International Journal of Engineering Researches and Management Studies

EXERGY ANALYSIS OF A COMPLEX RANKINE CYCLE COAL-FIRED POWER PLANT

Ayush Painuly*[1], Gaurav Joshi[2], Vineet Kumar Pal[3], Mohit Kumar[4], Diwakar Suman5, Sunil Kumar Yadav[6] & Shravan K. Singh[7]

[*1,3,4,5&6]M.Tech Scholar, Department of Mechanical Engineering, NIT Jamshedpur (India)
[2]M. Tech Scholar, Centre of Energy and Environment Engineering, NIT Hamirpur (India)
[7]Associate Professor, Department of Mechanical Engineering, NIT Jamshedpur (India)

ABSTRACT

In this paper exergy analysis method has been applied to analyse a 350MW thermal power plant which is fired using commercial Indian bituminous coal. The analysis and comparison of performance of various major components of the plant is discussed. In the exergy analysis one can present qualitative results about actual energy consumption and the energy potential loss due to irreversibility during the cycle by determining origin of exergy loss thus, providing a much clearer picture. It also presents major losses of available energy, second law efficiency and exergy destruction at all sections of the system as well as equipment wise also..

Keywords: Exergy, Energy, Exergy destruction.

NOMENCLATURE:

I	Irreversibility (kW)
$\dot{m}$	mass flow rate (kg/s)
T	temperature (K)
t	temperature (°C)
$\dot{Q}$	thermal energy (kW)
boil	boiler
LCV	lower calorific value
$\dot{W}$	Work done (kW)
$\dot{S}$	entropy (kW/K)
hpt	high pressure turbine
ipt	intermediate pressure turbine
lpt	low pressure turbine
ilt	intermediate & low pressure turbine
cond	condenser
bfwp	boiler feed water pump
cep	condenser extraction pump
dtr	deaerator

SUBSCRIPTS:

cv	control volume
gen	generation
in	flow in
out	flow out
loss	loss in exergy

GREEK SYMBOLES:

$\dot{\Psi}$	flow exergy (kW)
η	exergy efficiency

International Journal of Engineering Researches and Management Studies

1. INTRODUCTION

At present, increasing demand of power has made the power plants of scientific interest, but majority of the power plants are designed from the energetic performance criteria which is based on first law of thermodynamics only. The first law of thermodynamics deals with the quantity of energy that cannot be created or destroyed. It does not give complete ideas about the useful energy losses taking place in the cycle because the difference between the energy quality and energy quantity is not considered [1].The second law however deals with the quality of energy. It considers the degradation of energy during a cycle and provides plenty of room for improvement. Exergy analysis is one of the method to find out true exergy losses at different points and components in a thermal power plant so that implementations can be made to reduce losses and destructions [2].

It has been suggested thatthe ability to perform useful work is a measure ofexergy quality by Gibbs, A. Stodola, G. Gouy, J. H. Keenan and many others. The term exergy was tossed by Zoran Rant in 1956 for "technical working capacity" but the concept was given by J. Willard Gibbs.

The analysis is based on "Fuel and Product concept" of thermodynamics suggested by Spanish scholar A. Valero [3, 4, 5].

2. GOVERNING EQUATIONS

The exergy analysis of a thermodynamic system or component involves enthalpy and entropy. The ratio between exergy used or gained and consumption exergy is equal to exergy or second law efficiency of the system or component [6].

As per the fuel product concept, for steady state operation, the energy balance equation for the open system can be given by following equation:

$$I = f - p$$

where, I = exergy destruction,
f = consumption exergy or fuel, and
p = exergy produced, released or lost by consuming fuel.

This can also be written as:

$$I_{cv} = \sum \left\{1 - \left(\frac{T_o}{T}\right)\right\} \dot{Q}_{cv} + \sum \dot{\Psi}_{in} - \sum \dot{\Psi}_{out} - \sum \dot{W}$$

Moreover, the unit exergy consumption is given as:

$$k = \frac{f}{p}$$

If, k> 1, the process is real,
k = 1, the process is reversible,
k< 1, the process is impossible.

From here, exergy efficiency can be given as the reciprocal of unit exergy consumption, that is:

$$\eta = \frac{1}{k} = \frac{p}{f}$$

3. 350 MW COAL-FIRED STEAM POWER PLANT AND ITS COMPONENTS

Physical Structure

The unit consists of a reheating, 3 high pressure feed water heaters, 1 deaerator and 4 low pressure feed water heaters. There are 3 turbines, high pressure, intermediate pressure and the low pressure turbine.

