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# Exergy Analysis of Raipur Thermal Power Plant in Raipur (India); A Case Study

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## Abstract

In this paper, the exergy analysis of "(56MW) thermal power plant Raipur (India); a case study" are presented. The main objectives of this paper are to analyze the plant's component separately and to identify the parts having largest exergy losses. This paper will also justify the major sources of losses and exergy destruction in the power plant. According to the study, percentage ratio of the exergy destruction to the total exergy destruction was found to be maximum in the boiler system (57 %) followed by the turbine (33.3%), and then the condenser (5.34%). the exergy efficiency of the power plant was 31.12%. Which are low compared to modern power plants. According to analysis found that boiler is the major source of irreversibility in the power plant, but exergy destruction rate in boiler can be reduced by reheating the system. It is a suitable technique for decrease boiler's irreversibility. How reheating is the best tool for improvement of overall performance and comparison to the real condition of power plant is also presented in this paper. Without any change of fuel consumption, how reheating minimized exergy destruction, has also be investigated.

**Keywords**: Thermal power plant, Exergy analysis, Rankine cycle, Exergy destruction, Reheating cycle, exergy efficiency

## Introduction

Power generation industry plays the major role in the economic growth of the any Country. Now, 80% of total electricity in the world is approximately produced from fossil fuels (coal, petroleum, fuel-oil, natural gas) fired thermal power plants. The total power generating capacity of India are 225793.10MW (June 2013), out of that coal fired thermal power plants have the generation capacity 132288.39MW and natural gas fired thermal power plants have the generation capacity of 20359.85MW. According to power sector the share of thermal, hydro, nuclear and renewable power generation is 68.14%, 17.55%, 2.12% and 12.20%, respectively (CIA , June 2013) [1-2]. It seems that, in India, the performance of coal fired thermal power plants is of crucial importance for improving power availability in the country [3].

Studies of exergy analysis for power plants are of scientific interest and also essential part for the efficient utilization of power resources. For this reason, the exergy analysis has drawn much attention by scientists and system designers in current years. The exergy analyses are based on the Second law of thermodynamics [4]. It is the function of irreversible production of entropy [5]. Energy consumptions are one of the most important factor showing the development stages of countries and living standards of communities. The second law of thermodynamics introduces the useful concept of exergy in the analysis of the power plants. Exergy analyses are measure of quality of energy and it can be destroyed in the thermal system [6]. Population problem, industrializing, and technologic development result directly in increasing energy consumption. Thermodynamics analyses of power generation systems are of scientific interest and it also essential for the efficient utilization of energy resources [7].

Coal based thermal power plant working based on "Rankine power cycle". Power consumption increases with increasing of population, and as an expected result of this increase primary energy sources such as fossil fuels are being consumed rapidly [8]. The optimizations of power generation systems are one of the most important subjects in the

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energy-engineering field. Due to the high prices of energy and the decreasing fossil fuel recourses, the optimum application of energy and the energy consumption management method is very important [9]. The most common method for analysis of an energy-conversion process is the first law of thermodynamics. However, there are increasing interests in the combined utilization of the first and second laws of thermodynamics, using such concepts as known as exergy analysis. Therefore, the demands of energy are increasing day by day [10]. This rapid growing trend brings about the crucial environmental effects such as contamination and greenhouse effect. In recent decades, exergy analyses based on Second Law of Thermodynamics are found as useful method in the design, evaluation, optimization and improvement of thermal power plants [11]. The exergy analysis of thermal power plant is based upon the combination of the first and the second laws of thermodynamic together, while the energy analysis is based upon the first law only. For these reasons, the modern approach to process analysis uses the exergy analysis, which provides more realistic and understanding view for the process and a useful tool for engineering evaluation [12-14]. To assist in improving the efficiencies of power plants, their thermodynamic characteristics and performances has usually investigated [15]. Now, exergy analysis has been used by many researchers in thermal systems, especially for power plants. It is well-known that the exergy can be used to identify the location, type and true magnitude of exergy destructions and losses. Therefore, exergy analysis played an important role in developing strategies and providing guidelines for more effective use of energy in the existing power plants [16-19].

