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OPTIMIZATION OF A BOILER PERFORMANCE BY VARYING OPERATING PARAMETERS

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ABSTRACT

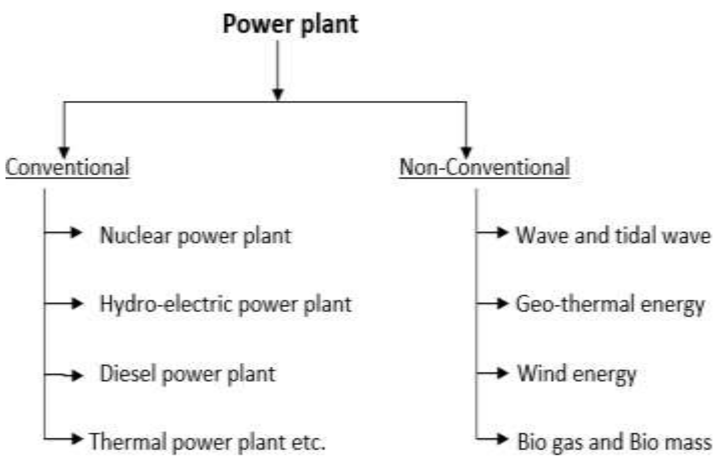
Cleaner The main motive of this study is to identify maximum energy loss areas in any thermal power stations and generate a plan to reduce them using energy and exergy analysis as the tools. The energy sources are decreasing down day by day around the world due to the growing demand and sometimes due to ageing of machinery. Most of the power plants are designed by the energetic performance criteria based not only on the first law of thermodynamics, but the real useful energy loss cannot be justified by the fist law of thermodynamics, because it does not differentiate between the quality and quantity of energy The main objective of this paper is survey the technical options for waste heat capture and consider in greater depth of Waste heat capture method through the use of real-life examples. Present study deals with the comparison of energy and exergy analysis of thermal power plants stimulated by coal. Our national electricity requirement is about 2100MW against 1615MW supply; this is evident of about 21% deficit in terms of power requirements. In view of this situation, greater need of efficiency improvement of a thermal power plants.

Keywords: Energy, Exergy, heat balance sheet, Thermal Power Station, fuel, thermal efficiency

1. INTRODUCTION

Power plant is assembly of systems or subsystems to generate electricity. Power plant generates the electricity result of combustion of fuel into mechanical work and in thermal energy. The availability of electricity and its per capita consumption shows index of national standard of living in the present day and flourishing power generation. Industry is a sign of grooving gross national products which reflects prosperity of people i.e energy has synonyms with progress. Electricity is the only form of energy which is easy to produce, easy to transmission and easy to control and produced by conventional and non-conventional method. The role of efficiency monitoring lies in maximizing generation from power plants. It enhances energy efficiency of the power plant. In order to keep maximum output from a given input, the units must run at the maximum possible efficiency. Power sector is one of the key sectors contributing significantly to the growth of country's economy. Power sector needs a more useful role to be played in defining, formulating and implementing the research projects with close involvement of all utilities like solar energy and other various non conventional sources.

1.2 TYPES OF POWER PLANT



1.3 PROCESS OF THERMAL POWER PLANT

The whole process comprises of generating heat energy in the boiler and then converting heat energy generated in the boiler into mechanical energy in the turbine and further converting this mechanical energy generated in the turbine into electrical energy in the alternator. Coal will be used as fuel in the boiler. The combustion of the fuel generates the heat energy in the boiler. The heat energy transfer to heat transfer area provided in the different area like (bed coils, water wall, steam drawn /mud drum economizer super heater, air pre heater. This will be transferred to the water which will pass through and steam is generated and this steam will be further superheated in the super heater so that dry superheated steam will be generated. This steam will be fed into the turbine and this steam expands in the turbine and generates mechanical energy will be converted in to electrical energy. The whole process is comprising in the Fig. 1.1.

The whole process is as known by modern cycle. We mention here brief description of working of modern cycle i.e known as Rankine cycle (Fig. 1.2)

