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Energy and Exergy Analysis of CFBC Boilers

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Abstract: India has progressed a lot by increasing its electricity generating capacity from 1362MW at the time of independence to 209276.03 MW as on 31st October 2012,which compromises of 19.03% hydro, 66.54% thermal, 2.31% nuclear and 12.10% renewable energy sources. Contribution of referred thermal is more than 56.80% from coal based steam turbine units. In addition to the installation of new thermal unit, renovation, modernization and refurbishment of the coal based old thermal units remained on the national priorities for more than last two decades. Coal quality deterioration is leading a new challenge before the design engineers to suitably innovate the coal based thermal power plants for degraded coal. CFBC are attracting the attention of power producers as an alternative to the conventional PCC boilers. This paper is focused on energy and exergy analysis of CFBC boiler and its comparison with PCC boiler under the compulsion to produce steam even when coal quality is very poor.
Keywords-'Energy', 'Exergy', 'CFBC', 'Boiler', 'Analysis'

I. INTRODUCTION

The exergy of heat is less than the heat itself for any reference of the actual boundary condition. Exergy supplied by the fuel and recovered by the flue gas is not same and difference between the two depends on the combustion condition such as fuel composition, air quantity, time, temperature, turbulence. Heat of the flue gas is utilized in raising the temperature of boiler feed water in economizer, converting it into steam in the evaporator and raising the temperature of steam in super heater and reheater. Destruction of exergy in these heat exchangers because of high differential temperatures with large variation can be controlled quite significantly by stabilizing the combustion conditions and improving the feed water management. Conventional Steam power plants are widely utilized throughout the world for electricity generation, and coal is often used to fuel these plants. Although the world's existing coal reserves are sufficient for about two centuries, the technology largely used today to produce electricity from coal causes significant negative environmental impacts. To use coal more efficiently and effectively efforts are been made to improve an efficiency of thermal power plant. Cogeneration is a technique for producing heat and electricity in one process that can save considerable amounts of energy. To improve efficiency of thermal power plant, a heat rate improvement of only a few percent appears desirable which is carried out by analyzing an amount of heat loss in different components. Energy technologies are normally examined using energy analysis but for better understanding, complete thermodynamic view is taken by 2nd law of thermodynamics in conjunction with energy analysis, by exergy methods. An exergy analysis is a straight forward method for assessing and improving thermal generating stations. An exergy analysis is carried out in different components and identifies that where maximum heat loss occurs so that proper improvement can be done to increase an efficiency of coal based power plant.

II. ENERGY & EXERGY CALCULATION

2.1 Economizer:

Economizer is the first boiler component which adds the sensible heat to the feed water and supplies the same to the boiler drum at a temperature sufficiently less than the saturation temperature corresponding to the pressure in the boiler drum to prevent any possibility of evaporation of economizer is compensated by the evaporator, which cause the destruction of available energy. Required governing equations for the analysis of energy and exergy are mentioned here under:

$$Q_{fg} \times C_{pfg} \times \Delta T_{fg} = Q_{wec} \times C\left(t_{weco} - t_{weci}\right)$$

$$\varepsilon_d = \varepsilon_s + \varepsilon_r = Q_{fg}\left[C_{pfg} \times \Delta T_{fg} - T_o * C_{pfg} * In\left(\frac{T_{fgeco}}{T_{fgeci}}\right)\right] - Q_{wec} * C\left[\left(t_{weco} - t_{weci}\right) - T_o * \ln(t_{weco} / t_{weci}\right]$$

$$\varepsilon_d = T_o\left[Q_{fg} * C_{pfg} * In\left(\frac{T_{fgeco}}{T_{fgeci}}\right)\right] - Q_{wec} * C * \ln(t_{weco} / t_{weci})$$