The main objective of this work is to analyze Raipur thermal power plant from an energy and exergy perspective. Sites of primary exergy destruction will be determined. The effect of reheating of the same plant and comparison between the plants on the basis of exergy analysis will also be investigated in this study.

## Plant Description

The power plant has total installed power capacity of 56 MW in full load condition. It is located 300 m above the sea level in the City of Durg, 46 km of Raipur which are Capital of Chhattisgarh state (India). It started to produce power in the last of nineties. The power plant consists of one steam turbines capacity (56) MW at full load condition. Still to date there are no reheating used in this thermal power plant. The power plant used poor quality, E grad of coal as a fuel. The schematic diagram of actual power plant is shown in Fig. 1 Feed water heating is carried out single stage of low pressure heater. Steam is superheated to 837.9 K and 131.1 Bar in the boiler and fed to the turbine. The turbine exhaust streams are sent to condenser at 0.80 Bar. After then it passes through the turbine, the steam is condensed in a condenser and recycled to where it are heated; this known as a 'Rankine cycle'. This power cycle starts over and over again. The operating condition of thermal power plants at 100% load shown in table no. 1

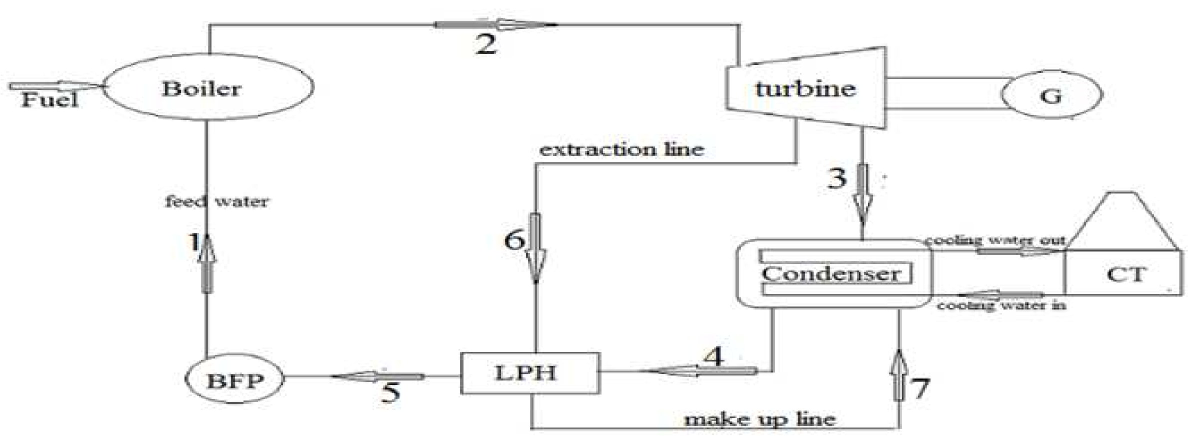


fig. 1 **Schamatic diagrame of 56 MW thermal power plant**

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**Table 1**
Operating condition of power plant

| Operating condition | value |
|---|---|
| Mass flow rate of coal | 5.79 kg/s |
| Mass flow rate feed water | 162.36 ton/h |
| Superheated steam temperature | 837.9 K |
| Gross calorific value of coal | 16770.75 kj/kg |
| Boiler pressure | 140.1bar |
| Steam pressure | 131.6 bar |
| Mass flow rate of cooling air | 2520 ton/h |
| Ambient Temperature | 300 K |
| Ambient Pressure | 1.01325 bar |

**Reheating cycle**

If higher steam pressures are used, in order to limit the quality to 0.85, at the turbine exhaust, reheat can be adopted. In that case all the steam after partial expansion in the turbine is brought return back to the boiler, reheated by combustion gases and then feed back to the turbine for further expansion. In the first step, steam expands in the high pressure turbine from the initial state and the steam is then reheated in the boiler and the remaining expansion is carried out in low pressure turbine. With the use of reheat cycle the net work output of the plant and performance will increase of same fuel consumption [20].