IJERMS
International Journal of Engineering Researches and Management Studies

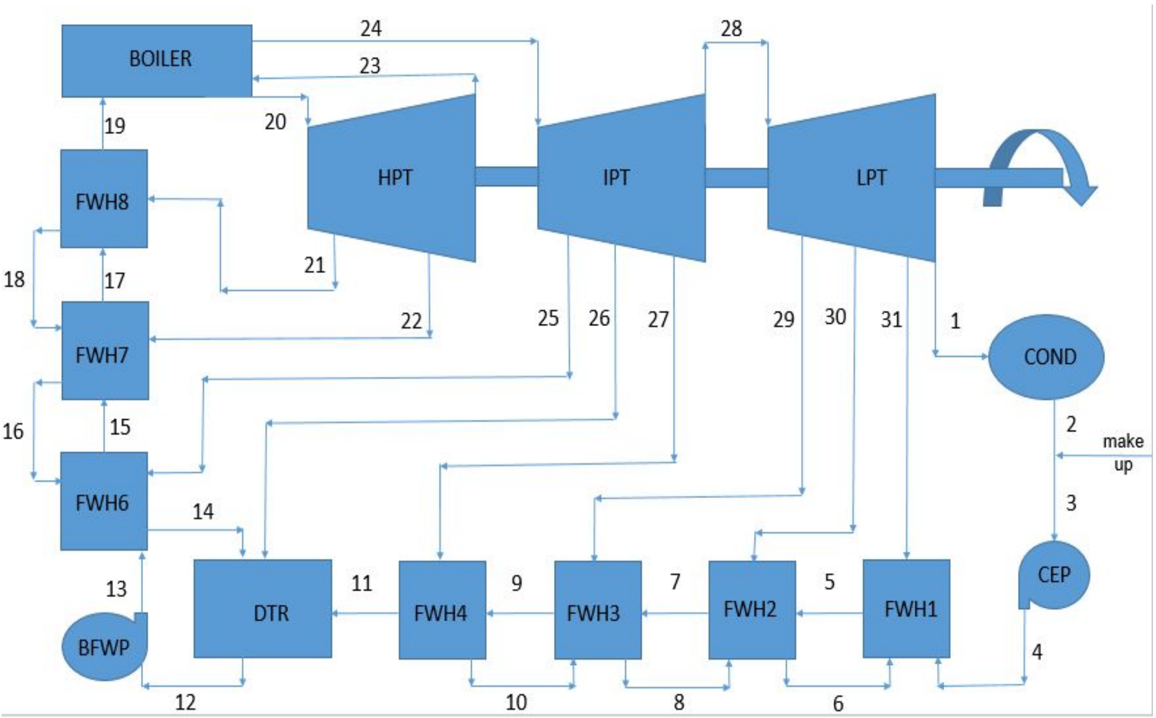

Figure 3.1 Physical structure of the 350MW coal-fired Steam Power Plant

Component wise definition of Fuel and Product

According to Figure 3.1, main components of the system are as follows:

- Boiler

$$f = \dot{Q}_{in}\left(1 - \frac{T_0}{T_{coal}}\right)$$

where, $Q_{in} = \dot{m} * LCV$

$$p = \dot{\Psi}_{20} + \dot{\Psi}_{24} - \dot{\Psi}_{19} - \dot{\Psi}_{23}$$

where, Ψ_{20} is the high pressure turbine inlet steam exergy, Ψ_{24} is the intermediate turbine inlet steam after reheating, Ψ_{19} is exergy of water coming from the high pressure feed water heater (FWH8) and Ψ_{23} is the high pressure turbine exit steam exergy.Fuel exergy algorithm method has been given in literature [7]. The lower calorific value of the fuel used is 32184 kJ/kg.

- Turbine

For HPT

$$f = \dot{\Psi}_{20} - \dot{\Psi}_{21} - \dot{\Psi}_{22} - \dot{\Psi}_{23}$$

$$p = W_{hpt}$$

For IPT & LPT

$$f = \dot{\Psi}_{24} - \dot{\Psi}_{25} - \dot{\Psi}_{26} - \dot{\Psi}_{27} - \dot{\Psi}_{29} - \dot{\Psi}_{30} - \dot{\Psi}_{31} - \dot{\Psi}_{1}$$

$$p = \dot{W}_{ilt}$$

- Condenser

$$f = \dot{\Psi}_{1} - \dot{\Psi}_{2}$$

IJERMS
International Journal of Engineering Researches and Management Studies

$$\dot{\Psi}_{loss} = \dot{Q}_{out}(1 - \frac{T_0}{T_{cond}})$$

where, Ψ_{loss} is the exergy loss due to heat transfer in the condenser with the cooling water.

