Exergy Method for Analysis of A Steam Power Plant

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Abstract

In this paper a theoretical analysis of Power Plant is carried out according to Exergy (availability) Method. The primary objectives of this paper are to analyze the system components separately and to identify and quantify the sites having largest energy and exergy losses. The power plant is divided into main blocks (Boiler, Turbine, Condenser, and Feed water Heater and Pumps).Then, the irreversibility losses and coefficient for each block are calculated. As well as, exergy method has been used to calculate work losses in each block. Finally, the overall irreversibility and thermal efficiency of plant are calculated from exergy analysis.

Boiler has the largest amount of work losses in the plant 8,846,639 kW which was contributed about 97.42% from the losses of the plant. The results that identified from exergy method relies on the second law of thermodynamics. Exergy method is satisfying and giving direct relationship between components losses of power plant and its overall efficiency.

Keywords: Steam Power Plant, Analysis, Exergy Method, Work Losses.

Introduction

Studies of energy and exergy analyses for power generation systems are of scientific interest and also essential for the efficient utilization of energy resources. For this reason, the exergy analysis has drawn much attention by scientists and system designers in recent years. Some devoted their studies to component exergy analyses [1,2] and efficiency improvement[3]. Efficiency is one of the most frequently used terms in thermodynamics, and it indicates how well an energy conversion or process is accomplished.

Real irreversible processes are amenable to thermodynamic analysis. The goal of such an analysis is to determine how efficiently energy is used or produced and to show quantitatively the effect of inefficiencies in each step of a process. The cost of energy is an important concern in any manufacturing operation, and the first step in any attempt to reduce energy requirements is to determine where and to what extent energy is wasted through process irreversibilities. The treatment here is limited to steady-state flow processes, because of their predominance in industrial practice. With increasing fuel prices and the possibility of diminishing supplies in the years ahead, the importance of developing systems which make efficient use of energy is apparent. The second law of thermodynamic method of analysis is particularly suited for furthering the goal of more efficient energy use, for it identifies the locations, types, and the true magnitudes of energy resources waste and loss, such method can also be used to guide steps taken to reduce inefficiencies. According to this second law, different criteria are defined for analysis of the performance of power plants based on the concept of exergy (availability). If all of these criteria are used, they must all give the same results. Although availability pinpointed the real losses of a steam power plant, it is difficult, complex and cannot give direct relationship between component losses and overall efficiency of plant. Thus, the criteria for selecting the best procedure to evaluate thermodynamic analysis should be, best ease of use, best degree of correspondence with the viewpoint and background of intended users and greatest breadth of application. The exergy of a system is defined as the maximum shaft work that could be done by the composite of the system and a specified reference environment that is assumed to be infinite, in equilibrium, and ultimately to enclose all other systems. Typically, the environment is specified by stating its temperature, pressure and chemical composition. Exergy is not simply a thermodynamic property, but rather is a co-property of a system and the reference environment.

Exergy Method Analysis of The Thermal Power Plant [5]

Exergy analysis involves the evaluation of inputs, outputs, accumulations and consumptions of exergy for a system. These terms are related as follows:

Exergy input-Exergy output-Exergy consumption= Exergy accumulation

The processes in steam turbine plant are steady flow processes. where the general form of the exergy value was calculated from the following formula:

$$\varphi = (h - T_0S) - (h_0 - T_0S_0)$$

Reversible Work[5]

The reversible work will be a maximum when this mass leaves the control volume in equilibrium with the surroundings. This means that as the mass leaves the control volume it must be at the Pressure and Temperature of the surroundings.

Let us consider the exergy associated with steady state steady flow processes.

$$\dot{W}_{rev.} = \sum \dot{m_i}\left(h_i - T_0S_i + \frac{V_i^2}{2} + gZ_i\right) - \sum \dot{m_e}\left(h_e - T_0S_e + \frac{\dot{V_e}}{2} + gZ_e\right)$$

The reversible work will be a maximum when(h_e=h_0, S_e=S_0, V_e=0, and Z_e=0) and assigning this the symbol (φ) we have:

$$\varphi = \left(h - T_0S + \frac{V^2}{2} + gZ\right) - (h_0 - T_0S_0)$$

The reversible work per unit mass flow between any two states is equal to the decrease in exergy between these two states.

