical steam drum after successful hydraulic and pneumatic testing followed by NDT testing

6. CONCLUSIONS

Performance for bituminous D grade coal of maximum 5800kcal GCV of energy for CFBC furnace is 86.30% whereas for anthracite coal of maximum 8382kcal GCV is 87.13%. Utilization of anthracite coal fossil energy instead of high quality bituminous fossil energy of D grade has good effect on efficiency improvement and even saves 10-100 billion $ per annum (see Table-6). CFBC central heating boilers can be managed effectively with a number of energy sources like fossil energy, husk, and agro spend. CFBC central heating boilers can give ranked outcome even with substandard high quality energy sources. Since there are numerous fossil energy supplies in India and these central heating boilers can flame hot coals with ash material as high as 60% and having calorific value as low as 2500kcal/kg, coal-fired central heating boilers can be commonly used for enhancing efficiency of a furnace. These central heating boilers have a great capability of losing charges less than 6mm effectively. The circulation of ash from losing area will be in fluid condition which helps to make the ash elimination very easy. Inspection and maintenance play a crucial role in the boiler performance. Hence, every part has to be inspected regularly.

ACKNOWLEDGEMENT

The first author wishes to thank the authorites of Thermal[R] Systems Private. Limited, Hyderabad, India for giving training and guidance in Non-destructive Testing and Fabrication of AFBC boilers.

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