- Pump

For CEP

$$f = W_{cep}$$

$$p = \dot{\Psi}_4 - \dot{\Psi}_3$$

For BFWH

$$f = \dot{W}_{bfwp}$$

$$p = \dot{\Psi}_{13} - \dot{\Psi}_{12}$$

where, W_{cep} & W_{bfwp} are the input work for Condenser extraction pump and Boiler feed water pump respectively.

- Feed Water Heater

For low pressure side

FWH 1

$$f = \dot{\Psi}_6 + \dot{\Psi}_{31}$$

$$p = \dot{\Psi}_5 - \dot{\Psi}_4$$

FWH 2

$$f = \dot{\Psi}_8 + \dot{\Psi}_{30} - \dot{\Psi}_6$$

$$p = \dot{\Psi}_7 - \dot{\Psi}_5$$

FWH 3

$$f = \dot{\Psi}_{10} + \dot{\Psi}_{29} - \dot{\Psi}_8$$

$$p = \dot{\Psi}_9 - \dot{\Psi}_7$$

FWH 4

$$f = \dot{\Psi}_{27} - \dot{\Psi}_{10}$$

$$p = \dot{\Psi}_{11} - \dot{\Psi}_9$$

For high pressure side

FWH 6

$$f = \dot{\Psi}_{16} + \dot{\Psi}_{25} - \dot{\Psi}_{14}$$

$$p = \dot{\Psi}_{15} - \dot{\Psi}_{13}$$

FWH 7

$$f = \dot{\Psi}_{18} + \dot{\Psi}_{22} - \dot{\Psi}_{16}$$

$$p = \dot{\Psi}_{17} - \dot{\Psi}_{15}$$

FWH 8

IJERMS
International Journal of Engineering Researches and Management Studies

$$f = \dot{\Psi}_{19} - \dot{\Psi}_{17}$$

$$p = \dot{\Psi}_{21} - \dot{\Psi}_{18}$$

- Deaerator

$$f = \dot{\Psi}_{12} - \dot{\Psi}_{11}$$

$$p = \dot{\Psi}_{12} - (\dot{\Psi}_{26} + \dot{\Psi}_{14})$$

4. CALCULATIONS

The point function of all points as specified in the Figure 3.1 and the flow exergy at each point are listed in the Table below.

Table 4.1 State Point Parameters at all Points

S. No.	$\dot{m}$ (kg/s)	P (MPa)	t (°C)	h (kJ/kg)	s (kJ/kg K)	$\dot{\Psi}$ (kW)
1	167.8	0.007	40.00	2,357.7	7.570	14,775.04
2	167.8	0.007	40.00	167.57	0.573	-701.404
3	193.8	0.037	40.01	168.30	0.554	406.9800
4	193.8	0.037	40.01	168.30	0.554	232.56
5	238.0	2.205	70.20	295.50	0.945	2,820.900
6	35.01	0.110	75.20	314.90	1.002	498.54
7	239.0	1.850	99.60	418.80	1.290	7,442.800
8	35.01	0.110	75.23	314.90	1.002	498.5400
9	239.0	1.700	129.6	545.70	1.620	14,269.50
10	12.29	0.660	134.6	566.30	1.670	802.5000
11	239.0	1.380	159.6	674.30	1.910	24,212.70
12	310.7	2.200	194.4	827.60	2.304	42,472.70
13	310.7	20.30	198.8	860.50	2.303	52,694.72
14	57.66	2.600	203.8	869.90	2.350	9,508.130
15	301.4	20.17	228.9	989.50	2.600	63,138.40
16	44.20	4.750	233.9	1,008.9	2.640	9,586.980
17	301.4	20.00	262.4	1145.5	2.920	80,676.36
18	23.51	7.630	267.4	1,171.5	2.850	7,429.160
19	301.4	19.90	294.4	1333.3	3.210	111,608.42
20	309.9	20.10	553.0	3,393.5	6.330	463,145.6
21	23.30	7.900	425.9	3,205.2	6.460	29,778.03
22	20.69	4.900	351.4	3,068.9	6.450	23,450.05
23	257.5	4.800	350.8	3,072.4	6.490	289,790.5
24	257.5	4.480	560.0	3,573.4	7.150	367,813.5
25	13.45	2.500	475.0	3,406.5	7.250	16,563.0
26	14.00	1.400	400.0	3,257.5	7.300	14,946.00
27	26.21	0.690	301.4	3,059.1	7.300	22,777.80
28	199.9	0.690	301.4	3,054.1	7.300	173,723.1
29	11.71	0.110	124.1	2,916.6	7.400	8,107.800
30	11.02	0.110	124.1	2,726.3	7.490	5,290.48
31	9.704	0.0074	40.00	2,533.4	7.480	2,799.07

5. ANALYSIS OF EXERGY OF EACH COMPONENTAND DISCUSSION

According to the physical structure shown in Figure 3.1 of the system, component wise exergy analysis, exergy destruction, exergy loss and the exergy efficiency are listed below.