Ideal Rankine Heat cycle P-V Diagram

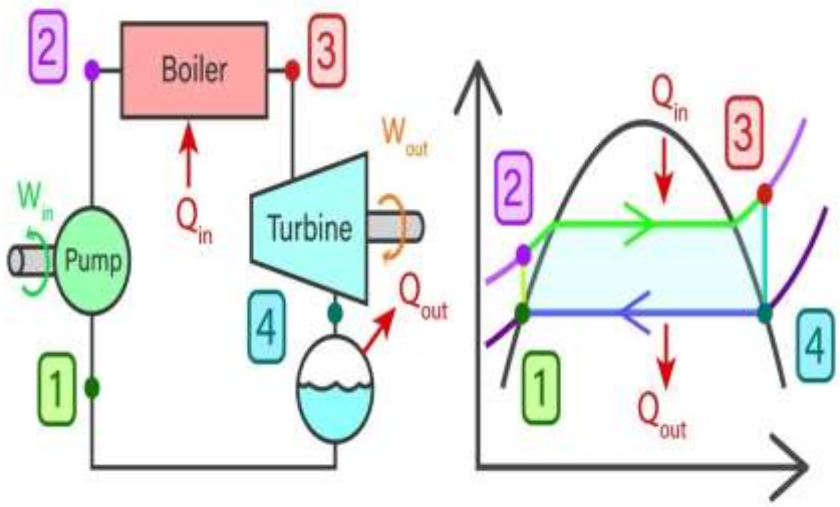


Fig 1.2 Power Plant Layo ut & Cycle

1.4 TYPES OF FUEL USED IN BOILER

There are many type of fuel used in boiler to generate necessary heat. Some are given below:

Table: 1.1 Types of Fuels Used in Boilers

Fuel	GCV(Kcal/kg)
Coal a) Bituminous b) Anthracite c) Lignite	 4,500 to 6,500 6,500 to 7,700 3,500 to 4500
Furnace oil	10,500 to 11,700
Natural Gas	8,200 to 8,600 K Cal/Nm^3
Agro fuels	3,100 to 4,500
Kerosene	11,100
LPG	11,600 to 11,700 KCal/Kg

1.5 GENRAL LAYOUT OF MODERN THERMAL POWER PLANT

The general layout of the thermal power plant consists of mainly four circuits.

The four main circuits are:

1. Coal and ash circuit.
2. Air and gas circuit.
3. Feed water and steam flow circuit.
4. Cooling water circuit.

1.6 WORKING OF THERMAL POWER PLANT

Steam is generated in the boiler of the thermal power plant using the heat of the fuel burned in the combustion chamber. The steam generated is passed through steam turbine where the part of the it's thermal energy is converted into mechanical energy which is further used for generation electric power. The steam coming out of the steam turbine is condensed in the condenser and condensate is supplied back to the boiler with the help of the feed pump and cycle is repeated. The function of the boiler is to generate the steam. The function of condenser is to condense the steam coming out of steam turbine at low pressure. The function of the steam turbine is to convert part of heat energy of steam into mechanical energy .The function of feed pump is to raise the pressure of the condensate from the condenser pressure (0.015 bar) to boiler pressure (200 bar) . The other components like economizer, super heater and steam feed heaters are used in the primary circuit to increase the overall efficiency of the thermal power plant.

2. LITERATURE REVIEW

The ability to perform useful work in a natural environment has been suggested and investigated as a measure of energy quality by Gibbs, A. Stodola, G. Gouy, J.H. Keenan, F. Bosnjakovic and many other researchers. The term exergy was suggested by Zoran Rant in 1956 to denote 'technical working capacity' but concept was developed by J. Willard Gibbs in 1873. A complete definition was given by H.D. Baehr in 1965; exergy is that part of energy that is convertible into all other forms of energy. Exergy is a measurement of how far a certain system deviates from a state of equilibrium with its environment (wall, 1977). Szargut et al. State that, "exergy is the amount of work obtainable when some matter is brought to a state of thermodynamic equilibrium with the common components of the natural surroundings" The fundamentals of the exergy method were laid down by Carnot in 1824 and Clausius in 1865 [i].

Kapooria have carried out thermodynamic analysis of Rankine cycle to enhance the efficiency and reliability of steam power plant. Further they identified factors such as reheating and regeneration affecting efficiency of the Rankine cycle and analyzed for improved working of the thermal power plants in subcritical range. The thermodynamic deviations resulting in non-ideal or irreversible functioning of various steam power plant components have been identified by kapooria et.al. Turbine, boiler and a pump are the components of steam thermal power plants [ii].

Srinivas have carried out thermodynamic analysis of Rankine cycle with generalization of feed water heaters in subcritical range. They studied the effect of number of feed water heaters and bled temperature ratio on overall performance of the Rankine cycle in subcritical range. They have developed computers code for the evaluation of first law efficiency, irreversibility's and second law efficiency of Rankine cycle with different numbers of feed water heaters. They concluded that, greatest increment in efficiency is brought by the first heater; the increment for each additional heater thereafter successively diminishes. An increase in feed water temperature reduces the heat absorption from the outgoing flue gases in the economizer and may cause a reduction in boiler efficiency [iii]. Habib have discussed first and second-law procedure for the optimization of the reheat pressure level in reheat regeneration thermal power plants in sub critical range. The procedure is general in form and is applied for a thermal power plant having two reheat pressure levels (low- and high-pressure levels) and two open types feed water heaters. The second – law efficiency of the steam generator, turbine cycle and plant were evaluated and optimized the reheat pressure ratio in both the pressure levels. The irreversibility's in the different components of the steam generator and turbine cycle sections were evaluated and discussed [iv].

