

ENERGY AND EXERGY ANALYSIS OF A 26MW THERMAL POWER PLANT

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ABSTRACT: *This paper, presents energy and exergy analysis method for thermal power plant and analysis carried out on 26 MW coal base thermal power plants at NAKODA ISPAT PVT.LTD.SILTARA RAIPUR. This paper deals with thermodynamic analysis of the steam cycles used in power plants has been undertaken to enhance the efficiency and reliability of steam power plants. The thermodynamic deviations resulting in non ideal or irreversible functioning of various steam power plant components have been identified. The real energy loss can not be justified by the first law of thermodynamics, because it does not differentiate between the quality and quantity of energy. Energy analysis presents only quantitative results while exergy analysis presents qualitative results about actual energy consumption. The primary objectives of this thesis is to analyse the system components and to identify the sites having larger energy and exergy losses. The aim of the exergy analysis is to identify the magnitudes and locations of real energy losses in order to improve the existing system, processes or components. The exergy losses occurred in the various sub systems of the plant and their components have been calculated using mass, energy and exergy balance equations. In the considered power cycle, the maximum exergy loss of 76.21% was found in the condenser in the present working condition of the input energy. The exergy analysis of the plant showed that the lost energy in the condenser is thermodynamically significant due to its low quality.*

Keywords: *power plant, energy analysis, exergy analysis, plant specification.*

I. INTRODUCTION

Nearly 45% of global electricity generation is derived from coal which natural gas and nuclear energy makes up about 20% and 15%, respectively of the world's electricity generation (energy information administration, 2007). Since these energy sources generally use boiler-steam turbine system to convert its chemical potential energy to electricity generation, one can only imagine the possible way of savings derivable from improving the efficiency of a steam power plant. The world energy needs rely heavily on fossil fuels for electricity generation. The majority of the world's power generation is met by fossil fuels, particularly coal and natural gas. Despite the growth the renewable energy installations like wind and solar power, the heavy dependence on fossil fuels is expected to continue for decades. Despite the depletion of fossil fuel reserves and environmental concerns such as climate change, the growth in oil demand is expected to be 47.5% between 2003 and 2030, 91.6% for natural gas

and 94.7% for coal. Power plays a great role wherever man lives and works-in industries, agriculture transportation etc. power provides our homes with light and heat. The living standard and prosperity of a nation vary directly with increase in use of power. By any standards, the Indian Economy was able to protect itself reasonably well in the turbulent conditions of the financial crisis. Economic growth slowed from 7.7% in the first half of 2008-09 to 5.95% in the second half, and 6.0% in the first quarter of 2009-10. However, in the second quarter it grew strongly at 8.6%. it again declined to 6.5% in the third quarter primarily because of the drought. The economy recovered in the fourth quarter and grew by 8.6%. the order of loss in growth momentum in the first half of 2009-10 was not only much smaller than that of the rest of the world, but the important point was, that the economy continued to grow at close to 7%, which itself is higher than in many years past. Now a days, there are a few methods to measure the performance of a power plant. Some researchers use the conservation of mass and the conservation of energy (first law of thermodynamics) principles; however the evaluation is actually not complete. The exergy analysis based on the second law of thermodynamics should be included in order to provide the information, which is useful for engineers or managers to know about the power plant performance. The information obtained from the result of the analysis will form a basis for the energy manager or operation engineer to make decision on how he should operate to save cost and energy usage. As energy analysis is based on the first law of thermodynamics, it has some inherent limitations like not accounting for properties of the system environment, or degradation of the energy quality through dissipative processes. An energy analysis does not characterize the irreversibility of processes within the system. In contrast, exergy analysis will characterize the work potential of a system. Exergy is the maximum work that can be obtained from the system, when its state is brought to the reference or "dead state" i.e. standard atmospheric conditions. Exergy analysis is based on the second law of thermodynamics. Exergy analysis of a steam power plant, in order to assess the distribution of irreversibilities and losses, which contribute to loss of efficiency in system performance. The fundamental of the exergy method were laid down by CARNOT in 1824 and CLAUSIUS in 1865. The energy-related engineering systems are designed and their performance is evaluated primarily by using the energy balance deduced from the first law of thermodynamics. Engineers and scientists have been traditionally applying the first law of thermodynamics to calculate the enthalpy balance for most than a century to

quantify the loss of efficiency in a process due to the loss of efficiency in a process due to the loss of energy.