$$W_{rev.} = \varphi_i - \varphi_e$$

If we have more than one flow into and out of the control volume in a steady- state, steady-flow processes we can write:

$$\dot{W}_{rev.} = \sum \dot{m_i}\varphi_i - \sum \dot{m_e}\varphi_e$$

Exergy destruction "Irreversibility"[5]

The energy that becomes unavailable for work as the result of irreversibilities in a process is called irreversibility, and is defined as the difference between the reversible work for processes and the actual work of the process. The irreversibility would be zero for a completely reversible process and other wise is always greater than zero.

$$I = W_{rev.} - W_{act.}$$

$$I = W_{rev.} - W_{act.} = T_0 \Delta S_{net.} = T_0 S_{net}$$

Cycle Thermal Efficiency

$$Effici. = output/input = W_{act.}/Q_{add.}$$

Second law efficiency[5]

The second law efficiency is intended to serve as a measure of approximation to reversible operation. Its value should range from zero in the worst case of complete destruction of exergy, to one in the best case of no destruction of exergy.

$$Effici.2nd = {}^{W_{act.}}/_{W_{rev.}}$$

Where:

$$W_{rev.} = \varphi_i - \varphi_e$$

Exergy Evaluation[5]

Exergy evaluation involves the use of dead state.

$$\varphi = (h - T_0 S) - (h_0 - T_0 S_0) \ \ (kJ/kg)$$

$$\varphi = m^{\cdot}(h - T_0 S) - (h_0 - T_0 S_0) \quad \text{(kW)}$$

Irreversibility[5]

From general exergy equation, the irreversibility is:-

$$I_{cv} = \sum \left(1 - \frac{T_0}{T_i}\right) Q_i^{\cdot} - W^{\cdot} + m^{\cdot}(\varphi_i - \varphi_e)$$

Irreversibility For Power Producing Devices[5]

$$I_{cv} = \sum \varphi^{\cdot}_{inlet} - \sum \varphi^{\cdot}_{outlet} - W^{\cdot}_{cv}$$

While the second law efficiency is given by:

$$Effici.2nd. = \frac{W_{cv}}{\sum \varphi^{\cdot}_{inlet} - \sum \varphi^{\cdot}_{outlet}}$$

Irreversibility For Power Consuming Devices [5]

$$I_{cv} = \sum \varphi^{\cdot}_{outlet} - \sum \varphi^{\cdot}_{inlet} - W^{\cdot}_{cv}$$

$$Effici.2nd. = \frac{\sum \varphi^{\cdot}_{outlet} - \sum \varphi^{\cdot}_{inlet}}{|-W_{cv}|}$$

Conclusions

1- The primary objective of this paper is to analyze the system components separately and to identify and quantify the site having largest energy and exergy losse

2- Exergy method has used to determine the losses of energy in blocks of steam power plant **Fig.(2) and Table(2),** since second law of thermodynamic is unambiguous.

3- Exergy Method (irreversibility) is dependent on dead state except for the value of (T_0) . Where the exergy is determined in relative to restricted dead state, which can be somewhat misleading.

4- Exergy method which is easy to apply which requires two properties (entropy and enthalpy).

5- The exergy method is carrying out the real losses in each component and giving direct relationship between them and the overall efficiency of the plant. By this the effect of inefficient components can be directly reduce the energy losses and improve the performance of plant.

6- The exergy method shows that combustion temperature does not possess influence on the irreversibility losses of the boiler.

7- The study emphasizes that the thermal system based on the first law of thermodynamics alone may lead to misinterpreting the results of the analysis, so that analysis based on both first law and second law of thermodynamics is essential for understanding and explaining the effect of any parameter on the thermal system performance.

8- Exergy analysis for stream cycle system can be used to predicate plant efficiency more precisely.

9- The exergy analysis is excellent tool to analyze the cause of performance deterioration in steam power plant components.

10- Lost work or exergy analysis is a powerful tool to measure the efficiency of energy utilization of real processes.