Ibrahim Acar has used the second law analysis of the reheat regenerative Rankine cycle in the subcritical range. He performed the energy and exergy analysis for each component in the system at operating parameters of (i) turbine inlet pressure of 150 bar, (ii) turbine inlet temperature of 600^0c and (iii) condenser pressure of o.1 bar. He inferred that, exergy analysis is better in comparison with energy analysis, as it gives a clear understanding of real losses in the systems [v].

3. METHODOLOGY AND FORMULA USED

EVAPORATION RATE

The quantity of water evaporated into steam per hour is called the evaporation rate. it is expressed as kg of steam/h,or kg of steam /h/m^2 of heating surface, or kg of steam/h/m^3 of furnace volume, or kg of steam/kg of fuel fired.

EQUIVALENT EVAPORATION

It is the equivalent of the evaporation of 1 kg of water at 100^0 C to steam at 100^0 C. it requires 2256.9 kj = 2260 kj.

FACTOR OF EVAPORATION

The ratio of actual heat absorption above feed water temperature for transformation to steam (wet, dry, or superheated), to the latent heat of steam at atmospheric pressure (1.01325 bar) is known as factor of evaporation.

Then equivalent evaporation = Actual evaporation× Factor of evaporation

Where $m_e = [(h_1 – h_f) / h_{fg}]\times m_s = F \times m_s$

h_1 = specific enthalpy of steam actually produced

h_f = specific enthalpy of feed water

h_{fg} = specific enthalpy of evaporation at standard atm. Pressure

m_s = actual evaporation expressed in kg/kg of fuel or kg/h of Steam

m_e = equivalent evaporation expressed in kg/kg of fuel or kg/h

F = factor of evaporation

4. PERFORMANCE ANALYSIS

The performance of a boiler may be explained on the basis of any of the following terms:

EFFICIENCY: It may be expressed as the ratio of heat output to heat input.

COMBUSTION RATE: It is the rate of burning of fuel in kg/m^3 of grate area/h.

COMBUSTION SPACE: It is the furnace volume in m^3/kg of fuel fired/h.

HEAT ABSORPTION: It is the equivalent evaporation from and at 100^0C in kg of steam generated/m^2 of heating surface.

HEAT LIBERATED: It is the heat liberated/m^3 of furnace volume/h.

BOILER THERMAL EFFICIENCY: It is the ratio of heat absorbed by steam from the boiler per unit time to the heat liberated by the combustion of fuel in the furnace during the same time.

Boiler efficiency, $\eta_b = \left[\frac{(h1 - hf) \times ms}{m_f \times C.V}\right]$

Where –

m_s = mass of steam generated in kg/h

m_f = mass of fuel burned in kg/h

C.V = calorific value of fuel in kj/kg

5. HEAT LOSSES IN A BOILER PLANT

1. **Heat used to generate steam**, $Q = m_s (h_1 - h_f)$
2. **Heat lost to flue gases**.

The flue gases contain dry products of combustion and the steam generated due to the combustion of hydrogen in the fuel.

Heat lost to dry flue gases,

$Q_1 = m_g c_{pg}(T_g - T_a)$

m_g = mass of gases formed per kg of fuel

c_{pg} = specific heat of gases

T_g = temperature of gases, ^{0}c

T_a = temperature of air entering the combustion chamber of the boiler, ^{0}c

3. **Heat carried by steam in flue gases-**

$Q_2 = m_{s1}(h_{s1} - h_{f1})$

m_{s1} = mass of steam formed per kg of fuel due to combustion of H_2 in fuel

h_{f1}= enthalpy of water at boiler house temperature

h_{s1}= enthalpy of steam at the gas temperature and at the partial pressure of The vapour in the flue gas

4. **Heat loss due to incomplete combustion:**

If carbon burns to CO instead of CO_2 then it is known as incomplete combustion. 1kg of C releases 10,200 kj/kg of heat if it burns to CO whereas it releases 35,000 kj/kg if it burns to CO_2. if the percentages of CO and CO_2 in flue gases by volume are known, then

5. Heat lost due to unburnt fuel

$Q_4 = m_{f1} \times C.V$

m_{f1}= mass of unburnt fuel per kg of fuel burnt

6. Heat unaccounted

$Q_6 = Q - (Q_1+Q_2+Q_3+Q_4+Q_5)$

$Q = m_f \times C.V$

= heat released per kg of fuel

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6. BOILER TRIAL AND HEAT BALANCE SHEET

There are three purposes of conducting the boiler trial.

