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Research Article

Performance Optimization of Steam Power Plant through Energy and Exergy Analysis

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Abstract

This article aims to identify the magnitude, location and source of thermodynamic inefficiencies in thermal power plant. It is hoped that this examination as it includes both energy and exergy analysis will yield new insights in to the performance of steam power plant. Exergy analysis can be particularly effective in identifying ways to optimize the performance of existing operations and designing the plant while energy balance gives heat transfer between the system and its surrounding.

***Keywords**: Exergy, Exergy efficiency, Energy losses, Exergy losses, irreversibility.*

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1. Introduction

Traditional methods of thermal system analysis are based on the first law of thermodynamics. These methods use an energy balance on the system to determine heat transfer between the system and its environment. The first law of thermodynamics introduces the concept of energy conservation, which states that energy entering a thermal system with fuel, electricity, flowing streams of matter, and so on is conserved and cannot be destroyed. In general, energy balances provide no information on the quality or grades of energy crossing the thermal system boundary and no information about internal losses. By contrast, the second law of thermodynamics introduces the useful concept of exergy in the analysis of thermal systems. Exergy is a measure of the quality or grade of energy and it can be destroyed in the thermal system. The second law states that part of the exergy entering a thermal system with fuel, electricity, flowing streams of matter, and so on is destroyed within the system due to irreversibility. The second law of thermodynamics uses an exergy balance for the analysis and the design of thermal systems. An exergy analysis identifies the location, magnitude and the sources of thermodynamic inefficiencies in a thermal sys¬tem (Flavio *et al*., 2000; Zhang *et al*., 2000). This information, which cannot be provided by other means (e.g., an energy analysis), is very useful for improving the overall efficiency and cost-effectiveness of a system or for comparing the performance of various systems. In recent years, the use of exergy analysis in thermal design has been discussed and demonstrated by numerous authors (Cengel and Boles, 1998; Jones and Dugan, 1996; Moran and Shapiro, 2000; Verkhivker and Kosoy, 2001). Moran *et al*. provided a brief survey of exergy principles and analyses along with emphasis on areas of application. They concluded that the exergy balance can be used to determine the location, type, and true magnitude of the waste of energy resources, and thus can play an important part in developing strategies for more effective fuel use. Jin *et al*. analyzed two operating advanced power plants using a methodology of graphical exergy analysis. They pointed out the inefficient segments in the combined cycle plant. They stated that the inferior performance of the combined cycle plant are due to the higher exergy loss caused by mixing in the combustor, the higher exergy waste from the heat recovery steam generator and the higher exergy loss in the bottoming cycle.

2. Background

The schematic arrangement of equipments of steam power plant is shown in figure 1.

2.1 The steam generation section

This section includes furnace to burn the coal, boiler to produce high pressure steam at desired temperature, an economizer, and a superheater. Safety valves are also located at suitable points to avoid excessive boiler pressure. Heat produced due to burning of coal is utilized in converting water contained in boiler drum into steam at suitable pressure and temperature which is passed then passed through superheater

