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IMPROVING THE EFFICIENCY OF THERMAL EQUIPMENTS OF 210 MW TPS THROUGH THERMAL AUDIT

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ABSTRACT

In the present work, energy analysis of a coal-based thermal power plant is done using the design data from a 210 MW thermal power plant under operation in India. The entire plant cycle is split up into three zones for the analysis: (1) main steam system, (2) steam turbine, condenser, feed pumps and the HP and LP heaters, (3) the entire analysis with boiler, turbo-generator, condenser, feed pumps, regenerative heaters and the plant auxiliaries. It helps to find out the contributions of different parts of the plant towards energy destruction. The energy efficiency is calculated using the operating data from the plant at different conditions, viz. at different loads, different condenser pressures, with and without regenerative heaters and with different settings of the turbine governing. Effect of regeneration on energy efficiency is studied by successively removing the high pressure regenerative heaters out of operation.. Increase in the condenser back pressure decreases the energy efficiency. Successive withdrawal of the high pressure heaters show a gradual increment in the energy efficiency for the control volume excluding the boiler, while a decrease in energy efficiency when the whole plant including the boiler is considered. Keeping the main steam pressure before the turbine control valves in sliding mode improves the energy efficiencies in case of part load. The boiler efficiency is calculated by the indirect method (losses calculation method) and HP and LP heaters performance analysis has been done by the calculations. The net heat rate of the station is also calculated and target for the reduction to achieved the design value of the net station heat rate.

Key words: Boiler, HP & LP heater, CEP

INTRODUCTION

Boiler is defined as the heat added to the working fluid expressed as a percentage of heat in the fuel being burnt. The theoretical limit to boiler efficiency is 100% unlike in case of turbo generator whose efficiency is limited by the cycle efficiency. The maximum boiler efficiency is thought of in terms of an optimum efficiency which depends on fuel being burnt and the fact that waste products of combustion take away heat with them.

When considering boiler energy savings, invariably the discussion involves the topic of boiler efficiency.

The boiler suppliers and sales personnel will often cite various numbers, like the boiler has a thermal efficiency of 85%, combustion efficiency of 87%, a boiler efficiency of 80%, and a fuel-to-steam efficiency of 83%. What does these mean?

Typically,

1) Thermal efficiency reflects how well the boiler vessel transfers heat. The figure usually excludes radiation and convection losses.
2) Combustion efficiency typically indicates the ability of the burner to use fuel completely without generating carbon monoxide or leaving hydrocarbons unburned.
3) Boiler efficiency could mean almost anything. Any fuel-use figure must

compare energy put into the boiler with energy coming out.

4) "Fuel to steam efficiency" is accepted as a true input/output value.

Each term represents something different and there is no way to tell, which boiler will use less fuel in the same application! The trouble is that there are several norms to determine the efficiencies figures and it is practically very difficult to verify these without costly test procedures. The easiest and most cost effective method is to review the basic boiler design data and estimate the efficiency value on five (5) broad elements.

1) **Boiler Stack Temperature**: Boiler stack temperature is the temperature of the combustion gases leaving the boiler. This temperature represents the major portion of the energy not converted to usable output. The higher the temperature, the less energy transferred to output and the lower the boiler efficiency. When stack temperature is evaluated, it is important to determine if the value is proven. For example, if a boiler runs on natural gas with a stack temperature of 350°F, the maximum theoretical efficiency of the unit is 83.5%. For the boiler to operate at 84% efficiency, the stack temperature must be less than 350°F.

2) **Heat Content of Fuel:** The efficiency calculation requires knowledge of the calorific value of the fuel (heat content), its carbon to hydrogen ratio, and whether the water produced is lost as steam or is condensed, and whether the latent heat (heat required to turn water into steam) is recovered. Disagreements exist on what is considered an "energy input". Unfortunately any fuel has two widely published energy contents. They are:

   - The Higher Heating Value (HHV), also called Gross Calorific Value (GCV)
   - The Lower Heating Value (LHV), also called the Net Calorific Value (NCV)

   The gross calorific value (GCV) is the higher figure and assumes that all heat available form the fuel is to be recovered, including latent heat. In most equipment, this is not so the case, and the calculations of efficiency based on gross calorific value will give maximum obtainable efficiencies much lower than 100%, due to this irrecoverable loss.

   Both the gross calorific value and net calorific value are equally valid, but for comparison purposes, a particular convention should be used throughout.

3) **Fuel Specification:** The fuel specified has a dramatic effect on efficiency. With gaseous fuels having higher the hydrogen content, the more water vapor is formed during combustion. The result is energy loss as the vapor absorbs energy in the boiler and lowers the efficiency of the equipment.