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Notation:

Effic.: Efficiency

h: Enthalpy(kJ/kg)

I_{cv}: *Irreversibility of conrol volume*

$I_{irrev.}$: *Irreversibility(kw)*

m:Mass flow rate (kg/s)

p:Pressure (Mpa)

Q_i: *inlet heat(kJ)*

$Q_{add.}$: *Added heat(kJ)*

s: Entropy (kJ/kg.K)

S_{net}: *Entropy generation* $(\frac{kJ}{kg}.K)$

ΔS_i: *Change of entropy per unit mass* $(\frac{kJ}{kg}.K)$

T:Temperature(C^0)

T_0: Ambient temperature(C^0)

T_i : Inlet temperature(C^0)

$\dot{W}_{lost}$: *Lost work rate*(*kw*)
$\dot{W}_{rev.}$: Reversible work(kw)
$\dot{W}_{act.}$: Actual work(kw)

GREEK

φ: Exergy per unit mass)($\frac{\text{kJ}}{\text{kg}}$)
$\dot{\varphi}$: *Exergy*
$\dot{\varphi}_i$: Inlet exergy
$\dot{\varphi}_e$: Exit exergy

SUBSCRIPTS

act. :Actual
i:inlet
e:exit
rev.:reversible
irrev.:irreversible

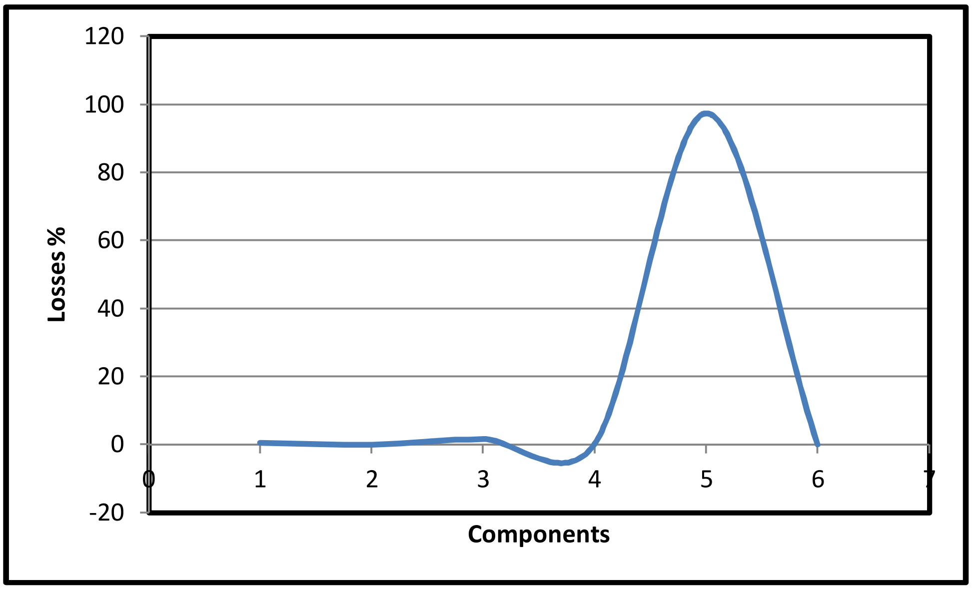
Table (1) :Description Data Of Steam Cycle For Power Plant [9]

Pt	mass (kg/s)	Temperature (C^0)	Pressure(Mpa)	S(kJ/kg.K)	h (kJ/kg)
1	85.9683	45	1.216	0.6381	189.5
2	85.9683	70	1.216	0.9541	293.9
3	85.9683	100	1.216	1.306	419.9
4	85.9683	125	1.216	1.58	525.6
5	109.803	148	1.216	1.82	624
6	109.803	150	9.801	1.831	638
7	109.803	193	9.727	2.252	824.8
8	109.803	230	9.595	2.597	991.6

Pt	mass (kg/s)	Temperature (C^0)	Pressure(Mpa)	S(kJ/kg.K)	h (kJ/kg)
9	109.803	537.8	9.595	6.742	3475
10	75.9366	76.82	0.04154	7.657	2638
11	3.1780	76.82	0.04154	7.657	2638
12	4.1908	105	0.1226	1.363	440.1
13	2.6758	130	0.2695	7.028	2721
14	5.9780	166	0.7245	2.002	701.7
15	11.1444	198.2	1.495	6.446	2792
16	6.7255	235	2.858	6.23	2816
17	6372.0194	21.7	0.1013	0.3208	91.15
18	6372.0194	29	0.1013	0.423	121.7
19	0.1422	76.82	0.04161	7.656	2638
20	76.0788	40	0.007384	0.5724	167.5
21	9.8894	80	0.04739	1.075	334.9
22	85.9683	44	0.00911	8.183	2581
23	2.6630	130	0.2695	7.028	2721
24	4.1908	105.7	0.1216	7.296	2685
25	3.1780	76.82	0.04053	7.669	2639
26	10.0319	---	---	---	---
27	6.7255	235	2.857	6.231	2816
28	11.1444	198	1.489	6.447	2792
29	17.87	212.2	1.99	2.445	907.6
30	6186.11805	537.8	22.09	6.219	3331