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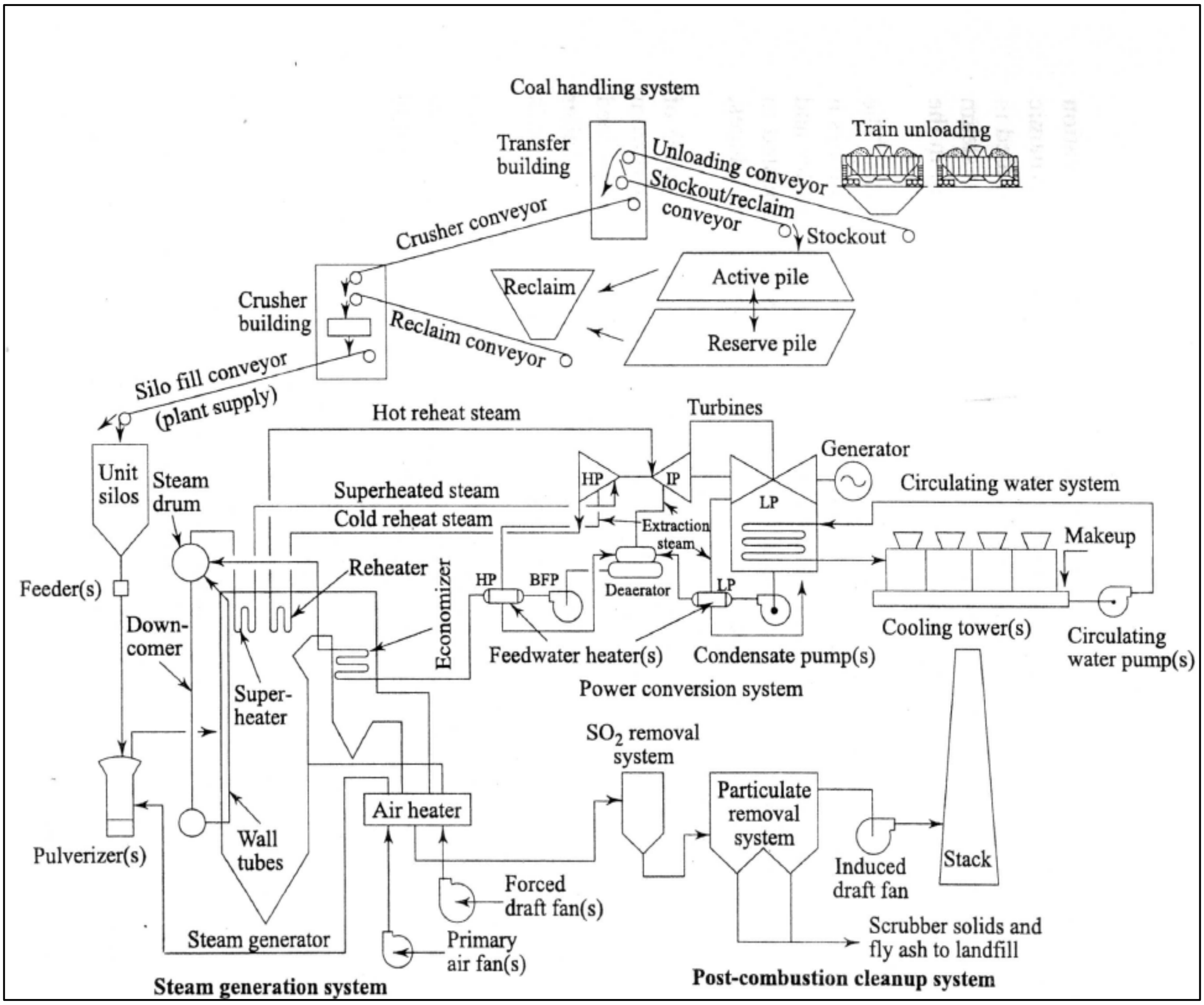

Fig. 1 Schematic arrangement of equipments of steam power plant

.2.2 The power production section

In this section superheated steam is expanded in High pressure (H.P), Intermediate pressure (I.P) and Low pressure (L.P) turbines and then passed through the condenser which maintains the low pressure of steam at the exhaust of turbine.

2.3 The condensation section

Exhaust from L.P turbine is taken in the condenser in which pressure depends upon flow rate and temperature of cooling water and on effectiveness of air removal equipment. Water circulating through the condenser is taken from the canal. Bled steam taken from the turbine at suitable extraction points is sent to low pressure and high pressure water heaters.

2.4 The preheating section

Air taken from the atmosphere is first passed through the air pre-heater, where it is heated by flue gases. This hot air is then passed through the furnace. The flue gases after passing over boiler and superheater tubes flow through dust collector, economizer and air pre-heater before their exhaust to the atmosphere through chimney.

3. Theory

Total energy consists of available energy plus unavailable energy. Considering flows of energy in a system, total energy is simply called energy and available energy is called exergy. These are defined mathematically as

Energy= Enthalpy*flow rate = **h*M** (KJ/s)

Exergy=Availability*flow rate = **a*M** (KJ/s)

Where **h**=Enthalpy; **M**= Flow rate; and **a**= Availability.

3.1 Energy calculations

The mass and energy flows in the system are shown in figure 2.

