EXERGY ANALYSIS OF STEAM SYSTEM COMPONENTS OF POWER PLANT AT S&PG DEPT. OF GNFC BHARUCH

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ABSTRACT

The exergy analysis is a new way of analysis of any system using energy. Until now, the performance of power plant was analysed based upon 1st law of thermodynamics which is called Exergy analysis. But in exergy analysis the performance of the plant is estimated by using both 1st and 2nd law of thermodynamics. In different types of power plant, steam system is the most commonly found. Therefore this exergy analysis is concentrated upon steam system of a small scale captive power plant. The primary objective is to analyse, identify and quantify the components and sites having exergy losses in the steam system. Plant parameters were collected for boiler house and 1st law and 2nd law analysis was done for different components of the steam system by using EES software .The Exergy and exergy efficiency of the plant were found to be 35.33 % and 47.11 % and maximum exergy destruction was found in boiler.

Keywords: Exergy Analysis, Steam System, Exergy Analysis, Power Plant

I INTRODUCTION

Exergycan be viewed as “the ability to cause changes” [20]. The majority of the world’s power generation is met by fossil fuels, particularly coal and natural gas. Due to higher cost of renewable Exergy technology, our dependence on fossil fuel will be continued for decades. Therefore it is important to increase the life of fossil fuel by increasing the efficiencies of power plants. However, Exergy efficiencies are often misleading in that they do not always provide a measure of how the performance of a system approaches ideality. Further, the thermodynamic losses which occur within a system (i. e., those factors that cause performance to deviate from ideality) often are not accurately identified and assessed with Exergy analysis [22]. Exergy analysis is a thermodynamic analysis technique based primarily on the second law of thermodynamics. It yields efficiencies which provide a true measure of how nearly actual performance approaches the ideal and identifies more clearly the types, causes and locations of thermodynamic losses.

Exergy is not simply a thermodynamic quality, but rather it is a co-property of a system and the surrounding or more specifically the reference environment. Exergy is conserved only when all the process of the system and the environment are reversible. Exergy is destroyed when an irreversible process occurs[23]. In exergy analysis the same set of equations is applicable to all power plant components, disregarding the differences in the internal thermodynamic cycle of the components. This approach provides a common scale to compare performances of components which are thermodynamically different in nature. Following equation is the set of Exergyequations for open systems

$$\frac{dE}{dt} = \sum_{i=0}^{n} \dot{Q}_i - \dot{W} + \sum_{in} \dot{m}h - \sum_{out} \dot{m}h$$

$$S_{gen} = \frac{dS}{dt} - \sum_{i=0}^{n} \frac{\dot{Q}_i}{T_i} - \sum_{in} \dot{m}s + \sum_{out} \dot{m}s \geq 0$$

The entropy generation and heat lost to the atmosphere are the prime variables of interest to be calculated for all components using this equation. The entropy generation is directly proportional to the exergy destruction. All variables in this equation, for all components, are available as either directly measured data or calculated data from the first law analysis [25]. Exergy losses are mainly associated with turbine, boiler and heat exchangers which all are having steam as working fluid. So concentrating upon steam system, steam properties and behaviour of steam can make more insights for the causes of exergy destruction.

II. PLANT DESCRIPTION

Gujarat Narmada Valley Fertilizers Company Ltd. (GNFC) is a joint sector company promoted by the Government of Gujarat and Gujarat State Fertilizers and Chemicals Ltd. (GSFC) at Narmadanagar, Bharuch District of Gujarat. . Much power is needed to run such a big plant and also process steam at different temperature and pressure levels. For satisfying the demand of process steam, a whole Steam & Power Generation Department is established which generate 83.3 MW (25 + 25 + 33.3) power. The S & PG department consist of total 4 boilers, 2 steam turbines, 1 gas turbine and 1 heat recovery steam generation