2.2 Evaporator:

Drum water enters to the evaporator at the saturation temperature where a portion of it converts into steam. Ratio of total water and steam mixture to the steam at the outlet of the evaporator is known as circulation number. This varies from 6 to 8 for the natural circulation boiler, which converts around 12 to 17% water into steam. Evaporator size, tube material and its properties, flue velocity and temperature gradient, furnace vacuum etc depend upon the evaporation. Required governing equations for the analysis of energy and exergy are mentioned as:

$$Q_{fg} \times C_{pfg} \times \Delta T_{fg} = Q_{sg} * L$$

$$\varepsilon_d = \varepsilon_s + \varepsilon_r = Q_{fg} * C_{pfg} * \left[\Delta T_{fg} - T_o * C_{pfg} * In\left(\frac{T_{fgeco}}{T_{fg}}\right)\right] - Q_{sg} * \left[L - T_o * (S_s - s_w)\right]$$

$$\varepsilon_d = T_o * [Q_{fg} \times C_{pfg} * \ln(T_{fgo} / T_{fg}) + Q_{sg} * (S_s - s_w)]$$

2.3 Super Heater:

Sensible heat of stream is added in the various super heaters over and above the saturation temperature corresponding to the boiler drum pressure. Specific heat of steam at constant pressure is very low in comparison to specific heat of water and latent heat of steam, which cannot allow the designer to place the super heater in the high heat flux zone, though there is a heat transfer from highest temperature hot media to the highest temperature cold media fluid. Pressure drop in the super heater and final steam temperature at the outlet of super heater play a vital role in energy and exergy management of the boiler. Required governing equations for the analysis of energy and exergy are mentioned here under:

$$Q_{fg} \times C_{pfg} \times \Delta T_{fg} = Q_{ms} * C_{psh} * \Delta T_{sh}$$

$$\varepsilon_d = T_o * [Q_{fg} \times C_{pfg} * \ln(T_{fgsho} / T_{fgi}) + Q_{ms} * C_{pssh} * \ln(T_{ms} / T_s)]$$

2.4 Re Heater:

Highest steam temperature is restricted by the metallurgical limitations of the boiler tubes, which is taken care of by providing the reheat system for the high pressure boilers. Degree of super heat is utilized in the high pressure a super steam turbine and the steam is supplied back to the reheater for further addition of sensible heat, well within the prescribed metallurgical limits. Re heated is allowed to expand in the intermediate pressure turbine and low pressure turbine. The thermal units, with ultra super critical pressure may have two or more stages of reheating to fully utilize the pressure under the metallurgical limitations. Required governing equations for the analysis of energy and exergy are mentioned here under:

$$Q_{fg} * C_{pfg} * \Delta T_{fg} = Q_{hrh} * C_{psrh} * \Delta T_{srh}$$

$$\varepsilon_d = T_o * [Q_{fg} * C_{pfg} * \ln(T_{fgrho} / T_{fgrhi}) + Q_{hrh} * C_{psrh} * \ln(T_{hrh} / T_{crh})]$$

Exergy supplied by flue gas:

$$\varepsilon_s = Q_{fg} * C_{pfg}(T_{ad} - T_{fget})(1 - T_{fg} / T_{fget})$$

Exergy recovered water/steam:

$$\varepsilon_r = Q_{wec} * C(T_{weco} - T_{weci}) - T_o * \ln(t_{weco} / t_{weci}) + Q_{sg}[L - T_o(S_s - s_w)] + Q_{ms} * C_{psh}[\Delta T_{sh} - T_o * \ln(T_{ms} / T_s)] + Q_{hrh} * C_{prh}[\Delta T_{srh} - T_o * \ln(T_{hrh} / T_{crh})]$$

3. Boiler Efficiency Calculation:

3.1 Direct Method: Steam is output of boiler and fuel is the input and hence the ratio of heat supplied to steam in boiler and heat released by the fuel in boiler. This method is also known as input-output method.

$$\eta_b = (Q_{ms} * \left(H_{ms} - h_{fw}\right) + Q_{rh} * (H_{hrh} - H_{crh})) / (Q_c * CV + H_{credit})$$

Where η_b is the boiler efficiency, Q_{ms} is flow of main stream, H_{ms} is the enthalpy of the main stream, h_{fw} is the enthalpy of the feed water, Q_{rh} is the mass flow of steam trough re heater, H_{hrh} is the enthalpy of steam at re heater outlet, H_{crh} is the enthalpy of steam at the inlet of the re heater, Q_c is the coal flow, CV is calorific of the coal and H_{credit} is the heat added to the boiler from an outside source.

3.2. Indirect Method:

In this method percentage of heat loss is determined and deducted from 100 and hence this method is also known as determination of boiler efficiency by estimation of losses.