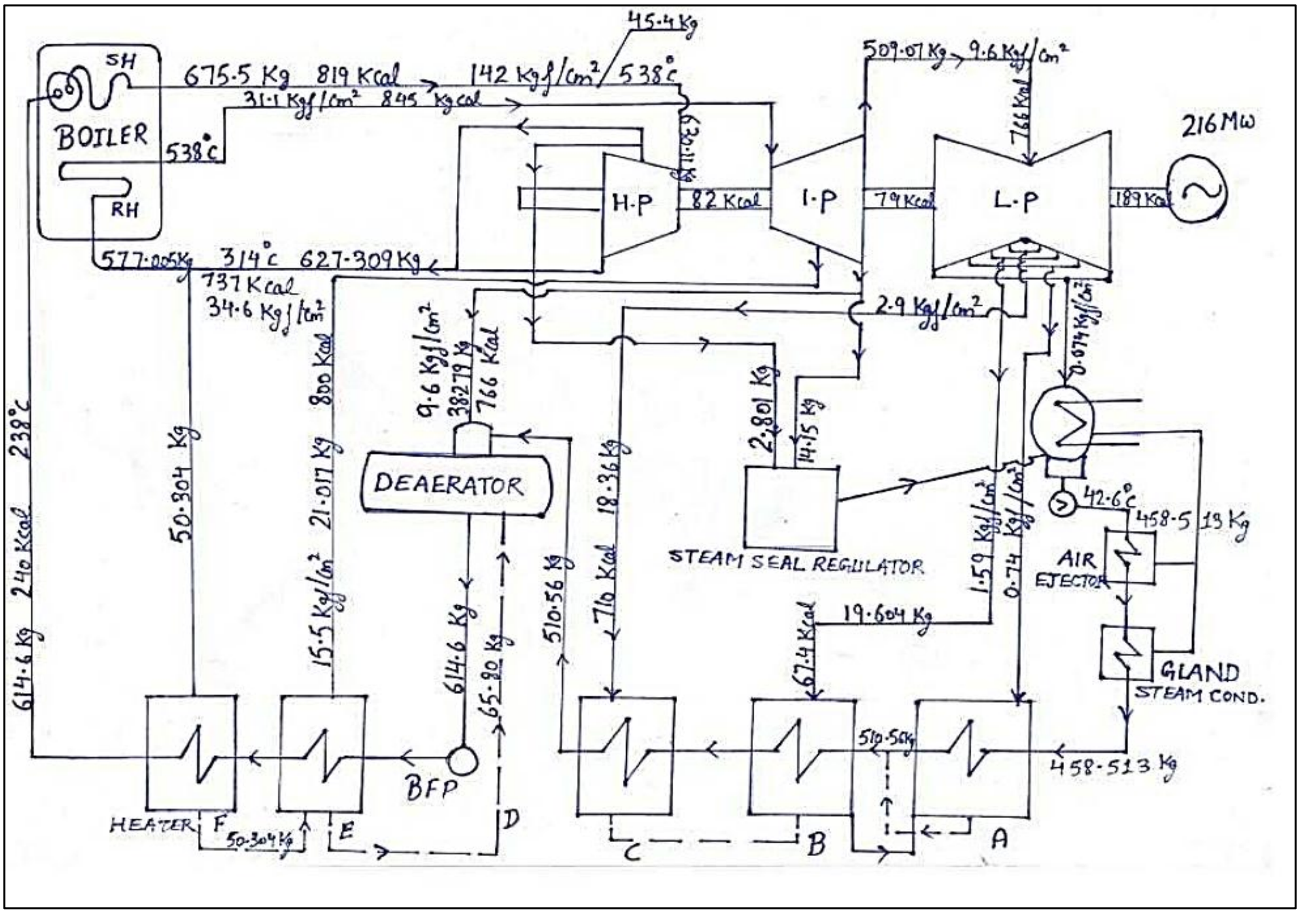

Fig. 2 Heat balance diagram

The data used in the analysis is obtained from actual operating data of the steam power plant. Steam at 5380 C and 142 Kgf/cm2 after expansion in HP turbine enters the Re-Heater and then flows to IP turbine inlet at 5380 C and 31.1 Kgf/cm2. There are three points where extractions are made i.e. bled steam to HP heater E, bled steam to Deaerator and bled steam to steam sea regulator. There are extraction stages made at LP turbine for feed water heater A, B and C. There are certain auxiliary equipment in the power plant like F.D and I.D fans, pulverizer, crushers, crushers, conveyers and so on which are driven by electricity but are not shown in figure 2. The important process data for the unit is summarized in table 1.