II. PROBLEM FORMULATION & PLANT DESCRIPTION

2.1 PLANT DESCRIPTION

The power plant has a total installed power capacity of 26MW unit of NAKODA ISPAT LTD. under power plant phase -2 in the city of Raipur; India has been chosen for the study. It started to produce power in the middle seventies. The power house consist of three steam turbines units (6+12+8) MW at 100% load. The power plant uses coal as fuel and its employs a rankine cycle with regenerative feed water heating system, and a pair of steam-driven boiler feed pumps (BFP). This unit employs regenerative feed water heating system in table 3.1 summaries the salient flow and thermodynamic property data at a load of 26 MW. The turbine has two cylinders high and low pressure is connected to the generator. The energy and exergy flows are computed using the plant operation data at full load (electrical power output at the generator terminal). Steam is superheated to the steam generator and fed to the turbine. The turbine exhaust wet steam is exhausted to condenser at a very low pressure. A large quantity of circulating water (CW) flows to the condenser almost at ambient temperature, takesaway heat of condensation and flows back to the river. The condenser exits the condenser exits the with low energy and almost negligible exergy and is pumped by the condensate extraction pump (CEP). Deareator feeds to BFP, which raise the pressure of feed water and back to the boiler for generation of steam and the cycle continues. Thus, energy and exergy flows associated with the flow of working fluid to the control region of the steam cycle. Heat rejection to the environment is made possible at a low temperature by maintaining a low back pressure at the condenser. Final feed water temperature rises across feed heaters by transferring heat from turbine extraction steam and facilitates high temperature heat addition in boiler.

The coal used at power plant, consist of high ash. On its combustion approximate 85% of the ash is carried away by the flue gases (combustion product) and remaining 15% is precipitated at the bottom of the combustion chamber in the form of clinkers. The ash is removed from flue gases (combustion products) by means of electro static precipitator (ESP), subsequently water is mixed to form ash slurry is disposed off at remote location through ash slurry pumps. The ash precipitated at the bottom of the combustion chamber in the form of clinkers is disposed off through "bottom ash disposal system". The clinkers are ground in clinkers grinder, water is mixed in it to form slurry is added to the ash slurry formed with ESP ash to dispose it off through same ash slurry pumps.

2.2 PROBLEM IDENTIFICATION

There few problems are indentified in energy and exergy analysis of a steam power plant such as:

- To find an approach for evaluating the thermal and exergetic efficiencies for steam power plant and for

the entire sub-systems of the plant.

- Boiler is the location for most of the exergy destruction in the plant and needs maximum attention on its designing and operation for optimum use of available energy of the fuel. The above has already been mentioned in previously available literatures. However detailed exergy analysis covering internals of a boiler is not available in literatures. Exergetic efficiency of boiler has only been worked out in previous works considering entire boiler as a component.
- To measure mass flow rate, pressure and temperature at each point of entire power plant.
- Calculation of enthalpy and entropy at each location of the plant.
- Calculation of turbine work and pump work.
- Calculation of irreversibility for each component in the plant.
- Calculation of heat input to the plant, boiler, heat rejected in the condenser and heat exchanged in the feed water heater.
- Calculation of first law efficiency and second law efficiency.

III. STEAM POWER PLANT

3.1 DESCRIPTION OF THE SYSTEM

The process flow diagram is shown in fig. 3.1, which is chosen for analysis. The twin shell condenser is connected with exhaust part of low pressure casing. The condenser has been designed to create the vacuum at the exhaust of steam turbine and to provide pure condensate for reusing as feed water for the boiler. The steam is condensate as the tubes through which cooling water is passed. The condensate water is collected in the hot-well. Two number of condensate extraction pumps are installed for pumping the condensate water from the hot-well to the deaerator through low various heat-exchangers. One pump is for normal operation and another works as standby. Condensate water is sucked by condensate extraction pump (CEP) from the hot-well and discharges it to the tube side of air ejector. Two air ejectors are installed; one air ejector will be kept running and other as standby. Two air ejectors are installed; one air ejector will be kept running and other as standby. The two stages steam jet air ejector serve for removing the air vapour mixture from the condenser and creating vacuum inside the condenser, since air and other gases would not condensate at the temperature prevailing in the condensate and reduce the efficiency of the condenser. The steam for air ejector is taken from the manifold, which is charged from steam receiver. The steam, which is supplied to air ejector, is gives the some heat to the condensate water, which is supplied by CEP and temperature, is rising of the condensate water.