## Exergy System

The maximum work potential of a system is the amount of energy extract as useful work. Exergy is the maximum amounts of work that can be produced by a stream of matter or energy of different kinds when reaching the equilibrium with a reference environmental condition [21].The exergy analysis allow the identification of the irreversibility and therefore the exergy destruction rate in each system component [22]. Exergy can also identify better than energy, the environmental benefits and economics of power technologies [23]. The useful work potential of a system at the specified state is called exergy. The maximum useful work that can be obtained from a system at a given state in a given environmental condition; in other words, the most possible work one can get out of a system [24].

The exergy analysis can be made when each component of the power plant installation are considered as an open system [25]. Exergy are measure of the maximum capacity of a system to perform maximum useful work as it proceeds to a specified final state in equilibrium with its surroundings. Exergy are not conserved as energy but destructed in the system. Exergy destruction are the measurement of irreversibility that are the source of performance loss. Therefore, an exergy analysis assessing the magnitude of exergy destruction identifies the location, the magnitude and the source of thermodynamic inefficiencies in overall system [3].

The second law of efficiency is defined as;

$$\acute{\eta} = \text{Actual thermal efficiency} / \text{max thermal efficiency}$$

$$\acute{\eta} = \text{Exergy output} / \text{Exergy input}$$

For a steady state operation, and choosing each component in control volume, the exergy destruction rate (I) and the exergy efficiency ($\acute{\eta}$) is shown by:

For boiler:

$$I_B = X_{fuel} + X_{in} - X_{out} \quad (1)$$

$$\acute{\eta}_{II_B} = (X_{out} - X_{in}) / X_{fuel} \quad (2)$$

For turbine:

$$I_T = X_{in} - X_{out} - W_T \quad (3)$$

$$\acute{\eta}_{II_T} = 1 - I_T / X_{in} - X_{out} \quad (4)$$

For condenser:

$$I_C = X_{in} - X_{out} + W_F \quad (5)$$

$$\acute{\eta}_{II_C} = X_{out} / X_{in} + W_f \quad (6)$$

For pump:

$$I_P = X_{in} - X_{out} + W_P \quad (7)$$

$$\acute{\eta}_{II_P} = 1 - I_P / W_P \quad (8)$$

For overall cycle:

$$I_{Cycle} = \sum I_{all\ component} \quad (9)$$

$$\acute{\eta}_{II_{Cycle}} = W_{net\ out} / X_{fuel} \quad (10)$$

## Exergy Analysis

Exergy analyses are method that uses the conservation of mass and conservation of exergy principles together with the second law of thermodynamics for improvement of the systems. The exergy methods are useful tool for consumption

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of more efficient energy-resource. It helps the designers to identify locations and magnitudes of wastage, losses and to determine the meaningful efficiencies of the system [6].

The exergy ($\Psi Q$) of heat transfer (Q) from the control surface at temperature (T) is determined from maximum rate of conversion of thermal energy to work $(W_{max})$ is given by:

$$W_{max} = X_Q = \sum Q\left(1 - \frac{T_0}{T}\right) \quad (11)$$

And the specific exergy is given by

$$\Psi = (h - h_o) - T_o(s - s_o) \quad (12)$$

Then the total exergy rate associated with a fluid stream becomes

$$X = m\,\Psi \quad (13)$$

$$X = m\,[(h - h_o) - T_o(s - s_o)] \quad (14)$$

Where $h_o$, $T_o$ and $s_o$ are the value of reference condition.