IJERMS
International Journal of Engineering Researches and Management Studies

Table 5.1 Exergy analysis under Designed Conditions

Component	Fuel (kw)	Product (kW)	Exergy Destruction (kW)	Unit Exergy Consumption	Exergy eff (%)
Boiler	553,591.5	489,813.3	63,778.1	1.15	86.7
HPT	120,127.0	100,786.0	19,341.0	1.19	83.9
IPT & LPT	282,555.3	255,285.0	27,270.3	1.12	90.3
Condenser	15,476.4		15,476.4		
CEP	617.600	600.780	16.8200	1.02	97.7
BFWP	8,878.68	8,575.32	302.680	1.04	96.45
FWH1	3,530.18	2,828.91	709.270	1.38	72.3
FWH2	5,2904.8	4,621.90	668.580	1.14	87.4
FWH3	8,411.76	6,826.70	1,585.06	1.23	81.2
FWH4	21,975.3	9,943.20	12,032.1	2.21	45.25
Deaerator	18,260.0	18,018.57	241.430	1.01	98.68
FWH6	16,641.87	10,443.68	6,198.19	1.59	62.8
FWH7	21,292.21	17,537.96	3,754.25	1.21	82.4
FWH8	30,932.06	22,348.87	8,583.19	1.38	72.25

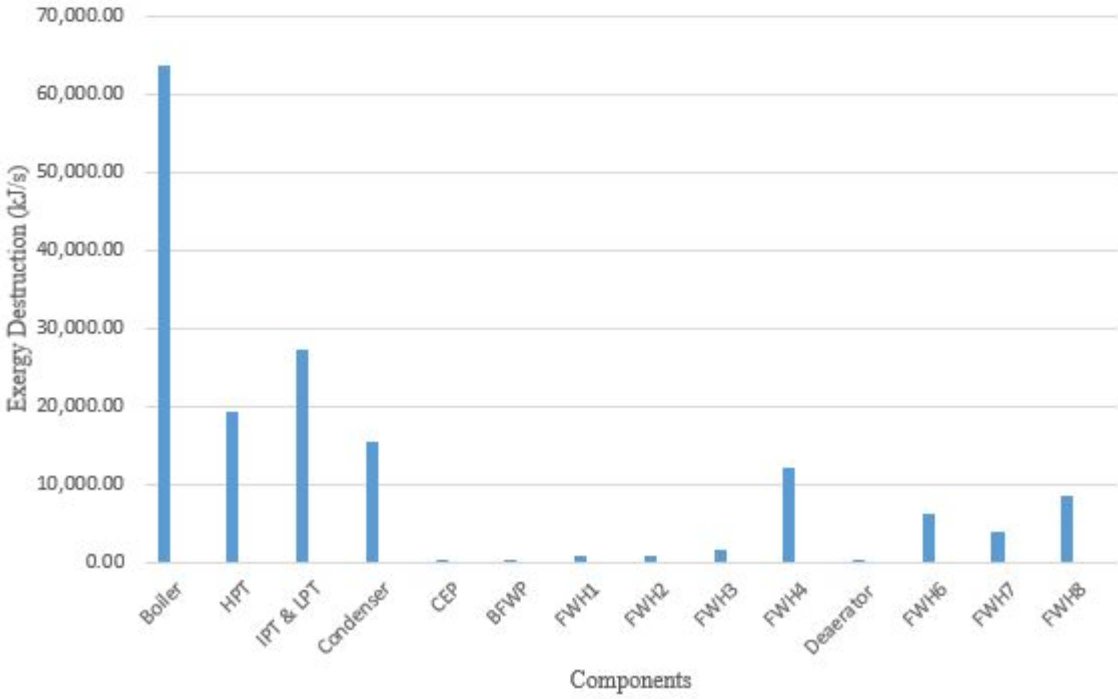

Figure 5.1 Exergy destruction of various components

From the data tabulated above, the exergy destruction is maximum inside the boiler (63,778.1 kW) due to large amount of temperature difference between the boiler bed and the water coming out from the Boiler Feed Water Pump. It also varies with the thermodynamic processes taking place inside the boiler such as combustion, heat dissipation and heat exchanging processes. During these processes most of the exergy is destroyed. The exergy loss inside the condenser is equal to the exergy coming inside it as no product is formed during the heat exchanging process. It transmits the low grade energy to the cooling water in the form of exergy loss.

