Consideration the Important Factor to Power Plant Efficiency

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***Abstract*— In this study, the energy and exergy analysis of a power plant is presented. 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. In addition, the effect of varying the reference environment state on this analysis will also be presented. The performance of the plant was estimated by a component wise modeling and a detailed break-up of energy and exergy losses for the considered plant has been presented. Energy losses mainly occurred in the condenser. For a moderate change in the reference environment state temperature, no drastic change was noticed in the performance of major components and the main conclusion remained the same; the boiler is the major source of irreversibilities in the power plant. Chemical reaction is the most significant source of exergy destruction in a boiler system which can be reduced by preheating the combustion air and reducing the air–fuel ratio.**

***Keywords*—**Energy Analysis, Exergy Analysis, Ambient Temperature and Thermal Power Plant

I. INTRODUCTION

The general energy supply and environmental situation requires an improved utilization of energy sources. Therefore, the complexity of power-generating units has increased considerably. Plant owners are increasingly demanding a strictly guaranteed performance. This requires thermodynamic calculations of high accuracy. As a result, the expenditure for thermodynamic calculation during design and optimization has grown tremendously [1]. The most commonly-used method for evaluating the efficiency of an energy-conversion process is the first-law analysis. However, there is increasing interest in the combined utilization of the first and second laws of thermodynamics, using such concepts as exergy (availability, available energy), entropy generation and irreversibility (exergy destruction) in order to evaluate the efficiency with which the available energy is consumed. Exegetic analysis allows thermodynamic evaluation of energy conservation, because it provides the tool for a clear distinction between energy losses to the environment and internal irreversibilities in the process.

A thermal power plant is a good example of the utilization of exergy analysis. According to energy (first-law) analysis, energy losses associated with the condenser are carried into the environment by the cooling water and are significant because they represent about half of the energy input to the plant. An exergy (second-law) analysis, however, shows that virtually none of the exergy (resource which went into the power plant) is lost in that water. The real loss is primarily back in the boiler where entropy was produced. Thus, it is not reasonable to attempt to take advantage of the energy lost in the condenser [2]. Recently, exergy analysis has become a key aspect in providing a better understanding of the process, to quantify sources of inefficiency, to distinguish quality of energy (or heat) used [3–13]. Exergy is defined as the maximum theoretical useful work (or maximum reversible work) obtained as a system interacts with an equilibrium state. Exergy is generally not conserved as energy but destructed in the system. Exergy destruction is the measure of irreversibility that is 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 a thermal system [14].

Boiler efficiency therefore has a great influence on heating- related energy savings. It is therefore important to maximize the heat transfer to the water and minimize the heat losses in the boiler. Heat can be lost from boilers by a variety of methods, including hot flue gas losses, radiation losses and, in the case of steam boilers, blow-down losses [15] etc. To optimize the operation of a boiler plant, it is necessary to identify where energy wastage is likely to occur. A significant amount of energy is lost through flue gases as all the heat produced by the burning fuel cannot be transferred to water or steam in the boiler. As the temperature of the flue gas leaving a boiler typically ranges from 150 to 250 1C, about10–30%of the heat energy is lost through it. A typical heat balance in a boiler is shown in Fig. 1. Since most of the heat losses from the boiler appear as heat in the flue gas, the recovery of this heat can result in substantial energy saving [16].This indicates that there is huge savings potentials of a boiler energy savings by minimizing its losses. Having been around for centuries, the technology involved in a boiler can be seen as having reached a plateau, with even marginal increase in efficiency painstakingly hard to achieve [17] In this study, several measures to improve efficiency, primarily developed based on exergy analysis, are considered in this paper. The modifications considered here, which increase efficiency by reducing the irreversibility rate in the steam generator, are decreasing the fraction of excess combustion air and/or decreasing the stack-gas temperature. The impact of implementing these measures on efficiencies and losses is investigated. This work aims to identify and assess methods for increasing efficiencies of steam power plants, to provide options for improving their economic and environmental performance

II. EXERGY ANALYSIS

The process flow diagram for the boiler and power plant is shown in Figure. 1. The process parameters for the power plant is shown in Table 1 and 2. The following thermodynamic analysis of the power plant will consider the balances of mass, energy, entropy and exergy. Unless otherwise specified, the changes in kinetic and potential energies will be neglected and steady state flow will be assumed. For a steady state process, the mass balance for a control volume system in Fig. 1 can be written as:

$$\sum_i \dot{m}_\iota = \sum_i \dot{m}_e \quad (1)$$

The energy balance for a control volume system is written as

$$\sum_i \dot{E}_\iota + \dot{Q} = \sum_{out} \dot{E_{out}} + \dot{W} \quad (2)$$