1. To determine and check the specified generating capacity. Of the boiler when working at full load conditions.
2. To determine the thermal efficiency of the plant.
3. To draw up the heat balance sheet so that suitable corrective measures may be Taken to improve the efficiency.

The following measurements should be observed during the boiler trial.

1. The fuel supplied and its analysis.
2. Steam generated and its quality or superheat.
3. Flue gases formed from exhaust analysis.
4. Air inlet temperature and gases exhaust temperature.
5. Volumetric analysis of exhaust gases.
6. Mass of fuel left unburnt in ash.
7. Feed water temperature.

The Heat balance sheet is a symmetric representation of heat released from burning of fuel and heat distribution on minute, hour or per kg of fuel basis. A Performa for heat balance sheet is given in table:

7. VARIOUS COMBUSTION EQUATIONS OF SOLID FUELS

The following chemical equations represent the combustion of different constituents of a fuel and they are most frequently used in combustion calculations-

1. BURNING OF CARBON-TO-CARBON DIOXIDE

When carbon burns in sufficient quantity of oxygen, carbon dioxide is Produced along with a release of large amount of heat.

C + O2 = CO2

2. BURNING OF CARBON-TO-CARBON MONOXIDE

If sufficient oxygen is not available, then combustion of carbon I Incomplete. It then produces carbon monoxide instead of carbon dioxide.

$2C + O_2 = 2CO$

3. BURNING OF CARBON MONOXIDE TO CARBON DIOXIDE

$2CO + O_2 = 2CO_2$

4. BURNING OF SULPHUR-TO-SULPHUR DIOXIDE

When sulphur burns with oxygen, it produces sulphur dioxide.

S + O2 = SO_2

8. MINIMUM AIR REQUIRED FOR COMPLETE COMBUSTION

Adequate supply of oxygen is very essential for the complete combustion of a fuel, and hence for obtaining maximum amount of heat from the fuel Consider 1 kg of fuel. We know that 1kg of carbon requires 8/3 or 2.67kg of oxygen for its complete combustion Similarly, 1kg of hydrogen requires 8kg of oxygen and 1kg of sulphur requires 1kg of oxygen for its complete combustion.

9. MINIMUM VOLUME OF AIR REQUIRED FOR COMPLETE COMBUSTION

Consider 1 m^3 of gaseous fuel

Let

Volume of carbon monoxide = CO m^3

Volume of hydrogen = H_2 m^3

Volume of methane = CH_4 m^3

Volume of ethylene = C_2H_4 m^3

We know that 1 volume of carbon monoxide requires 0.5 volume of oxygen for its complete combustion, 1 volume of methane requires 2 volumes of oxygen and 1 volume of ethylene requires 3 volumes of oxygen.

Total oxygen required for complete combustion of 1 m^3 of fuel

$= 0.5\,CO + 0.5\,H_2 + 2CH_4 + 3\,C_2H_4\ m^3$

If some oxygen is already present in the fuel, then total oxygen required for complete combustion of 1 m^3 of fuel-

$= [0.5\ CO + 0.5\ H_2 + 2CH_4 + 3\ C_2H_4\ m^3] – O_2\ m^3$

Since the air contains 23% of oxygen on volume basis, there theoretical or minimum volume of air required for complete combustion of $1m^3$ of fuel-

$= \underline{100}\ [(0.5\ CO + 0.5\ H_2 + 2CH_4 + 3\ C_2H_4\ m^3) – O_2\ m^3]\ 23$

MASS OF FLUE GASES PER KG OF FUEL BURNT

The mass of flue gases may be obtained by comparing the mass of carbon present in the flue gases with the mass of carbon in the fuel.

$$\text{Mass of flue gas per kg of fuel} = \frac{\text{Mass of carbon in 1 kg of fuel}}{\text{Mass of carbon in 1 kg of flue gas}}$$

MASS OF EXCESS AIR SUPPLIED

The mass of excess air supplied may be calculated by the mass of unused oxygen. found in the flue gases in order to supply 1kg of oxygen .we require 100/23 kg of air

Mass of excess air supplied = $\underline{100}$ × Mass of excess oxygen 23

Total mass of air supplied = mass of necessary air + mass of excess air

10. CONCLUSION

This paper shows the enervative ideas to reduce losses of boiler and improve boiler efficiency by using the variation of boiler load and also percentage of excess air.

We are concluding the following point which points show in thesis and by using of heat balance sheet clearly indicate unnecessary loss of heat. Give some ideas to reduce unnecessary loses and improve boiler efficiency.

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