IJERMS
International Journal of Engineering Researches and Management Studies

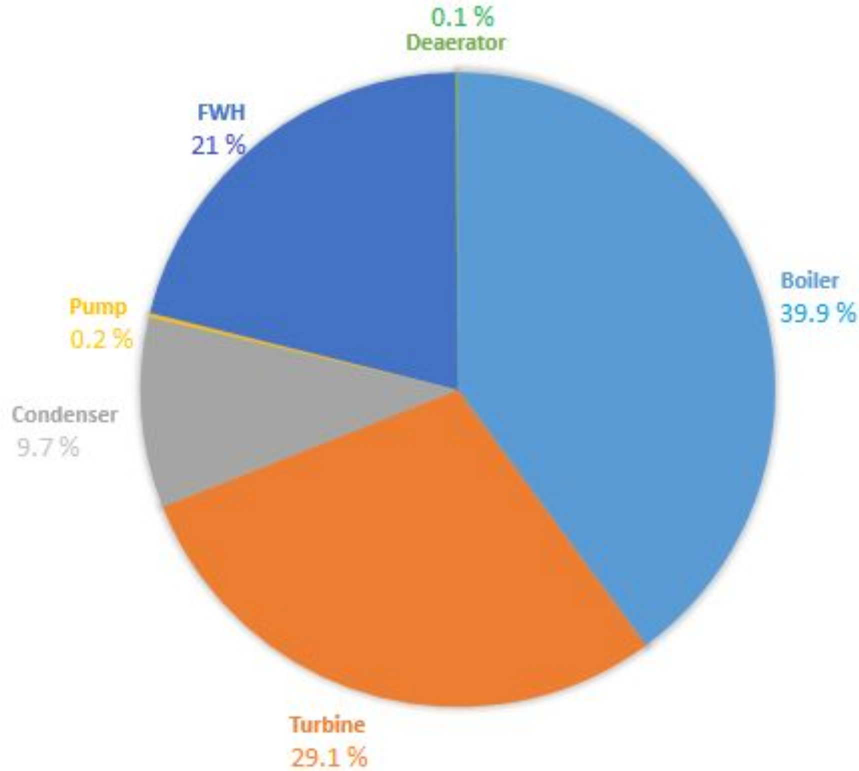

Figure 5.2 Percentage Exergy destruction

6. CONCLUSION

Exergy loss of the power plant is obtained by the detailed analysis of the plant design data. Boiler is the largest exergy destructor of the plant. Almost 40% of the exergy gets destructed inside it from the overall exergy destruction inside the plant due to high amount of temperature gradient between the heat transferring medium. From the analysis, we can easily read that where the exergy destruction spots are. In the actual thermal power plant, the exergy parameters of corresponding equipments can be read and any further changes can be made to reduce the exergy loss. So that the exergy loss analysis and second law analysis of the power plant are helpful to increase the overall efficiency of the plant.

REFERENCES

1. *J. X. Wang, S. F. Zhang, Exergy method and its application in thermal power plants. Beijing: Resources and Electric Power Press, (1993) 9-43.*
2. *Dr. K. C. Yadav, Dr. Abid Haleem, Exergy Assessment and Analysis of Thermal Power Plant Process Equipment. National Seminar on Thermal Power Plant Performance Management(2014) 85.*
3. *Q. Z. Wang, N. H. Song, J. X. Wang, "Calculation of thermal power system based on the concept of fuel and product", Electric Power, vol. 35 (2002) 27-31.*
4. *M. S. Zhu, Exergy analysis of energy system, Beijing: Tsinghua University Press (1988) 121-123*
5. *Yong Li, Lei Liu, Exergy Analysis of 300MW Coal-Fired Power Plant, Energy Procedia 17 (2012) 926 – 932.*
6. *Q. S. Fu, Thermodynamic analysis methods of energy systems, Xi'an Jiaotong University Press, (2005) 154.*
7. *C. Zhang, "Thermoeconomic analysis and optimization of complex systems", Ph.D. thesis, Wuhan: Huazhong University of Science and Technology (2006) 56-76.*