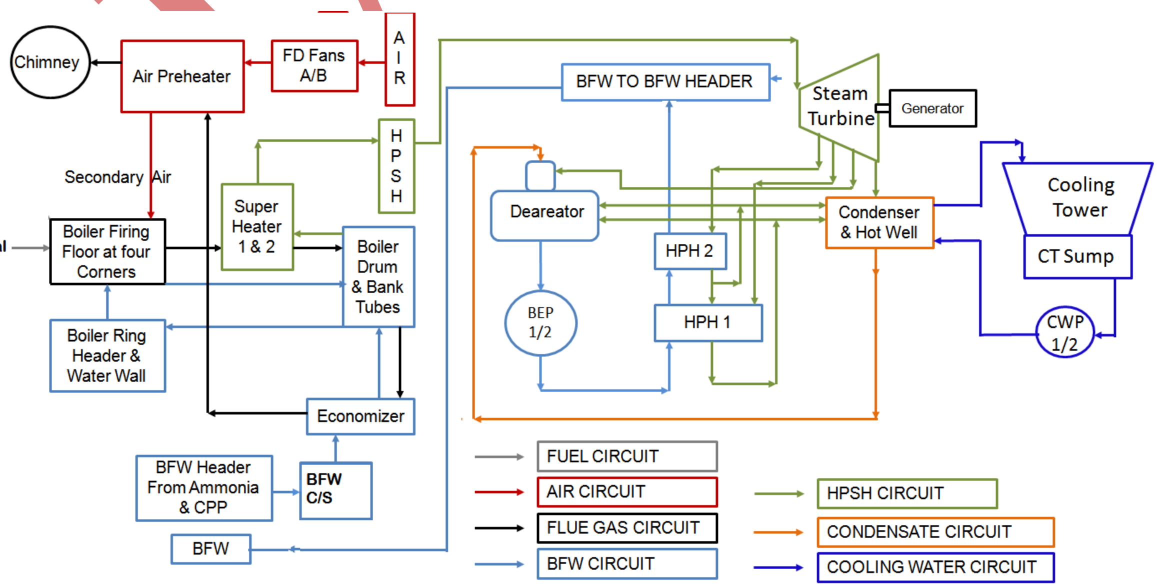


Fig. 1.2 Plant Layout

unit. 3 pulverised coal fired steam boilers produce 180TPH steam which is used in 25 MW turbines and as process steam in the plant.

Table 1.1: Plant Data

Component	Inlet temp (°C)	Inlet pressure (bar)	Outlet temp (°C)	Outlet pressure (bar)
Air in APH	29.8	-	300.5	-
Furnace	300.5	-	936.65	-
Economiser (BFW)	171.2	131.58	257.7	131.58
Boiler Drum	257.7	131.58	311.033	105.022
Super heater 1	314.65	105.06	377.906	102.8
De-super heater	377.906	102.8	322.5	80.6
Super heater 2	322.5	80.6	496.41	97.905
Turbine inlet	493.2	94.842	50.2	0.12
Condenser	50.2	0.12	56.78	7.84
De-aerator	56.78	7.84	78.76	0.62

III. EXERGYANALYSIS

3.1 First law efficiency is calculated as

$$\eta = \frac{Energy\ Out}{Energy\ in}$$

Thermal efficiency of regenerative cycle is given by

$$\eta = W.D. / Heat\ Supply$$

3.2 For boiler

$$\therefore \eta_B = \frac{m_s(h_{out} - h_i)}{m_f \cdot GCV}$$

3.3 The total work of the turbine is

$$W_{out} = m(h_i - h_1) + m_1(h_1 - h_2) + m_2(h_2 - h_3) + m_3(h_3 - h$$

3.4 Turbine efficiency can be calculated as

$$\eta_t = \frac{actual\ work\ done}{isentropic\ work\ do}$$

$$= \frac{m(h_i - h_1) + m_1(h_1 - h_2) + m_2(h_2 - h_3) + m_3(h_3 - h_4)}{m(h_i - h'_1) + m_1(h'_1 - h'_2) + m_2(h'_2 - h'_3) + m_3(h'_3 - h'}$$

In this way we can do first law analysis of the system.