   The specification used to calculate efficiency must be based on the fuel to be used at the installation. As a rule, typical natural gas has a hydrogen/-carbon (H/C) ratio of 0.31. If an H/C ratio of 0.25 is used for calculating efficiency, the value increases from 82.5% to 83.8%.

4) **Excess Air Levels:** Excess air is supplied to the boiler beyond what is required for complete combustion primarily to ensure complete combustion and to allow for normal variations in combustion. A certain amount of excess air is provided to the burner as a safety factor for sufficient combustion air.

5) **Ambient Air temperature and Relative Humidity:** Ambient conditions have a dramatic effect on boiler efficiency. Most efficiency calculations use an ambient temperature of 80°F and a relative humidity of 30%. Efficiency changes more than 0.5% for every 20°F change in ambient temperature. Changes in air humidity would have similar effects; the more the humidity, the lower will be the efficiency.

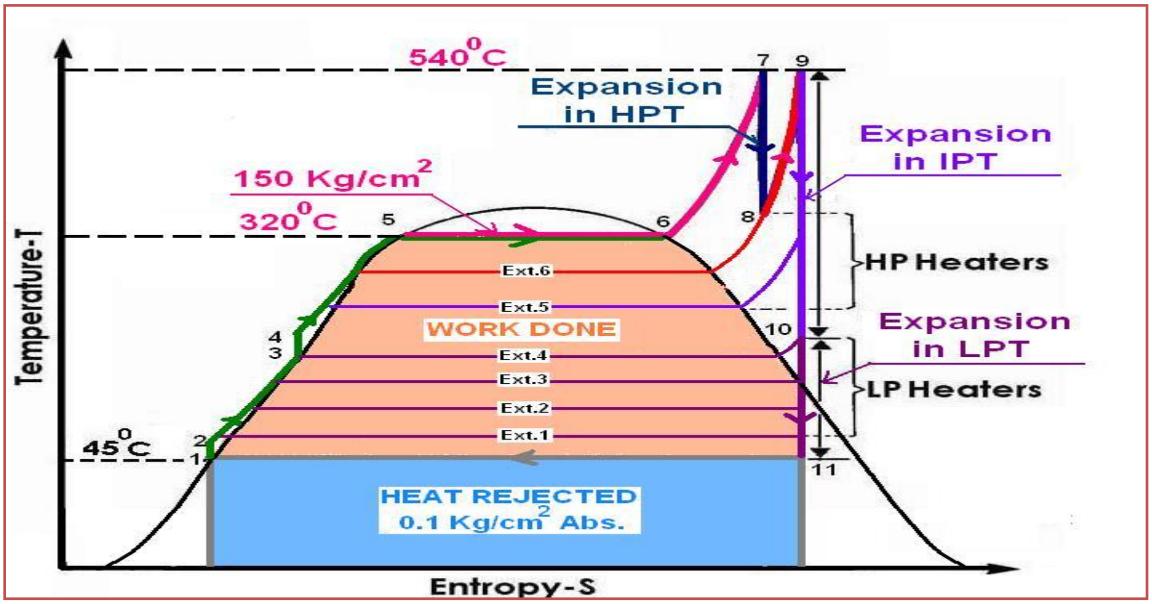

Fig :-Steam cycle for 210 mw

Operating efficiency of the boiler:

The test method employed is based on the abbreviated efficiency by the loss method (or indirect method) test, which neglects the minor losses and heat credits, which are covered in full text version. The major losses covered are:

- Heat loss due to dry flue gas losses
- Heat loss due to moisture in fuel
- Heat loss due to hydrogen (moisture of burning hydrogen)
- Heat loss due to combustibles in refuse
- Heat loss due to radiation
- Un accounted losses as per the contract with the Boiler Supplier

Indirect method is also called as **heat loss method.** The efficiency can be arrived at, by subtracting the heat loss fractions from 100. The standards do not include blow-down loss in the efficiency determination process

Operating efficiency of the Turbine:

After evaluating the turbine heat rate and efficiency, check for the deviation from the design and identify the factors contributing for the deviations. The major factors to be looked into are:

- Main steam and reheat steam inlet parameters
- Turbine exhaust steam parameters
- Re-heater and super heater spray
- Passing of high energy draining
- Loading on the turbine
- Boiler loading and boiler performance
- Operations and maintenance constraints

COMBUSTION PROCESSES have been, are and will be for the near future, the prime generator of energy in our civilization, which is burning fossil fuels at an ever-increasing rate. The processes must be managed well for the sake of the environment and the sustainability of civilization. The principles of combustion are common to heaters, boilers and other forms of industrial combustion, e.g. in furnaces and kilns. In this sense, **the term "boiler" is interchangeable with "heater" throughout this text** (unless stated otherwise). Conventional fuels consist mainly of two elements – carbon and hydrogen. During combustion, they combine with oxygen to produce heat. The fuel value lies in the carbon and hydrogen content.