In the analysis of the plant, the cycle was assumed to operate at steady state with no stray heat transfer from any components to its surroundings and negligible kinetic and potential energy effects. Certain components such as boiler stop valves, fuel oil pumps, coolers, are neglected in the analysis and pressure drops along pipelines are also assumed to be negligible. From the energy analysis, the overall plant energy losses are calculated as 68%. The flows of energy in various components are shown in Fig. 3. It can be observed that the maximum energy loss of 210624 kcal (43.3%) occurred in the condenser. This is due to the reason that heat energy expulsion from the condenser is 2, 10, 624 kcal. Thus the First law analysis (energy analysis) diverts our attention towards the condenser for the plant performance improvement.

Table 1 Thermodynamic property data

Steam flow	T ^{o}c	P kgf/cm^2	h kcal	m kg/hr
HP Turbine Inlet	538	142	819	675.5
HP Turbine Outlet	314	34.6	737	627.3
Reheater Inlet	314	32.9	737	577
Reheater Outlet	538	31.1	845	577
IP Turbine Inlet	538	31.1	845	577
Steam To LP Turbine	310	9.6	766	509
LP Turbine Exhaust To Condenser	52	0.074	577	441.5
Condenser Outlet	42.6	0.7	100	458.1
Feed Water From Deaerator	175	9.6	177	614.6
Boiler Feed Pump Outlet	238	161.1	178	614.6
Boiler Drum inlet	238	142	178	614.6

Half of the total plant energy losses approximately occur in the condenser only and these losses are practically useless for the generation of electric power. Thus the analysis of the plant based only on the First law principles may mislead to the point that the chances of improving the electric power output of the plant is greater in the condenser by means of reducing its huge energy losses, which is almost impracticable. Hence the First law analysis (energy analysis) cannot be used to pinpoint prospective areas for improving the efficiency of the electric power generation. However, the Second law analysis serves to identify the true power generation inefficiencies occurring throughout the power station. The Energy flow diagram is shown below:

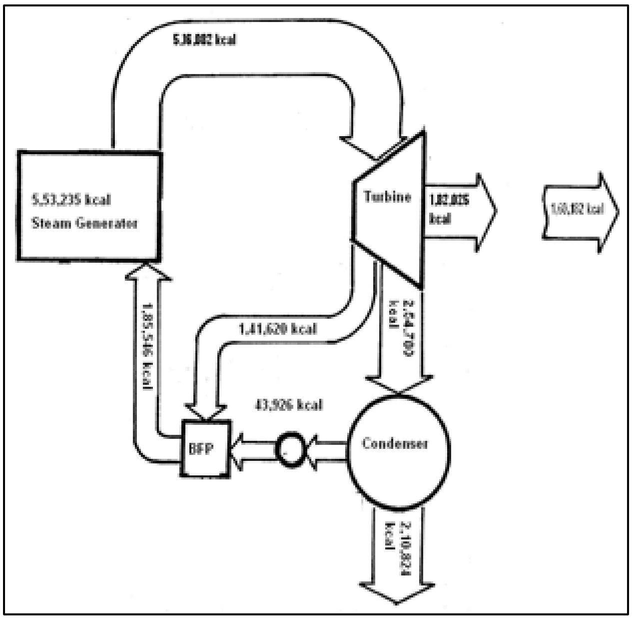

Fig. 3 Energy flow diagram

Table 2 Properties of Data

Steam flow	Xin	Xout	Xd	ή
HP Turbine	819	451.68	367.3	55.1
IP Turbine	845	480.18	364.8	56.8
LP Turbine	766	582.03	75.9	75.9
Condenser	577	463.02	113.97	80.2
LP Heater A	100	57.4	42.58	57.4
LP Heater B	120	55.39	64.67	46.1
Deaerator	177	123.5	53.49	69.7
HP Heater C	148	71.19	76.8	48.1
HP Heater E	210	188.2	21.79	89.6
Boiler Drum	819	421.26	397.7	51.4