IV EXERGY ANALYSIS

Exergyanalysis is based upon the second law of thermodynamics, which stipulates that all macroscopic processes are irreversible. Every such irreversible process entails a non-recoverable loss of exergy, expressed as the product of the ambient temperature and the entropy generated (the sum of the values of the entropy increase for all the bodies taking part in the process). Thermal efficiency tells us what we get out compared to what we put in. The elementary irreversible phenomena that generate entropy are: mechanical or hydraulic friction, heat transfer with a finite temperature gradient, diffusion with a finite gradient of concentration, and the mixing of substances with different parameters and chemical composition. Combustion is also a typical irreversible phenomenon. The second law efficiency tells us how much we get out compared to the maximum possible we could get out, given the inlet and exit condition.

In general definition

$$\eta_{II} = \frac{\text{exergy recovered(what's available after the process)}}{\text{exergy supplied (what's available at the beginning)}}$$

$$\eta_{II} = 1 - \frac{\text{exergy destroyed(I)}}{\text{exergy supplied}}$$

Another way to look at this: for a work output device

$\eta_{II} = Wu / Wrev$

$X_{destroyed} = I = T_o S_{gen}$

For non-flow Exergy

$Ex_{nf} = (u - u_0) + P_0 (v - v_0) - T_0 (s - s_0)$

Exergy of flow work

$Ex_{fw} = (P - P_0)\ v$

Flow Exergy

$Ex_{flow} = Ex_{nf} + Ex_{fw}$

$= (u - u_0) + P_0 (v - v_0) - T_0 (s - s_0) + (P - P_0)\ v$

Since $h = u + Pv$

$Ex_{flow} = (h - h_0) - T_0 (s - s_0)$

Also for a system component where heat is being transfer from high temperature to low temperature, Exergy destruction takes place due to generation of entropy. Finally maximum available Exergy(exergy) can be calculated as

$Ex_{in} = Q\ (1 - (T_0/T_{hot}))$

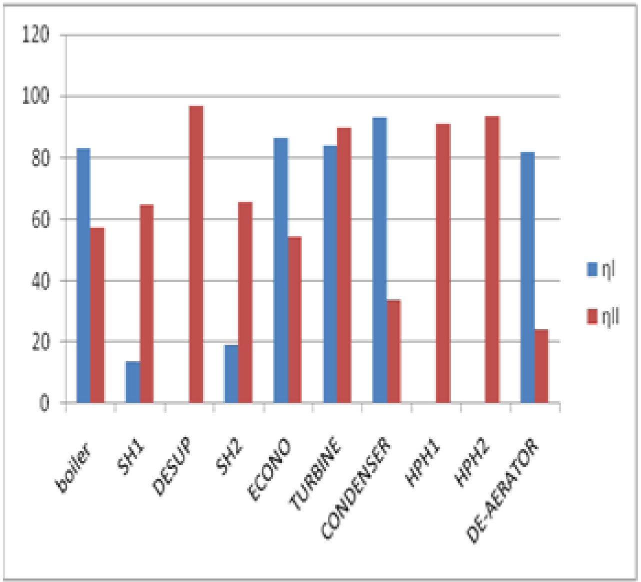
After heat transfer, due to exergy destruction, output exergy is lesser than input exergy and the difference is equal to the exergy destruction.