Table 3.1 Specifications of turbine

ame of turbine	Triveni turbine
Type	Impulse Reaction turbine
Stages of turbine	13
Power output	6 MW

Speed	8280
Live steam pressure	64
Live steam temperature	480
Gauge pressure at exhaust	.1kg/cm ²
Steam consumption	4.2 tons/MW

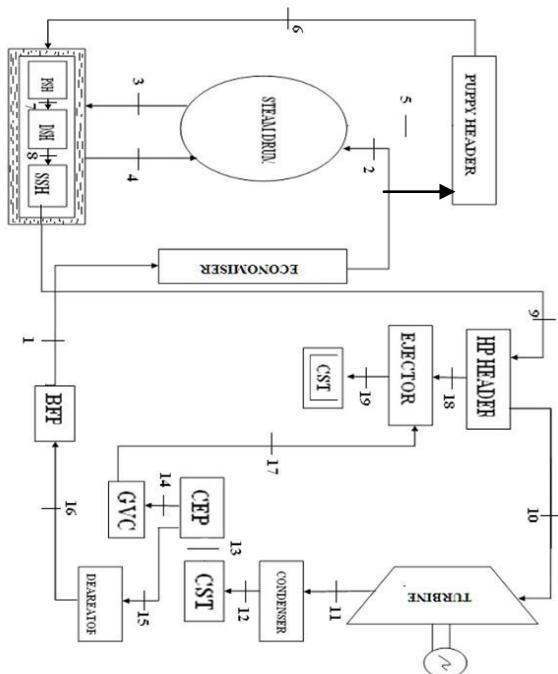


Figure 3.1 schematic diagram of NAKODA ISPAT LTD.

Table 3.2 Table showing the operating condition, design value and working value of steam power plant

OPERATING CONDITION	DESIGN VALUE	WORKING VALUE
Mass flow rate of fuel		16-17
Stack gas temperature	890°C	700°C
Feed water inlet temperature	120°C	
Steam flow rate	70 kg/sec	30kg/sec
Steam pressure	64-68 kg/cm ²	50-60 kg/cm ²
Steam temperature at boiler outlet	480	440-450
Power output	12 MW	

Table 3.3 Specifications of water and steam temperatures in boiler.

LOCATION	TEMPERATURE
After deaerator	105°C
In drum screen tubes	280°C
At economizer inlet	120°C
After 1st stage super heater	385°C
After attemperator	310°C
Ater 2nd stage superheater	490°C

IV. METHODOLOGY

The following assumptions are considered for energy analysis of steam power plant:

- The mass flow through the system remains constant.
- Fluid is uniform in composition.
- The only interaction between the system and the surrounding are work and heat.
- The state of fluid at any point remains constant with time.
- The energy and exergy destroyed by kinetic energy and potential energy are negligible.
- No chemical reaction takes place.

4.1 BOILER SUBSYSTEM

The energy loss (Q) of the subsystems components are determined using the energy balance of the first law and similarly the exergy losses are calculated from the exergy balance equation of the second law. Then using the energy losses the energy efficiency is calculated and the exergy efficiency is determined using the exergy losses. Figure 5.1 shows the schematic diagram of boiler subsystem.

Energy analysis:-

$$Q = m_s (h_4 - h_{16}) \text{ MW}$$

Where;

- m_s – Mass flow rate of steam at inlet of turbine (kg/sec)
- h_4 – specific enthalpy at inlet of turbine (KJ/sec)
- h_{16} – specific enthalpy at inlet of economiser (KJ/sec)
- m_f – mass flow rate of fuel (kg/sec)
- First law Efficiency:

$$\text{Boiler Efficiency} = \frac{\text{steam flow rate} \times (\text{steam enthalpy} - \text{feed water enthalpy}) \times 100}{\text{fuel firing rate} \times \text{GCV of fuel}}$$