3.2 Exergy Calculations

Exergy flows to and from components however do not balance indicating a disappearance or “consumption” of exergy. This disappearance is really a conversion from available energy to unavailable energy. Consumption is a descriptive term indicating the loss of available energy. Components consume exergy by virtue of the ineffectiveness of their ability to transfer available energy. In order to compare the quality levels of various energy carriers, e.g. fuels, it is necessary to determine the equivalents of each energy quantity at a particular grade level. This can be done by using exergy concept, which overcomes the limitations of the first law of thermodynamics; and is based on both the first and the second law of thermodynamics . An exergy analysis can identify locations of energy degradation and rank them in terms of their significance . This knowledge is useful Fin directing the attention of process design, researchers, and practicing engineers to those components of the system being analyzed that offers the greatest opportunities for improvement. In order to perform the exergy analysis of the plant, the detail steam properties, mass, energy and exergy balances for the unit were conducted. The exergy values of each component are calculated by assuming that the component is in an open (control volume) system and there are only physical exergy associated with the material streams. Table 2 shows the results of the analysis for the main components of the plant. The exergetic efficiency and the ratio of exergy destruction to the total exergy destruction of each component are also determined. The flow rate of the exergy destroyed, the exergy efficiency and exergy destruction ratio of each component are shown in Table 2. Referring to column 4 of Table 2, the exergy destroyed in the turbines, the condenser and feed water heaters are small when compared to the exergy destroyed in the furnace or boiler. It is apparent from the analysis, maximum total exergy destruction occurs in the boiler. This large exergy loss is mainly due to the combustion reaction and to the large temperature difference during heat transfer between the combustion gas and steam. Obviously, a lower boiler superheated steam temperature of 538°C than the desired operating value is one clear indication of the imperfection in boiler. Comparing with the exergy input to the plant, this actually reduces the overall plant output by Other factors that may contribute to the high amount of irreversibility are tubes fouling, defective burners, fuel quality, inefficient soot blowers, valves steam traps and air heaters fouling. Inspections of this equipment need to be carried out during the boiler outage. The exergy losses in the turbines are due to the frictional effects and pressure drops across the turbine blades as well as the pressure and heat losses to the surroundings. The high pressure (HP), intermediate pressure (IP) and low pressure (LP) turbines constitutes a combined 29.7% of the total exergy destruction which indicates a need for reducing its irreversibility. Other factors that may contribute to the irreversibility are most likely due to the throttling losses at the turbine governor valves, silica deposited at the nozzles and blades and operating lower steam temperature than the recommended value. Amongst the three turbine stages, the IP turbine produces the highest exergy destruction. Overhauling the turbine maybe needed to check the real causes for improving plant performance. The exergy losses in the feed water heaters, from the thermodynamics point of view, are due to the finite temperature difference between the streams, which interchange heat, heat loss to the atmosphere and also due to the pressure drop. Amongst the feed water heaters, the high pressure (HP) heater C shows much higher losses as compared to the other heaters. Tubes inspection should be recommended during plant outage to determine the real cause. Other causes of high irreversibility are probably due to high percentage of plugged tubes, wrong venting operation, poor maintenance and wrong operating water level.

Conclusions

This paper has presented the results of energy and exergy analysis performed in a steam power plant. From the energy analysis, the overall plant energy losses are calculated as 68%.The results of the exergy indicate that the boiler produces the highest exergy destruction. On comparing the three turbine stages, the results of the analysis indicate that the HP and IP turbine produces higher exergy destruction than the LP turbine. Feed water Heater analysis states that LP feed water heater produces highest exergy destruction. All this information can assist the designer in the improvement of the efficiency and therefore reduction in generation cost.

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Nomenclature

X	Exergy (kcal)
Xin	Exergy at inlet (kcal/kg)
Xout	Exergy at outlet (kcal/kg)
Xd	Exergy destruction (kcal/kg)
h	Enthalpy (kcal/kg)
m	Mass flow (kg/hr)
ή	Exergy Efficiency