**Table 2**

**Exergy destruction and exergy efficiency of the power plant components when $T_o$ = 300 K, $P_o$ = 1.01325 bar**

| Component | Exergy destruction(KJ) | Percent exergy destruction | Exergy efficiency |
|---|---|---|---|
| Boiler | 21836.5 | 57 | 67.8 |
| Turbine | 12659 | 33.3 | 81.4 |
| Condenser | 2032.5 | 5.34 | 19.1 |
| CEP Pump | 25 | .03 | 89 |
| LP Heater | 800 | 2.1 | 81 |
| Boiler feed pump | 670 | 2.23 | 76 |
| Power cycle | 38022 | 100 | 31.12 |

**Exergy analyses with reheating**

In this thermal power plant all condition for reheating are fulfill but reheating is not apply still to date. For heat recovery and reducing the effect of exergy destruction of same power plant, exergy analyses with reheating without any extra fuel consumption is shown in table no. 3

**Table 3**

**Exergy destruction and exergy efficiency of the power plant with reheating when To = 300 K, Po = 1.01325 bar**

| Component | Exergy destruction(KJ) | Percent exergy destruction | Exergy efficiency |
|---|---|---|---|
| Boiler | 8880 | 40 | 91 |
| Turbine | 10438 | 47 | 92 |
| Condenser | 2032.5 | 5.34 | 19.1 |
| CEP Pump | 25 | .03 | 89 |
| LP Heater | 800 | 2.1 | 81 |
| Boiler pump | 670 | 2.23 | 76 |
| Power cycle | 22844.5 | 100 | 39.99 |

## Results and Discussion

The exergy analysis has been investigated in the Raipur thermal power plant Raipur in India. The power plant had analyzed using the above relations and formulation noting that the environmental temperature and pressure are 300 K and 1.013 bar,

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respectively. Coal is the supply fuel of the power plant, with the following components: moisture = 8%, ash = 40%, hydrogen = 2.3%, nitrogen = 0.7%, sulphur = 0.30%, oxygen = 6.60%, carbon = 42%, GCV = 16770 KJ.

Analysis defines that the reference temperature does not have an effect on the energy efficiency, but it affects the exergy efficiency. The performance nd efficiency of the system depends on the surroundings of the system. It can be seen from the analysis that the plant performance and efficiency, decreases with a reduction in the generator output, with respect to exergy,

In this power plant major loss was found in the boiler system where 57% of the fuel exergy input to the cycle was destroyed. Next to it was the turbine which represents 33.3% of exergy destruction. The percent exergy destruction in the condenser was 5.34% while all heaters and pumps destroyed less than 5%. The exergy efficiency of the power plant was 31.12%, which is low compare to modern plants.

According to exergy analysis component wise exergy destruction of power plant as shown in fig.2