Energy and Exergy balance of Boiler

$$\eta_{\text{BOILER}} = \frac{m_s (h_4 - h_{16})}{m_f \times \text{GCV}} \times 100 \dots \dots \dots 5.1$$

Exergy Analysis:

$$I_{\text{BOILER}} = X_{\text{FUEL}} + X_{\text{IN}} - X_{\text{OUT}}$$

Where;

$$X_{\text{FUEL}} = m_f \Psi_{\text{ch}}$$

$$X_{\text{IN}} = m \Psi = m_s [(h_{16} - h_0) - T_0 (S_{16} - S_0)]$$

$$X_{\text{OUT}} = m \Psi = m_s [(h_4 - h_0) - T_0 (S_4 - S_0)]$$

Second law Efficiency or Exergy Efficiency:

$$\eta_{\text{II,BOILER}} = \frac{X_{\text{OUT}} - X_{\text{IN}}}{X_{\text{FUEL}}}$$

4.2 ENERGY ANALYSIS

At temperature 25°

$$Q = m_s (h_{\text{out}} - h_{\text{in}})$$

$$Q = 10(3381.532 - 440.15)$$

$$= 29413.82 \text{ KW}$$

$$\text{Boiler Efficiency} = \frac{\text{steam flow rate} \times (\text{steam enthalpy} - \text{feed water enthalpy}) \times 100}{\text{fuel firing rate} \times \text{GCV of fuel}}$$

$$\eta_1 = \frac{10 \times (3381.532 - 440.15)}{\frac{15 \times 1000}{3600} \times 2200 \times 4.18} \times 100$$

$$\eta_1 = 76.765 \%$$

4.3 EXERGY ANALYSIS

At temperature 25°

$$X_{IN} = m\Psi = 10 \times 38.542 = 385.42 \text{ kJ/sec}$$

$$X_{OUT} = m\Psi = 10 \times 1382.22 = 13.822 \text{ MW}$$

$$X_{FUEL} = Y_{FUEL} \times \text{LCV}$$

$$\text{LCV} = \text{HCV} - 588.76 \times W$$

W = Moisture content in percentage

As we have HCV = 2200 kcal/kg

$$\text{LCV} = 2099.9108 \text{ kcal/kg}$$

$$X_{FUEL} = 38767.852 \text{ kwatt}$$

Second law Efficiency or Exergy Efficiency:

$$\eta_{II, \text{BOILER}} = \frac{X_{OUT} - X_{IN}}{X_{FUEL}} = \frac{13.822 - 385.42}{38.767} = 35.65\%$$

COMPONENT : TURBINE

INLET : SUPERHEATED STEAM INLET TO TURBINE

OUTLET : 1. TURBINE EXHAUST STEAM
2. STEAM INLET TO DEAERATOR

TEMPERATURE : 35°C

ENERGY ANALYSIS:-

$$Q_{\text{cycle}} = m_{in}h_{in} - m_{out}h_{out} - m_d h_d = 10 \times 3381.532 - 9.3056 \times 2213.68 - .694 \times 2829.49 = 11252.03 \text{ kW}$$

$$\eta_{ITURBINE} = \frac{W}{Q_{\text{cycle}}} \times 100 = \frac{6}{11.252} \times 100 = 53.32\%$$

EXERGY ANALYSIS:-

$$X_{\text{destroyed}} = m_{in}\Psi_{in} - m_{out}\Psi_{out} - m_d\Psi_d = 10 \times 1319.3568 - (1.40990 \times 1000 + .39577 \times 1000) = 11.387 \text{ MW}$$

$$\eta_{IITURBINE} = \frac{W}{X_{\text{destroyed}}} \times 100 = \frac{6}{11.387} \times 100 = 52.71\%$$

COMPONENT: CONDENSATE EXTRACTION PUMP (CEP)

INLET : FEED WATER OUTLET FROM CST

OUTLET: CEP WATER OUTLET

TEMPERATURE : 35°C

ENERGY ANALYSIS:-

Pump work

$$W_p = (m_{in}h_{in} - m_{out}h_{out}) / \eta_{\text{comb}} = 8.89 (200.9 - 411.5) / 1$$

$$= -1872.234 \text{ kw}$$

First Law Efficiency

$$\eta_{1 \text{ CEP}} = \frac{w_p \times 100}{w_{\text{net}}} = \frac{1872.234 \times 100}{6000 - 1872.234} = 45.357\%$$