Non-fossil fuels, such as biomass and alcohol, also contain oxygen in their molecular structures. Ideally, combustion breaks down the molecular structure of the fuel; the carbon oxidizes to carbon dioxide (CO2) and the hydrogen to water vapour (H2O). But an incomplete process creates undesirable and dangerous products. To ensure complete combustion, even modern equipment with many features must operate with excess air. That is, more air (carrying about 21 percent oxygen by volume) is passed through the burner than is chemically required for complete combustion. This excess air speeds up the mixing of fuel and air. On one hand, this process ensures that nearly all the fuel receives the oxygen it needs for combustion before it is chilled below combustion temperatures by contact with heat exchange surfaces. It also prevents fuel that is not burned completely from exploding within the boiler. On the other hand, excess air wastes energy by carrying heat up the stack. A fine line exists between combustion efficiency and safety in ensuring that as little excess air as possible is supplied to the burner. Boiler owners and operators will want to know if their operations are efficient. As the objective is to increase the energy efficiency of boilers, reviewing the causes of heat loss in boiler operations may be useful.

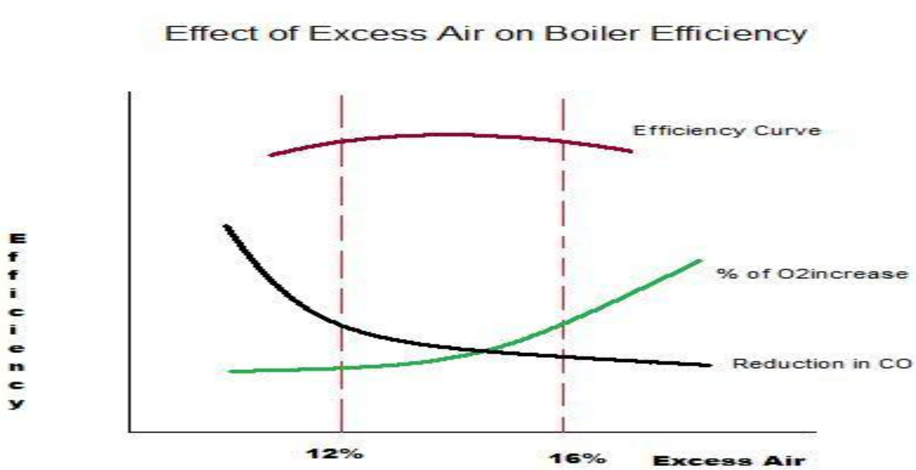

Fig:-Excess air on boiler efficiency

HEAT LOSSES :In such systems, many of the losses listed in the code do not apply. And other systems are small enough for their losses to be rolled into an "unaccounted for" category, for which a value can be assumed. A simplified method for quantifying boiler efficiency uses this equation:

Efficiency (E) % 5 **(Output** 4 **Input)** 3 **100, where: Output** 5 **Input** 2 **Losses**

Alternatively,

Efficiency (E) % 5 **100** 2 **losses, where**

losses can be calculated according to the ASME power test code.

Since this code uses Imperial units, it is necessary to convert temperatures to degrees Fahrenheit (°F) and heating units to British thermal units per pound (Btu/lb.), which can be done with the following conversion formulas:

°F 5 **(1.8** 3 **°C)** 1 **32**
Btu/lb. 5 **0.4299** 3 **kJ/kg**

Dry flue gas loss (LDG) Heat is lost in the "dry" products of combustion, which carry only sensible heat since no change of state was involved. These products are carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), nitrogen (N_2) and sulphur dioxide (SO_2). Concentrations of SO_2 and CO are normally in the parts-per-million (ppm) range so, from the viewpoint of heat loss, they can be ignored. Calculate the dry flue gas loss (LDG) using the following formula:

$$L1 = \frac{m \times Cp \times (Tf - Ta) \times 100}{\text{GCV of fuel}}$$

Where,
L1 = % Heat loss due to dry flue gas
m = Mass of dry flue gas in kg/kg of fuel
= Combustion products from fuel: CO_2 + SO_2 + Nitrogen in fuel + Nitrogen in the actual mass of air supplied + O_2 in flue gas.
(H_2O/Water vapour in the flue gas should not be considered)
= 867.62&1184.8 kJ/kg of coal
Percentage loss **= 5.08&6.862%**