The entropy balance for a control volume system is

$$\sum_i \dot{S} + \sum_i \frac{\dot{Q}}{T} + \dot{S_{gen}} = \sum_{out} \dot{S} + \sum_{out} \frac{\dot{Q}}{T} \quad (3)$$

The exergy balance for a control volume system is written as

$$\sum_i \dot{E_{x,\iota}} + \sum_k \left(1 - \frac{T}{T_k}\right) \dot{Q}_k + \dot{Q} = \sum_{out} \dot{E_{x,out}} + \dot{W} + \dot{E_{x,d}} \quad (4)$$

Where the exergy rate of a stream is

$$E_{x,i} = \dot{m}\, e_x \quad (5)$$

(6)

The above exergy balance is written in a general form. For the combustion process, the heat input will be included when calculating the chemical exergy of gas. The heat exergy term in Eq. (4) will be used to calculate the exergy loss associated with heat loss to the surroundings. The specific exergy is given by

$$e_x^{tm} = (h - h_0) - T_0(S - S_0) \quad (7)$$

III. MODELING AND SIMULATION POWER PLANT

Fuel of boiler is natural gas including CH_4 ،C_2H_6 ،C_3H_6 ، C_4H_{10} ،$ISO\text{-}C_4H_{10}$ ،$n\text{-}C_4H_{10}$ ،$ISO\text{-}C_5H$, $n\text{-}C_5H_{12}$ ،CO_2, N_2. The energy and exergy analysis of the cycle has been made using the 'EES' software. The combustion process is assumed to be complete as follows [18]:

$$\sum_{i=1}^{l} \left[f_i C_{n_i} H_{m_i} + \alpha f_i \left(n_i + \frac{m_i}{4}\right) O_2 + 3.76 \alpha f_i \left(n_i + \frac{m_i}{4}\right) N_2 \right] + c\, CO_2 + dN_2 + n_{v,a} + H_2O \rightarrow \sum (f_i n_i + c)\, CO_2 + \sum \left(\frac{m_i f_i}{2} + n_{v,a}\right) H_2O + (\alpha - 1)\left[\sum f_i \left(n_i + \frac{m_i}{4}\right)\right] O_2 + \left[\sum 3.76 \alpha f_i \left(n_i + \frac{m_i}{4}\right) + d\right] N_2 \quad (8)$$

Where α is the percentage of the excess air, f_i is the molar fraction of the fuel components parts and $n_{v,a}$ is the number of moles of the humidity entering the combustion chamber with dry air. The unknown coefficients can be calculated by a molar balance and then the energy and exergy balance of the combustion gases can be performed. For different components of the cycle, the exergy destruction and the exergy efficiency can be obtained by applying exergy balance as follows:

$$\dot{E}_{x,b}^{d} = \dot{m}_f e_{x,f}^{ch} + \dot{W}_{in,b} + \dot{m}_a e_{x,a} - \dot{m}_g e_{x,g} + \sum_{in} \dot{m}_w e_{x,w} - \sum_{out} \dot{m}_w e_{x,w} \quad (9)$$

$$\eta_{II,b} = \frac{\sum_{out,b} \dot{m}_w e_{x,w} - \sum_{in,b} \dot{m}_w e_{x,w}}{\dot{m}_f e_{x,f}^{ch} + \dot{m}_a e_{x,a} + \dot{w}_{in,b}} \quad (10)$$

$$\eta_{I,b} = \frac{\sum_{out,b} \dot{m}_w h_w - \sum_{in,b} \dot{m}_w h_w}{\dot{m}_f LHV + \dot{m}_a h_a + \dot{w}_{in,b}} \quad (11)$$

The energy balance equation for calculating adiabatic flame temperature is

$$\sum N_r \left(\bar{h}_f^0 + \bar{h} - \bar{h}^0\right)_r = \sum N_p \left(\bar{h}_f^0 + \bar{h} - \bar{h}^0\right)_p \quad (12)$$

The destroyed exergy due to combustion process and heat transfer can be expressed as:

$$\dot{E}_{x,d,c} = \dot{m}_f e_{x,f}^{ch} + \dot{m}_a e_{x,a} - \dot{m}_p e_{x,p,adiabatic} \quad (13)$$

$$\dot{E}_{x,d,ht} = \dot{E}_{x,d,b} - \dot{E}_{x,d,c} \quad (14)$$

The second law efficiency of combustion process, heat transfer process of boiler and power plant can be expressed as:

$$\eta_{II,c} = \frac{\dot{m}_p e_{x,p,adiabatic}}{\dot{m}_f e_{x,f}^{ch} + \dot{m}_a e_{x,a}} \quad (15)$$