$\eta_{1 \text{ CEP}} = 45.357\%$

EXERGY ANALYSIS:-

$$X_{\text{pump}} = m_{in}\Psi_{in} - m_o\Psi_o + w_p$$

$$X_{\text{pump}} = .009031 - .21372 + 1872.374$$

$$X_{\text{pump}} = 1.667 \text{ MW}$$

$$\eta_{II} = \left(1 - \frac{1.667}{1.872234}\right) \times 100 = 10.92\%$$

COMPONENT : DEAERATOR

INLET : 1. CONDENSATE WATER OUTLET
2. STEAM INLET TO DEAERATOR

OUTLET : FEED WATER OUTLET TO BFP

TEMPERATURE : 35°C

$$Q_{\text{deaerator}} = m_{out}h_{out} - m_{in}h_{in} + m_s h_s = 10 \times 467.1 - 8.889 \times 251.5 - .694 \times 2829.49 = 471.49 \text{ kW}$$

$$\eta_I = \frac{\text{Total inlet}}{\text{outlet}} \times 100$$

$$\eta_I = \frac{8.89 \times 251.5 + .694 \times 2829.49}{10 \times 467.1} \times 100 = 89.90\%$$

EXERGY ANALYSIS:-

$$X_{\text{destroyed}} = m_{in}\Psi_{in} + m_{\text{steam}}\Psi_{\text{steam}} - m_{out}\Psi_{out} = .037191 + .39577 - (10 \times .034676) = .0862 \text{ MW}$$

$$\eta_{II} = \frac{X_{out}}{X_{in}} \times 100$$

$$\eta_{II} = \frac{.34676}{.432961} \times 100 = 80.08\%$$

COMPONENT : CONDENSER

INLET : TURBINE EXHAUST STEAM

OUTLET : CONDENSATE

WATER OUTLET

TEMPERATURE : 35°C

ENERGY ANALYSIS:-

$$Q_{\text{condenser}} = m_{in}h_{in} - m_{out}h_{out} = 20.6 - 2.236 = 18.364 \text{ MW}$$

First law efficiency

$$\eta_I = 1 - \frac{Q_{\text{condenser}}}{\text{Energy Input}}$$

$$= 1 - \frac{18.364}{104.4} = 82.40\%$$

EXERGY ANALYSIS:-

$$\begin{aligned}
 x_{in} &= \text{Turbine exhaust steam} + \text{cooling water inlet condenser} \\
 x_{in} &= 1.40990 + .029333 \\
 x_{in} &= 1.439233 \\
 x_{out} &= \text{Condensate water outlet} \\
 &\quad + \text{cooling water outlet from condenser} \\
 x_{out} &= 0.0371915 + .55733 \\
 x_{out} &= 0.59452 \\
 \eta_{II} &= \frac{x_{out}}{x_{in} + Q_{condenser}} \\
 &\quad \frac{0.59452}{1.439233 + 18.364} \\
 \eta_{II} &= 3.002 \%
 \end{aligned}$$

V. CONCLUSION

As an energy and exergy analysis was performed on Nakoda Ispat Pvt. Ltd., Raipur at 26 MW output of the steam power plant components have been calculated. In this study an energy and exergy analysis as well as effect of varying environment temperature on the exergy analysis of a power plant has been represented. For the increase of 20°C from temperature of 15 °C to 35°C there is an increase of 3.95% in energy and 2.97% in exergy efficiencies of turbine and there is no variation of efficiencies for increase in temperature for boiler because of refractory lining in boiler. Similarly for condenser there is an increase of 0.9061% in energy and decrease of 76.21% in exergy efficiency. There is an increase of 3.863% in energy efficiency and decrease of 34.81% in exergy efficiency for CEP and for deaerator there is an increase of 3.643% in energy and 37.41% in exergy efficiency. In the considered power cycl, the maximum exergy loss of 76.21% was found in condenser in the present working condition of the input energy was lost to the environment. The exergy analysis of the plant showed that lost energy in the condenser is thermodynamically significant due to its low quality.

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