Wet flue gas: The combustion of hydrogen causes a heat loss because the product of combustion is water. This water is converted to steam and this carries away heat in the form of its latent heat.

$$L2 = \frac{9 \times H2 \times \{2442 + Cp\ (Tf\ .\ Ta)\} \times 100}{\text{GCV of fuel}}$$

Where
H2 = kg of hydrogen present in fuel on 1 kg basis
Cp = Specific heat of superheated steam in k Cal/kg °C
Tf = Flue gas temperature in °C
Ta = Ambient temperature in °C

The following four significant types of energy losses apply to natural gas and heating fuel systems

584 = Latent heat corresponding to partial pressure of water vapour

Percentage loss = 8.26&8.26%

Moisture in combustion air: Moisture entering the boiler with the fuel leaves as a superheated vapour. This moisture loss is made up of the sensible heat to bring the moisture to boiling point, the latent heat of evaporation of the moisture, and the superheat required to bring this steam to the temperature of the exhaust gas. This loss can be calculated with the following formula

$$L3 = \frac{M \times \{584 + Cp\ (Tf\ .\ Ta)\} X\ 100}{\text{GCV of fuel}}$$

where
M = kg moisture in fuel on 1 kg basis
Cp = Specific heat of superheated steam in kCal/kg°C
Tf = Flue gas temperature in °C
Ta = Ambient temperature in °C
584 = Latent heat corresponding to partial pressure of water vapour

Percentage loss = 0.101&.099%

Heat loss due to unburnt in fly ash (%).

$$L4 = \frac{\text{Total ash collected / kg of fuel burnt x G.C.V of fly ash x 100}}{\text{GCV of fuel}}$$

Heat loss due to unburnt in bottom ash (%)

$$L5 = \frac{\text{Total ash collected per kg of fuel burnt x G.C.V of bottom ash x 100}}{\text{GCV of fuel}}$$

Heat loss due to radiation and convection: The other heat losses from a boiler consist of the loss of heat by radiation and convection from the boiler casting into the surrounding boiler house.

Normally surface loss and other unaccounted losses is assumed based on the type and size of the boiler as given below
For industrial fire tube / packaged boiler = 1.5 to 2.5%
For industrial watertube boiler = 2 to 3%
For power station boiler = 0.4 to 1%

L6 = 0.548 x [(Ts / 55.55)4 . (Ta / 55.55)4] + 1.957 x (Ts . Ta)1.25 x sq.rt of
[(196.85 Vm + 68.9) / 68.9]
where

L6 = Radiation loss in W/m2
Vm = Wind velocity in m/s
Ts = Surface temperature (K)
Ta = Ambient temperature (K)

Heat loss due to moisture present in air
Vapour in the form of humidity in the incoming air, is superheated as it passes through the boiler. Since this heat passes up the stack, it must be included as a boiler loss.To relate this loss to the mass of coal burned, the moisture content of the combustion air and the amount of air supplied per unit mass of coal burned must be known.

$$L7 = \frac{AAS \times \text{humidity factor} \times Cp \times (Tf . Ta) \times 100}{\text{GCV of fuel}}$$

Where

AAS = Actual mass of air supplied per kg of fuel
Humidity factor = kg of water/kg of dry air
Cp = Specific heat of superheated steam in kCal/kg°C
Tf = Flue gas temperature in °C
Ta = Ambient temperature in °C (dry bulb)

PERFORMANCE OF AIR PREHEATERS

Gas side efficiency: The gas side efficiency is defined as the ratio of the temperature drop, corrected for leakage, to the temperature head and expressed as percentage.

Temperature drop is obtained by subtracting the corrected gas outlet temperature from the inlet. Temperature head is obtained by subtracting air inlet temperature from gas inlet temperature

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$$T_{gnl} = \frac{AL * C_{pa} * (T_{gl} - T_{ae})}{100 * C_{pg}} + T_{gl}$$

		Units
T_{gnl}	Gas outlet temperature corrected for no leakage	°C
C_{pa}	The mean specific heat between T_{ac} and T_{gl}	Kcal/kg°C
T_{ae}	Temperature of the air entering the APH	°C
T_{al}	Temperature of the air leaving the APH	°C
T_{gl}	Temperature of the gas leaving the APH	°C
C_{pa}	The mean specific heat between T_{gl} and T_{gnl}	Kcal/kg°C

CONCLUSION AND ENERGY CONSERVATION OPPORTUNITIES

The improvement in the efficiency of the boiler by the plugging air-leakage in the air-pre heater and to improve the performance of HP and LP Heater to maintain the design feed water temperature in the two unit of 210 mw increasing the efficiency of the boiler by improving the performance of mill, air-pre heater and bringing down the excess air level to the design value and also improve the performance of HP and LP Heater by calculating its effectiveness. In the condensate extraction pump the discharge pressures of CEPs are very much higher than the pressure required to take condensate from hot well and pass through heaters and deliver to de-aerator Installing VFD on CEP can reduce power consumption by 757 kW total in the CEP systems of all units.