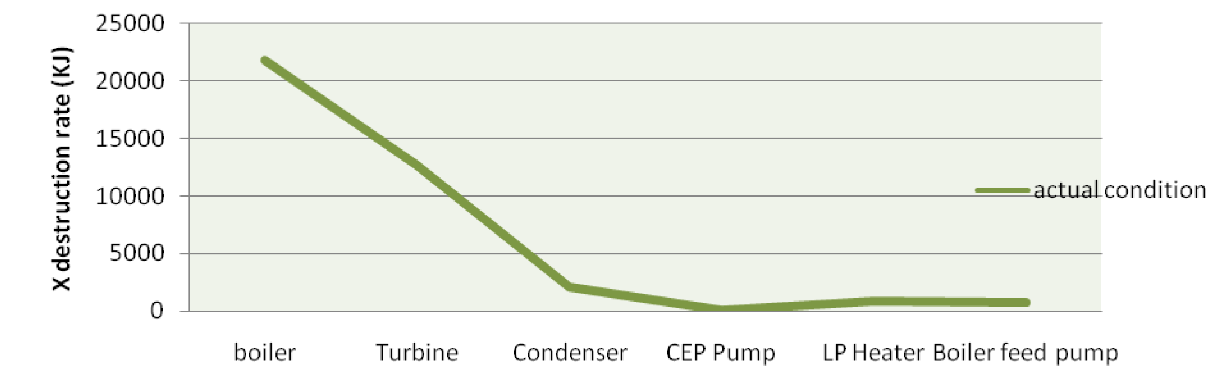


**fig.2 exergy destruction rate in actual condition**

Exergy and percentages of exergy destruction along with the exergy analysis are summarized in table no. 2 for all components present in the power plant. It was found that the exergy destruction rate of the boiler (57) is dominant over all other irreversibility in the cycle.

In the same plant not only boiler's exergy destruction minimized, but turbine's exergy destruction are also be minimized by the reheating process.

Comparison of exergy destruction rate before reheating and after reheating of same thermal power plant shown in fig. 3

In Raipur thermal power plant overall exergy destruction is 38021.2959 (KJ) while after reheating it can be minimize upto 22241.55409 (KJ) this is the great opportunity to improvement of overall performance of Raipur thermal power plant. This define as a fig.4

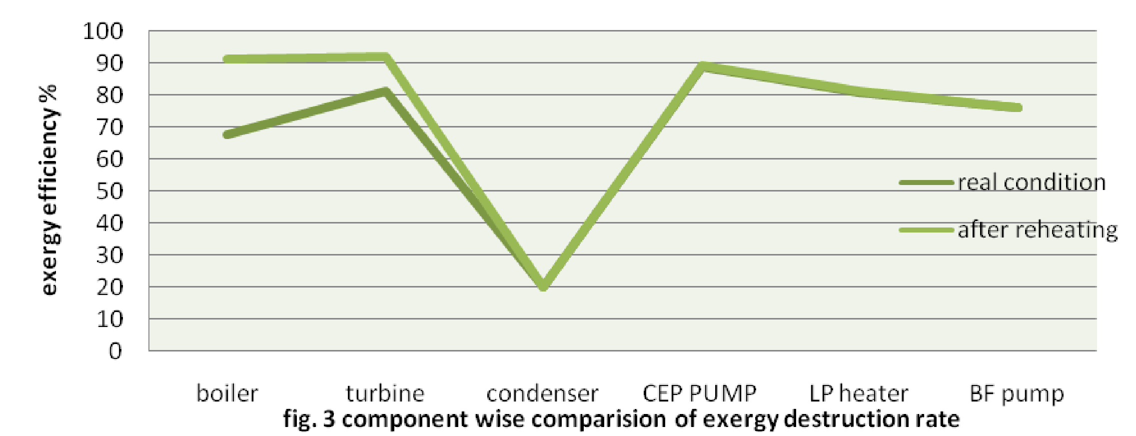


**fig. 3 component wise comparision of exergy destruction rate**

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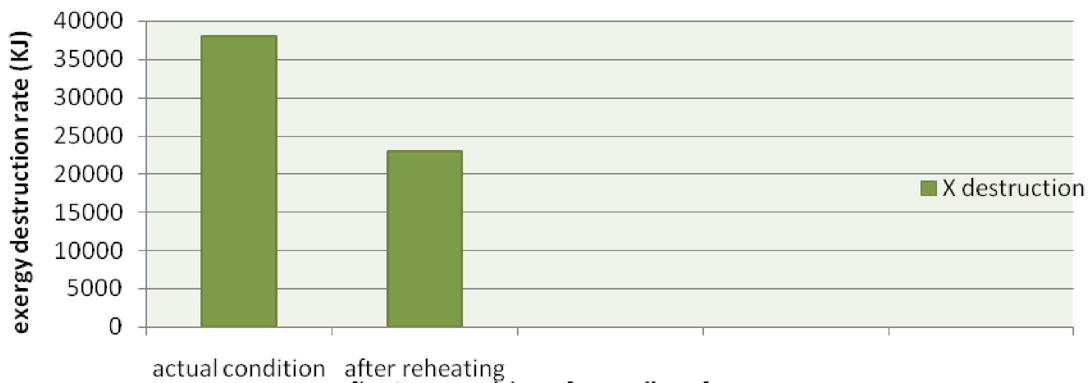