η (16)

=

η (17)

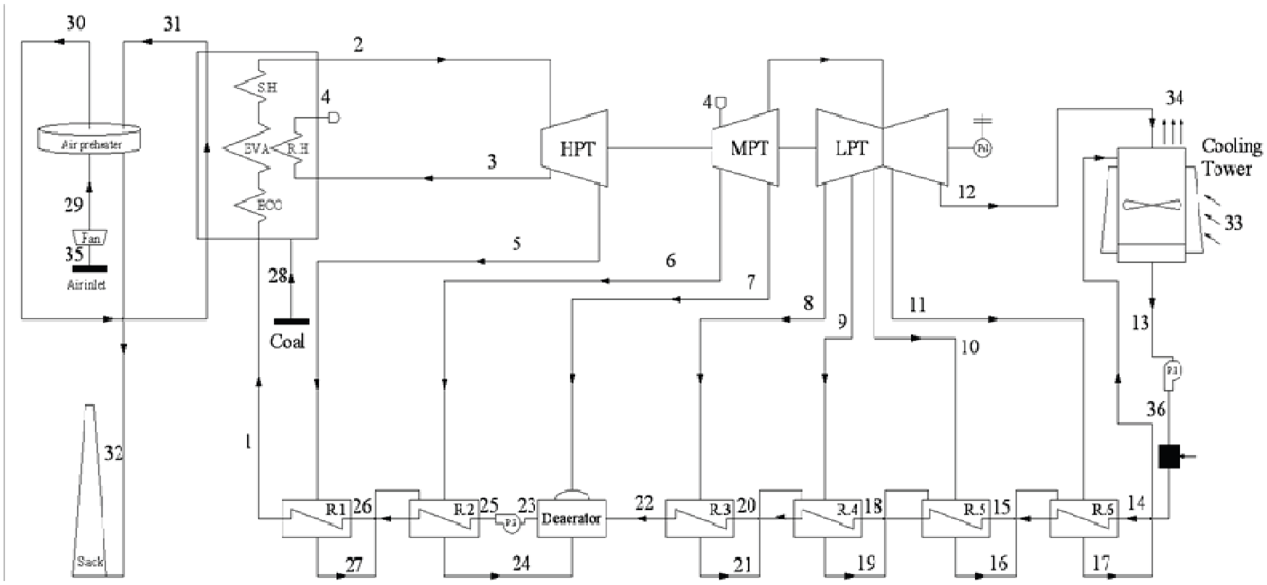

Fig. 1. Schematic diagram of power plant cycle

IV. RESULTS AND DISCUSSION

The power plant was analyzed using the above relations noting that the environment reference temperature and pressure are 298.15 K and 101.3 kPa, respectively. The reference environment state is irrelevant for calculating a change in a thermodynamic property (first law analysis). However, it is expected that the dead state will have some effects on the results of exergy (second law) analysis. Although, some researchers assumed that small and reasonable changes in dead-state properties have little effect on the performance of a given system. To find out how significant this effect will be on the results, the dead-state temperature was changed from 283.15 to 318.15 K while keeping the pressure at 101.3 kPa. Values of total exergy rates at different dead states for locations identified in Fig. 1.

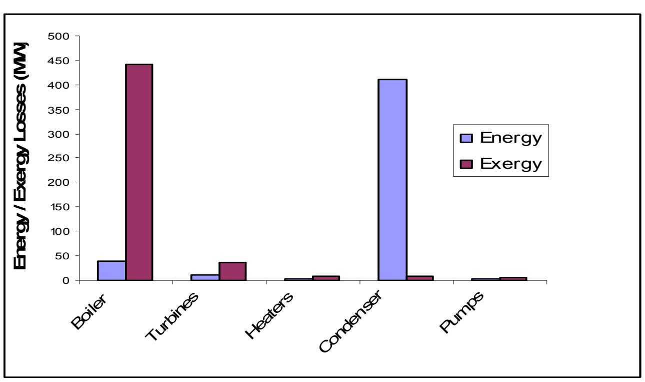

Fig. 2. Irreversibility vs heat loss in power plant component

Results of such analysis show, in Fig. 2 and 3, that the major source of exergy destruction is the boiler no matter what the dead state is. Fig. 4 shows that exergy efficiencies of the boiler and turbine did not change significantly with dead-state temperature; however, the efficiency of the condenser at 318.15 K is almost twice as much when the ambient temperature was 283.15 K. This can be explained by noting the diminution of temperature difference between the steam and the cooling air as the dead-state temperature is increased. This will decrease the exergy destruction and hence, will increase the exergy efficiency.