1. Air & flue gas cycle:-

a. Optimizing excess air ratio: - It reduces FD fan & ID fan loading.

b. Replacement of oversize FD and PA fan: - Many thermal power plants have oversize fan causing huge difference between design & operating point leads to lower efficiency. Hence fan efficiency can be improved by replacing correct size of fan. If replacement is not possible, Use of HT VFD for PA & ID fan can be the solution.

c. Attending the air & flue gas leakages: - Leakages in air & flue gas path increases fan loading. Use of Thermo vision monitoring can be adopted to identify leakages in flue gas path. Air preheater performance is one crucial factor in leakage contribution. If APH leakage exceeds design value then it requires corrective action.

2. Steam, Feed water and condensate cycle:-
a. BFP scoop operation in three element mode instead of DP mode: - In three element mode throttling losses across FRS valve reduces leads to reduction in BFP power.

b. Optimization of level set point in LP & HP heater: - Heater drip level affects TTD & DCA of heater which finally affect feed water O/L temp. Hence it requires setting of drip level set point correctly.

c. Charging of APRDS from CRH line instead of MS line: -APRDS charging from cold reheat (CRH) is always more beneficial than from MS line charging.

d. Isolation of steam line which is not in use: - It is not advisable to keep steam line unnecessary charge if steam is not utilized since there energy loss occurred due to radiation. For example deareator extraction can be charged from turbine Extraction/CRH or from APRDS. In normal running APRDS Extraction is not used so same can be kept isolated.

e. Replacement of BFP cartridge: - BFP draws more current If Cartridge is wore out, causing short circuit of feed water Flow inside the pump. It affects pump performance. Hence cartridge replacement is necessary.

f. Attending passing recirculation valve of BFP: - BFP Power consumption Increases due to passing of R/C valve. It requires corrective action.

g. Installation of HT VFD for CEP: - CEP capacity is underutilized and also there is pressure loss occurs across Deareator level control valve. There is large scope of energy saving which can be accomplished by use of HT VFD for CEP or impeller trimming.

3. Fuel & ash Cycle:-

a. Optimized ball loading in Ball tube mill: - Excessive ball loading increases mill power. Hence ball loading is to be Optimized depending upon coal fineness report.

b. Use of Wash Coal or Blending with A-grade coal: - F-grade coal has high ash content. Overall performance can be improved by using Wash coal or blending of F-grade coal with A-grade coal instead of only using F- grade coal.

c. Avoiding idle running of conveyors & crusher in CHP

d. Use of Dry ash Evacuation instead of WET deashing System: - Dry deashing system consumes less power & also minimizes waste reduction.

e. Optimize coal mill maintenance:-Mill corrective/preventive maintenance is to be optimized depending parameter like- running hrs, mill fineness, bottom ash unburnt particle, degree of reject pipe chocking etc.

4. ECW & ACW system:-

a. Isolating ECW supply of standby auxiliaries: - Many times standby coolers are kept charged from ECW side. Also Standby equipment's auxiliaries like Lube oil system kept running for reliability. We can isolate Standby cooler from ECW system & switching of standby auxiliaries, doing trade off between return & reliability.

b. Improving condenser performance by condenser tube cleaning & use of highly efficient debris filter: - Tube cleaning by bullet shot method increases condenser performance, condenser tube cleaning is necessary which is to be carried out in overhaul. Also highly advanced debris filter contribute condenser performance.

c. Application of special coating on CW pump impeller: - It improves pump impeller profile condition, increasing pump performance.

5. Compressed air system:-

a. Optimizing discharge air pressure by tuning loading/unloading cycle: - It helpful to reduce sp. Power consumption.

b. Use of heat of compression air dryer instead of electrically heated air dryer: - Heat of compression air dryer use heat generated in compression cycle, thus reduces sp. Power consumption.

c. Use of screw compressor instead reciprocating compressor: - Sp. Power consumption of screw compressor is less than reciprocating air compressor leads to reduce aux. power consumption.

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