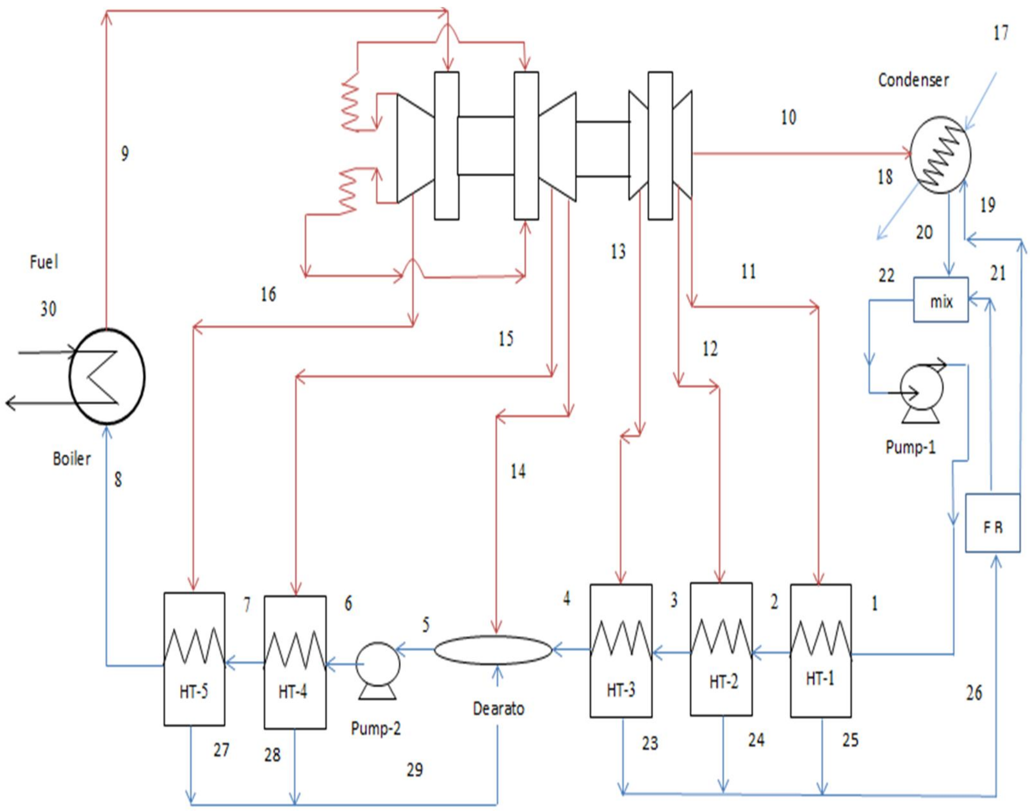
Table (2): Exergy Analysis Method Summary.

No.	Components	φ_i	φ_e	$\dot{\varphi_i}$	$\dot{\varphi_e}$	$\dot{W_{rev.}}$	$\dot{W_{act.}}$	$I_{irrev.}$	Effi %
1	Heaters	2984.87	6117.43	45968.3	340594.7	294626.5	--	294626.5	--
2	Dearator	313.842	74.087	7739.80	8134.975	395.171	--	395.171	--
3	Pumps	182.593	88.0663	17463.1	9591.13	10784.27	207130.24	196346.14	5.206
4	Condenser	643.397	11.5601	12145.6	39344.2	27198.58	--	27198.58	--
5	Boiler	1658.84	1437.90	9004525	157886.2	8846639	--	8846639	--
6	Turbine	1437.90	3149.07	157886.2	43649.89	114236.4	109490.8	4745.513	95.84
7	Power Plant	--	--	--	--	--	--	--	40.15



Figure(1): Exergy Method Analysis For Power Plant

X-Axis:- 1-Heaters 2-Dearator 3-Pumps 4-Condencer 5-Boiler 6-Turbin



Figure(2): Flow Sheet Of The Steam Power Plant [9].