fig. 4 comparision of overall performance

The calculated exergy efficiency of the power cycle is 31.12 %, which is low as compare to modern plants. This indicates that a tremendous opportunity is available for improvement. However, part of this irreversibility cannot be avoided due to physical, economic and technological constraints.

Exergy analysis and Second law of thermodynamics has been performed in this study is able to help to understand the performance of thermal power plant and justify possible efficiency improvements. It gives logical solution for improving the performance opportunities in thermal power plants. After reheating exergy efficiency reached about 40 %.

## Conclusion

An exergy analysis as well as the effect of reheating on the "exergy analysis of Raipur thermal power plant Raipur" has been presented in this case study. In terms of exergy destruction, the major loss was found in the boiler system where 57% of the fuel exergy input to the cycle was destroyed. Next to it was the turbine which represents 33.3% of exergy destruction. The percent exergy destruction in the condenser was 5.34% while all heaters and pumps destroyed less than 5%.The calculated exergy efficiency of the power cycle was 31.12%, which is low compared to modern power plants. In this power plant boiler system is the major source of exergy destruction, where chemical reaction is the most significant source of exergy destruction in a combustion chamber.

For the reducing exergy destruction we apply to reheating of the same plant and then found that not only boiler's exergy destruction minimized but turbine's exergy destruction is also be minimize by the reheating process.

In boiler actual exergy destruction is 21836.5 KJ but after reheating it reduced upto 8880 KJ which is 59.39 % reduction and in turbine is 17.89 % of exergy destruction detected.

Following conclusions can be drawn from this study;

- Improvements of the power plant efficiency leads to a meaningful improvement of the overall performance of the plant are showing by the exergy analysis.
- Exergy analyses are an effective method using the conservation of mass and conservation of energy principles together with the second law of thermodynamics for the design and analysis of thermal power plants.
- The second law (exergy) analysis shows that boiler and steam turbine in thermal power plants are main source of Irreversibility while the first law analysis shows major energy loss has been found to occur in condenser.
- An exergy method gives logical solution improving the power production opportunities in thermal power plants.
- The maximum exergy destructions are found to occur in boiler. As a result, efforts at improving the overall performance of the power plant should be directed at improving the boiler performance, since this will lead to the largest improvement to the plant's efficiency and overall performance.
- Reheating of the steams is the most common way of reducing the irreversibility of the boiler.
- Reheating is usually carried out using product of combustion and boiler after they have performed their main heating duty and before they are discharged into atmosphere.
- Reheating is the best technique for improvement of overall performance of the plant. With the help of reheating we can

reduced the irreversibility of not only boiler system but turbine also without any extra fuel consumption.

It is expected that, this article will help to the future's Engineers, Researchers and Policy makers in the area of thermodynamics performance improvements for power plants appreciate that exergy analysis is a useful method and makes better use of exergy efficiencies in thermodynamics performance of thermal power plants.

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## Nomenclature

h enthalpy (kJ/kg)
X exergy (kJ)
LHV Lower Heating Value (kJ/kg)
M mass flow rate (ton/h)
BFP boiler Feed Pump
G generator
P pressure (bar)
Q heat transfer (kJ)
S entropy (kJ/kg)
T temperature (k)

Subscripts and superscripts
Ph physical
O reference ambient condition
ST steam turbine
F fuel
In inlet
Out outlet
G gas
CT cooling tower
S steam
X exergy

Greek symbols
ή exergy efficiency
Ψ specific exergy (J/kg)
I irreversibility

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