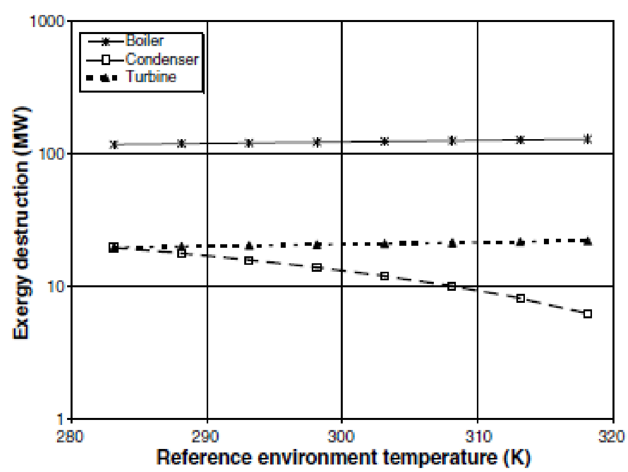

Fig. 3. Effect of reference environment temperature on total exergy destruction rate in major plant components.

V. CONCLUSIONS

In this study, an energy and exergy analysis as well as the effect of varying the reference environment temperature on the exergy analysis of an actual power plant has been presented. In the considered power cycle, the maximum energy loss was found in the condenser. Next to it was the energy loss in the boiler system. In addition, the calculated thermal efficiency of the cycle was 33%. On the other hand, the exergy analysis of the plant showed that lost energy in the condenser is

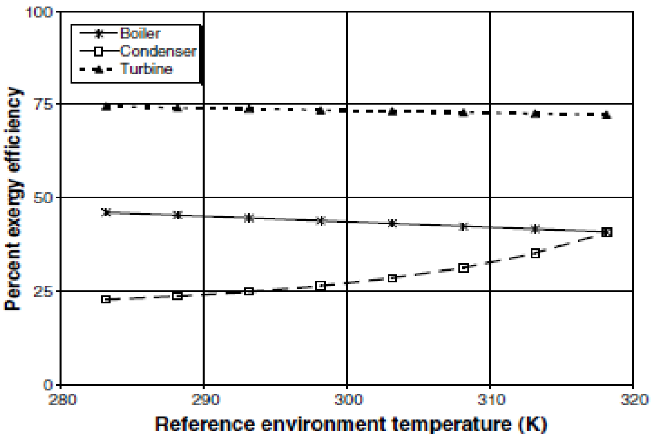

Fig. 4. Effect of reference environment temperature on the exergy efficiency of major plant components

boiler system where 65% of the fuel exergy input to the cycle thermodynamically insignificant due to its low quality. In terms of exergy destruction, the major loss was found in the was destroyed. The major source of exergy destruction was the boiler system where chemical reaction is the most significant source of exergy destruction in a combustion chamber. Exergy destruction in the combustion chamber is mainly affected by the excess air fraction and the temperature of the air at the inlet. The inefficiencies of combustion can be reduced by preheating the combustion air and reducing the air–fuel ratio. Although the percent exergy destruction and the exergy efficiency of each component in the system changed with reference environment temperature, the main conclusion stayed the same; the boiler is the major source of irreversibilities in the system.

Nomenclature

e_x	Specific flow exergy
$\dot{E}$	exergy (kW)
h	Specific enthalpy (kJ/kg)
$\dot{I}$	Irreversibility rate (kW)
LHV	Low heat value (kJ/kg)
$\dot{m}$	Mass flow rate (kg/s)
N	Number of moles
P	Pressure (MPa)
$\dot{Q}$	Heat rate (kW)
R	Gas universal constant
S	Specific entropy (kJ/kg K)
T	Temperature (ºC)
T_o	Ambient temperature (ºC)
$\dot{W}_t$	Turbine net output work
Greek	
Φ	Relative Humidity
$_{th}\eta$	Thermal Efficiency
$_{II}\eta$	Exergy Efficiency
Subscripts	
a	Air
b	Boiler
c	combustion
d	Destroyed
f	Fuel
fwp	Feed Water Pump
g	Product gas
he	Heater
ht	Heat exchanger
ipc	Medium-Pressure Turbine
in	Inlet
NG	Natural Gas
out	Outlet
pp	Power Plant

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