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Thermal Assessment of Boilers in A Coal-Fired Power Plant

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***Abstract*— The conventional coal-fired power plant operate well below at *60%* efficiency which means that *40%* or higher, useful heat energy is lost and is dissipated elsewhere. Even though every power plant is made to operate at best optimised operating parameters and tuned working conditions, certain losses are unavoidable. The maximum wastage of heat in a coal-fired boiler is the heat carried away by the products of combustion and normally termed to be sensible loss. This loss if at an acceptable level justifies the operation of the thermal power plant irrespective of the cost of the fuel. But if this wastage is huge and massive, the firing arrangements, damper adjustments, the primary and secondary air supply conditions, mill flow rate etc are to be thoroughly assessed towards proper and efficient running of a power plant. This paper focuses on the thermal assessment of coal-fired boilers targeting on the various heat losses associated with the system.**

***Keywords*— Coal-fired, Heat losses, Thermal assessment, boiler, operating parameters**

I. Introduction

Thermal assessment of an efficient boiler refers to how much of the fuel's energy is usefully utilised in conversion of liquid water to steam. It denotes the quantity of heat the boiler produces to the total thermal energy produced by burning of fuel. Thermal calculations of boilers are the main elements of heat transfer, especially in optimising processes, energy efficiency and to minimise harmful emissions[1,2,3]. It is to realise a boiler system structure created in the appropriate way in terms of boiler safety, reliability, operability, efficiency, and environmental compliances [4,5].

II. Boiler – An Over View

A boiler in a closed vessel which provides a means for combustion heat to be transferred to water until it becomes steam.[6] The quality and quantity of boiler heat in-take to heat out remains a highly technical challenge even for well established thermal generation system.

The efficiency of a coal -fired boiler is a measure of how much of heat energy output is used to generate steam to the thermal energy input received from burning the coal. As per the law of conservation of energy, the chemical energy is produced when coal is burnt with air and this energy is converted to thermal energy.

This thermal energy is the useful energy output form the boiler which converts the liquid water to steam considerably at a higher temperature and operating pressure.

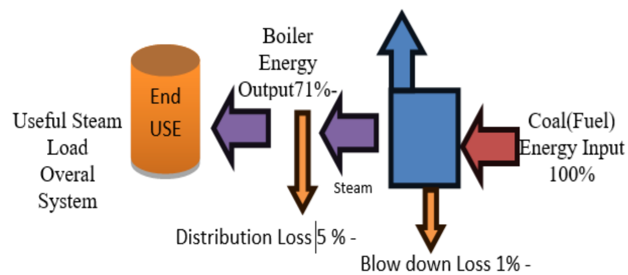

Figure No. 1. Energy Balance in a coal-fired boiler

Boilers work on traditional combustion methods must be designed and modified with stringent emission standards which forces designers and operators to carry out detailed thermal and thermodynamic calculations [7]. The water flows inside the tube which is the water walls and the hot flue gases pass around it transferring its useful energy. The efficiency of a water tube boiler is highly determined by its heat transferring capabilities and the primary modes of heat transfer viz Conduction, Convection and radiation. [8,9]

III. Heat Losses In Boiler

Significant amount of heat energy would be lost due to operational conditions and various design factors, called as the heat losses in boilers. The various heat losses include dry Flue gas loss L1, Heat loss due to moisture in fuel L2, Losses due to H2 in fuel L3,Heat loss due to partial conversion of C to CO L4, Heat loss due to Moisture in Combustion air L5, Heat losses due to convection and radiation L6. They normally account to a total of 30%. The distributed pattern of heat losses are shown in figure.2. below. The heat lost to the environment and the thermal efficiency of the boiler is the environmental indicator which will directly affect the amount of fuel burnt in the boiler and in-turn affect the change in environmental parameters [10-15].

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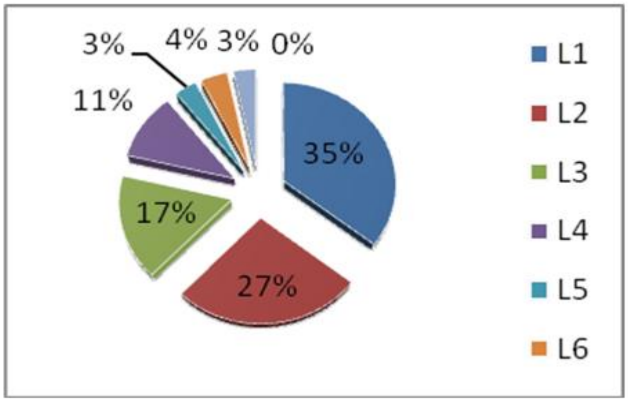

Figure 2. Various Heat losses in Boiler

Thermal assessment of the above losses is the major factor towards improving energy efficiency and reduction in operating cost of the power plant. Each thermodynamic parameter and the various factors detailed below accounts for every percent loss in the boiler.