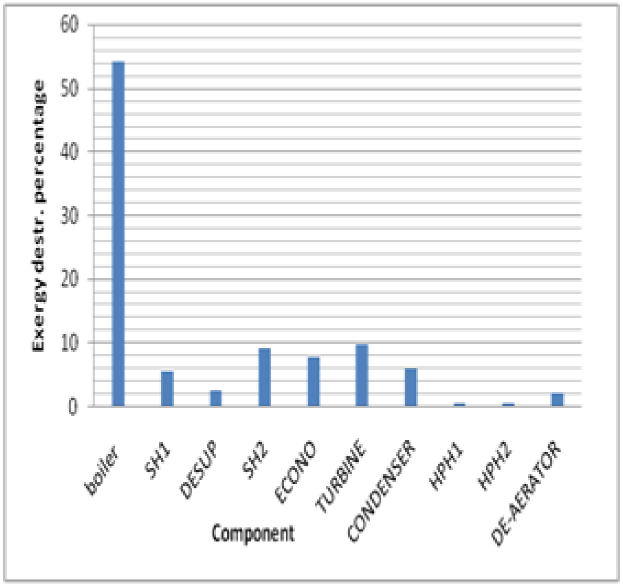
$Ex_d = T_0 * S_{gen}$

$S_{gen} = S_{out} - S_{in} = (Q_{out}/T_{out}) - (Q_{in}/T_{in})$

V. RESULTS AND DISCUSSION

The power plant was analyzed using the above relations noting that the environment reference temperature and pressure are 29.8° C and 101.3 kPa, respectively. The thermodynamic properties of water and air were calculated using EES software. The results of the analysis are shown in table 5.1. Comparing the 1st law and 2nd law Exergy destroyed in each component and it's efficiency can yield some fruitful results which can be useful to optimise the power plant performance. Also percentage out of total Exergy destruction is shown which reveals that boiler has the maximum amount of Exergy destruction and condenser, which gives a big amount of heat to atmosphere only makes 6.103 % Exergy destruction. This is due to the fact that the heat lost from condenser is low grade heat which can't be used for any useful work. Super heater2 also make significant 9.29 % Exergy destruction. Maximum second law efficiency was found for De-super heater, high pressure heaters and the turbine.





Plot 5.1: Percentage Exergy Destruction **Plot 5.2 : Exergyand Exergy Efficiency of components**

Lowest 2nd law efficiency was for condenser, Deaerator, economiser and boiler. But as the maximum amount of exergy destruction takes place in boiler, we should concentrate upon boiler because small increase in boiler exergetic efficiency will result in significant decrease in exergy destruction and will save more fuel.

By Exergy analysis of boiler we have got information of how total heat gained is distributed over boiler components. Super heaters have very low Exergy efficiency as whole of the heat content is available to them but they are only meant to superheat the steam. They actually increase the total heat gained by the boiler from 59 % to 83 % and therefore there 1st law efficiency is not to be considered and the percentage increase in heat gain of boiler should be taken into account. Table 5.2 shows this. Also we can see that super heaters are having the highest exergy efficiency of heat transfer. This is due to lower temperature difference between flue gases and steam. Finally the energetic and exergetic efficiency of the plant were found 35.33 % and 47.11 %.

Table 5.1: Efficiencies and E_d

Component	*I*	η_{II}	E_d	% E_d/E_{dT}
Whole Boiler	83.22	57.27	22304.8	54.166
Super heater 1	13.85	64.64	2319.13	5.632
De-super heater	-	96.94	1050.64	2.551
Super heater 2	19	65.55	3827.66	9.29
Economiser	86.44	54.54	3206.8	7.78
Turbine	84.06	89.89	4034.45	9.797
Condenser	92.86	33.71	2513.23	6.103
HPH 1		90.99	264.16	0.6415
HPH 2		93.46	288.755	0.701
Deaerator	81.9	24.22	1369.07	3.325

Table 5.2 % Heat Gained By Boiler Components

Component	**% Heat gained**
Boiler Drum and tubes	59.01 %
Super heater 1	11.22 %
super heater 2	19 %

VI. CONCLUSION AND REMARKS

In this study, an Exergy and exergy analysis was done for all the components of the steam system of the captive regenerative power plant at GNFC Ltd. Bharuch. In the considered power cycle, the maximum Exergyloss was found in condenser where 61 % of the input Exergy was lost to the environment. The calculated power plant efficiency was 35.33 %. On the other hand the exergy analysis shows that Exergylost in condenser is thermodynamically insignificant due to its low quality. The maximum exergy loss was found in boiler where 54.16 % of total exergy destruction was lost and the next was turbine where 9.8 % exergy destruction is taking place. The percentage exergy destruction in condenser was just 6 %. The exergetic efficiency of the plant was 47.11 % which shows that much performance improvement potential is available. The most significant cause of exergy destruction is the chemical reaction and large temperature difference in the boiler. If fluidised bed combustion type boiler is used, these losses can be reduced to much extent.

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