η_b=100- Losses calculated under

3.2.1 Dry flue gas Loss:

DFL= 30.6*(T-t)*(C/100+S/267-CinAsh)*100/12$\left(CO_2 + CO\right) KJ / Kgcoal$

3.2.2 Wet flue gas Loss:

WFGL=$[1.88*(T-25)+2442+4.2*(25-t)]*(M_c+9H)/100 KJ / Kgcoal$

3.2.3 Carbon in Ash Loss:

C in Ash L= C in A * 33820 KJ/Kg Coal

3.2.4 Unburnt Gas Loss:

$$UGL = 23717 * (C/100 + S/267 - CinAsh) * CO/12(CO_2 + CO) KJ/Kgcoal$$

3.2.5 Moisture in Combustion Air loss:

$$M_a = (C/100 + S/267 - CinAsh) * 3.03 N_2 / 12(CO_2 + CO) KJ/Kgcoal$$

3.2.6 Sensible Heat in ash loss:

SH in Ash L=0.8A*0.836*(T-t) +0.2A*1.17*$T_f - t$) KJ/Kg coal

3.2.7 Sensible Heat loss in Mill Reject:

Shin Reject L= $m_r * C_{pr} * (T_{c+a} - t)$

3.2.8 Radiation and Unaccounted Loss:

$$Log_{10} B = 0.8167 - 0.4238 \log_{10} C_{ap}$$

Where B is radiation and unaccounted loss and C is the boiler capacity in Kg/sec (steam produced)

III. COGENERATION PLANT

In several industries, saturated steam at required temperature and pressure is used for heating purpose. Apart from heating, industries also need electric power for running various machineries and for lightening purpose. Formally in industries moderate pressure of steam was generated for power purpose and saturated steam at required pressure for heating purpose. Having two different units for generating power and for heating purpose is wasteful. By modifying the initial and exhaust steam pressure required power can be generated and it makes available for process heating. In cogeneration plant, the exhaust steam from the turbine is used for the process heating purpose hence process heaters are kept instead of condensers of the ordinary rankine cycle.

IV. OVERALL PLANT RESULTS AND DISCUSSION

From energy and exergy analysis maximum exergy loss (68%) occurred in economiser section which leads to damage of certain portion of tubes suffering from fouling of the tubes, corrosive scaling of the tube and insulation leakage. Also whole heat recovery system has 62% of exergy loss which demands for cleaning of damaged tubes and replacing of fouled tube with new one.

Component	1^{st} law η	2^{nd} law η	% Energy Loss	% Energy Destruction
Combustor	98.93%	58.50%	1.07%	41.50%
Heat recovery system	73.20%	37.59%	26.8%	62.74%

Super heater	57.22%	34.86%	42.78%	65.14%
Economizer	85.49%	33.98%	14.51%	68.02%
Air Pre heater	94.67%	56.99%	5.33%	43.01%

V. CONCLUSION

From above result and discussions following conclusion are listed below:

a) Exergy efficiency of the plant is lower than energy efficiency due to so many losses occurring in the plant and energy degradation.

b) It has been found out that 65.04% exergy loss occurs in super heater and 68.02% exergy loss occurs in economizer (heat exchanger). Which are main parts that contribute more loss of exergy.

c) It has been found that 43% exergy loss occurs in combustor (furnace) which shows combustor is not fully

Adiabatic and combustion may not be completed. It is due to the irreversibility within the combustion process. This study indicates that the combustor requires necessary modification like refractory (insulation) modification to reduce exergy destructions thereby plant performance can be improved.

d) The major exergy destruction (64.74%) occurs in the heat recovery system which leads to inefficient heat transfer between hot stream (flue gas) and cold stream (water & air).It indicates that heat exchanger system need to be carefully inspected.

e) Back pressure turbine shows variation in energy and exergy losses which is due to variation in stream flow at extraction and exhaust stage according to variation in plant demand of heat and electricity. It should be optimized between heat load and electrical load at given mass ratio for better operation and to minimize the variation between energy and exergy efficiency.

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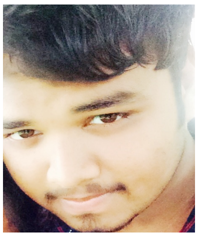

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