A. Dry Flue Gas Loss L1

It is the major loss that is carries away by the dry combustion gases without extracting the heat by the gases like carbon di-oxide, oxygen, sulphur di-oxide which exit the stack at a higher temperature.

$$L_1 = \frac{mxC_p(t_f - t_a)}{GCVofFuel} x\ 100$$

m is the mass of dry flue gas per unit mass of fuel in kg/kg
C_p is the specific heat of dry flue gas in kcal/kg^{0}C
t_f is the flue gas temperature in °C
t_a is the ambient air temperature in °C
GCV is the Gross calorific value of fuel in kcal/kg

B. Heat Loss Due To Moisture In Fuel L2

This is the energy loss occurring when water inside fuel absorbs the heat form the flue gases, and gets evaporated into steam by consuming latent as well as sensible heat . The sensible heat is wasted by heating the moisture present in the fuel and the latent heat is consumed when the liquid water is converted to steam. The evaporated steam is then superheated since the temperature inside is high and this heat escapes out to atmosphere.

$$L_2 = \frac{mx\ [h_g - h_f]}{GCVoffuel} x\ 100$$

m is the mass of dry flue gas per unit mass of fuel in kg/kg
h_g is the enthalpy of superheated steam at flue gas temperature in kcal/kg
h_f is the enthalpy of saturated liquid water at flue gas temperature in kcal/kg
GCV is the Gross calorific value of fuel in kcal/kg

C. Losses Due To H2In Fuel L3

This losses are are due to presence of hydrogen in fuel as burning hydrogen creates water vapour which takes away latent heat as it leaves the stack. THE hydrogen if present in the fuel reacts with oxygen to form water. For every kg of hydrogen burnet, 9 kg of water vapor are produced. Loss occurs be the conversion of this water to vapourand is calculated by the equation as below:

$$L_3 = \frac{9\ xH_2x\ [h_g - h_f]}{GCVoffuel} x\ 100$$

H_2 is the percentage of hydrogen present in fuel.
9 is the multiplication factor for kg of water produced per kg of hydrogen
h_g is the enthalpy of superheated steam at flue gas temperature in kcal/kg
h_f is the enthalpy of saturated liquid water at flue gas temperature in kcal/kg
GCV is the Gross calorific value of fuel in kcal/kg

D. Heat Loss Due To Partial Conversion C To CO L4

This loss is due to partial conversion of carbon present to carbon monoxide. Less heat is generated since incompletes combustion occurs.

$$L_4 = \frac{\%COxC}{\%CO + CO_2} x \frac{5744}{GCVoffuel} x\ 100$$

%CO is the volume of Carbon Monoxide in the flue gas.
%C is the carbon content in kg/kg of fuel
% CO_2 is the actual volume of carbon di-oxide in the flue gas
5744 is the heat released by burning 1 kg of carbon from CO to CO_2 in kcal/kg
GCV is the Gross Calorific Value of the fuel in kcal/kg

E. Heat Loss Due To Un burnt Carbon L5

When fuel particles do not burn properly, heat loss occurs since the residue has combustible carbon still to be burnt and useful heat has to be released. The reasons for this loss include improper fuel-air mixing, low combustion temperature, poor fuel preparation and very short residence time.

$$L_5 = \frac{TotalAshper\ \mathrm{kg}\ offuelx\ \%\ CarboninAsh}{GCVoffuel} x\ 8100\ x\ 100$$

8100 is the Gross calorific value of carbon, in kcal/kg
GCV is the Gross calorific value of fuel in kcal/kg

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F. Heat Loss Due To Moisture In Combustion AirL6

It is the heat energy taken away by the water vapour in the intake air as it is heated from the ambient temperature to a very high temperature of exhaust condition. The moisture in the air takes heat and rises in temperature up to boiling point which is the costly sensible heat. Latent heat is further wasted in order to convert this boiled water to vapour. The water vapour again is superheated since the temperature inside is very high.

$$L_6 = \frac{m_a x \Phi_a x C_{pwv} x (t_f - t_a)}{GCV of fuel} x\ 100$$

m_a is the mass of dry air supplied per kg of fuel in kg/kg of fuel.

Φ_a is the specific humidity of ambient air in kg of moisture/ kg of dry air

C_{pwv} is the specific heat of superheated water vapour in kcal/kg^{0}C

t_f is the temperature of flue gas in ^{0}C

t_a is the temperature of ambient air in^{0}C

GCV is the Gross calorific value of fuel in kcal/kg

G. Heat Losses Due To Convection And RadiationL7

These losses are due to thermal energy escaping from the hot external surfaces through convection and radiation mode of heat transfer. The Radiation losses are the thermal energy leaves as infrared electromagnetic waves from the outer boiler shell and pipes conveying steam. The heat is carried away across the hot outer surface area of the boiler due to convection and this heat is lost from the system.

$$L_7 = \frac{A_s x \{h_c + h_r\} x [t_s - t_a]}{GCV of fuel}\ 100$$

A_s is the outside surface area of the boiler in m^2

h_c is the convective heat transfer co-efficient in W/m$^{2 0}$C

h_r is the radiative heat transfer co-efficient in W/m$^{2 0}$C

t_s is the outside surface temperature of boiler in ^{0}C

t_a is the temperature of ambient air in ^{0}C

GCV is the Gross calorific value of fuel in kcal/kg

IV. CONCLUSION

The various losses incurring during the operation of the boiler are discussed. The combustion stoichiometry if properly identified for every quantity and quality of fuel and operated minuses the sensible heat loss considerably.

It is said that every *20^{o}C* reduction in flue gas temperature will improve efficiency around *1%*.Also for every *1 kg* of hydrogen burnt, *9kg* of water vapour is produced which wastes the useful energy. Well insulated system can reduce the thermodynamic losses from leaving out of the control volume. Implementation of the planned preventive procedures can greatly reduced the above discussed losses and increase the useful heat transfer, thereby lowering operating cost at a increased overall efficiency of the power plant.

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