Exergy Losses Calculation for a 125 MW Combined Power Plant

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Abstract

Theoretical exergy analysis is carried out for different components of a combined power plant which consists of a gas turbine unit, waste heat recovery boiler without extra fuel consumption and steam turbine unit. The results pinpoint that more exergy losses occurred in the gas turbine combustion chamber. Its reached 33% of the consumed fuel exergy while the exergy losses in other plant components are between 1% - 5% of the consumed fuel exergy .This paper also considered the effect of the pressure ratio, maximum temperature, boiler pressure and ambient temperature on the exergy losses in the plant, there are a clear effects in the exergy losses when changing pressure ratio, maximum temperature and boiler pressure.

Keywords: Exergy losses; combined power plant

حسابات خسائر الاكسيرجي لمحطة مشتركة

الخلاصة

يتضمن البحث حساب خسائر الاكسيرجي في مختلف مكونات محطة التوليد المشتركة التي تتكون من وحدة التوربين الغازي ومرجل استعادة الحرارة بدون حرق وقود أضافي ووحدة التوربين البخاري .نتائج البحث أظهرت أن معظم خسائر الاكسيرجي تتركز في غرفة الاحتراق حيث وصلت إلى 33%من اكسيرجي الوقود المستهلك أما بقية مكونات المحطة فان خسائر الاكسيرجي فيها تتراوح بين 1%-5% من اكسيرجي الوقود المستهلك. تضمن البحث أيضا بيان تأثير نسبة الضغط ودرجة الحرارة القصوى وضغط المرجل ودرجة حرارة المحيط على خسائر الاكسيرجي في مختلف مكونات المحطة .لقد كان هناك تأثيرا"واضحا" على خسائر الاكسيرجي عندما تتغير هذه البرامترات.

1-Introduction

Energy conservation concept (or first law of thermodynamics) do not give the detailed analysis of the losses in the power plant components like feed water heater, condenser,….ect., it's necessary to pinpointed the energy losses and it's value, the availability of energy can be measured by the amount of work that can be got from the energy which known as the available energy or exergy, second law analysis or exergy analysis enables one to determine the maximum work that can be expected from energy device or process, this is possible because the second law express the quality of energy[1,2,3,7].

The purpose of this work is to analyze performance of a combined power plant according to the second law of thermodynamics depending on the exergy method.

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2-Exergy analysis

Consider a control volume under steady state between x&y and the surrounding temperature T_o as shown in fig.1.

The exergy flow equation can be written as follows [4,8]:

$$E_x = [W_{cv}]_y^x + E^q + I^{cr} + E_y \quad .....(1)$$

Where:

E_x The inlet exergy (the ability of doing work)

W_{cv} The actual output work

E^q The potential work or thermal exergy which given by:

$$E^q = \int_x^y \{(T - T_o)/T\} dQ \quad ...... (2)$$

I^{cr} the lost work due to the internal irreversibility which is given by:

$$I^{cr} = T_o \Delta S_{cr} \quad ...... (3)$$

ΔS_{cr} The created entropy inside the control volume

E_y The exit exergy

if the heat transfer from the control volume is not used to produce work but it's gone to the surrounding (to generate more entropy) then the E^q become equal to I^q which represent the exergy loss due to the external irreversibility in this case the equation (1) become :

$$E_x = [W_{cv}]_y^x + I^q + I^{cr} + E_y \quad ..... (4)$$

3-The Combined Power Plant

Fig.(2) represents a flow diagram of a 125MW Brown-Bovary plant [5] ,the plant consist of a gas turbine unit, waste heat recovery boiler without extra fuel consumption and steam turbine unit, the description data of this plant is given in table (1) .

The exergy losses due to irreversibility in the plant component can be explained as follows:

A-Compressor

The process in the compressor can be considered as an adiabatic process so I^q=0 and I^{cr} can be calculated from equation (3) as:

$$I^{cr} = m_a T_o (s_2 - s_1) \quad .....(5)$$

Assuming the air as a perfect gas with specific heat at constant pressure of C_{P_a} then[8];

$$I_c^{cr} = m_a T_o \left[C_{P_a} \ln\left(\frac{T_2}{T_1}\right) - R_a \ln\left(\frac{P_2}{P_1}\right) \right] \quad ...(6)$$

B- Gas turbine

The expansion process in the turbine can be considered as an adiabatic process so I^q=0 and I^{cr} can be calculated as in the compressor from equation (3) as:

$$I_t^{cr} = m_g T_o \left[R_g \ln\left(\frac{P_4}{P_3}\right) - C_{P_g} \ln\left(\frac{T_4}{T_3}\right) \right] \quad ...(7)$$

C-Combustion chamber

Depending on references (1,8) the exergy loss in the combustion chamber can be calculated by the following equation[8]:

$$I_{cc}^{cr} = m_f L.C.V \left[\frac{T}{T_{lm}} \right] \quad ..... (8)$$

Where:

T_{lm} is the log mean temperature difference which is calculated from:

$$T_{lm} = \frac{\left(T_3 / T_2 \right)}{\ln\left(T_3 / T_2 \right)} \quad ...... (9)$$

D-Heat recovery steam boiler**:**

The exergy losses are given by [1]:

$$I_{sb}^{cr} = T_o [\Delta S_{st} - \Delta S_g] \quad ...... (10)$$

Where:

ΔS_{st} is given by:

$$\Delta S_{st} = m_{stHP}(s_7 - s_6) + m_{stLP}(s_8 - s_6) \ ...(11)$$

and ΔS_g is calculated from:

$$\Delta S_g = m_g \left[C_{P_g} \ln\left(T_5 / T_4 \right) - R_g \ln\left(P_5 / P_4 \right) \right] ...(12)$$

E-The flue gases

the exergy loss due to heat transfer to the surrounding is given by[1]:

$$I_{fg}^{q} = \int_{5}^{0}\left[\frac{T - T_o}{T}\right]dQ \qquad \text{........ (13)}$$

$$I_{fg}^{q} = m_g C_{p_g}\left[(T_5 - T_o) - \ln\left(T_5 / T_o\right)\right] \quad \text{...(14))}$$

F-The steam turbine

The exergy loss in the steam turbine with one stage regenerative can be formulated as:

$$I_{st}^{cr} = T_o\begin{bmatrix} m_7(s_8 - s_7) + (m_7 + m_8)(s_9 - s_8) \\ +(m_7 + m_8 + m_9)(s_{10} - s_9) \end{bmatrix} \quad \text{..(15)}$$

G-The feed water heater

Assume adiabatic mixing process then $I^{q} = 0$ and the exergy loss is given by:

$$I_{fh}^{cr} = T_o\left[m_{13}s_{13} - m_{12}s_{12} - m_9 s_9\right] \quad \text{.. (16)}$$

H-The condenser

Assume that the heat transfer from steam at a temperature of T_{con} to the cooling water at T_o then the exergy loss due to heat transfer to the surrounding is given by:

$$I_{con}^{q} = Q_{con}\left[(T_{con} - T_o) / T_{con}\right] \quad \text{..... (17)}$$

Where:

$$Q_{con} = m_{10}(h_{10} - h_{11}) \quad \text{......(18)}$$

4-Results and discussion

The exergy losses in the plant component consist of firstly the lost work due to the internal irreversibility in compressor ,gas turbine ,combustion chamber, steam boiler and steam turbine, secondly the lost work due to the external irreversibility as a result of external heat transfer in condenser and flue gases ,by using equations 5-18 the exergy losses for each plant components can be calculate; this is shown in the figure (3) .The most exergy losses occurs in the combustion chamber which represent 33% of the inlet fuel exergy while the remainder exergy losses due to the internal irreversibility is 17% .The external exergy losses due to the external irreversibility is about 2% of the inlet fuel exergy.

The internal irreversibility occurred due to viscosity, heat transfer through temperature gradient ,vortex and combustion, the last one is the main source of the internal irreversibility(6).

Figure (4) shows the energy analysis according to the first law of thermodynamics; we can note that the most energy losses occur in the condenser about 39% of the input energy and about 14% in the flue gases.

The effects of various parameters are considered as follows:-

A- Pressure ratio

As the maximum temperature is kept constant, the effect of the pressure ratio on the exergy losses in different plant components is shown in figure (5) from this figure we can note that the exergy losses in the combustion chamber decrease as pressure ratio increase, this is because of the inlet temperature to the combustion chamber (T_2) becomes closer to the maximum temperature ,the exergy losses in the steam boiler and in the flue gases also decrease due to the decreasing of the inlet and exit boiler temperature. Figure (5) also shows that exergy loss in the compressor and turbine are increasing as pressure ratio increased.

B-Maximum temperature

The effect of the maximum temperature is shown in the figure (6) , at the design pressure ratio of 10:1 the exergy losses is increased in the combustion chamber because of increasing in the fuel consumed and then irreversibility increasing due to chemical action . The exergy losses increase in the steam boiler and flue gases due to increasing of the inlet and exit boiler temperature. The gas turbine exergy losses remain constant because when the maximum temperature increases the flue gas temperature also increases at the turbine exit.

C-Boiler pressure

The changing in the exergy losses in the heat recovery steam boiler is shown in the figure (7), we can note that the exergy losses decrease with increasing in the boiler pressure this is because of entropy decreasing of the steam generated, while the losses dose not changing in each steam turbine, feed water heater and condenser.

D-ambient temperature

Because exergy analysis involves the calculation of irreversibility, the ambient temperature (T_o) is fully taken in account by this analysis (see equations 5-18), figure (8) shows this effect on the total exergy losses for different plant component.

Conclusions

A-The exergy analysis gives a real picture about the losses which occurred in different plant components.

B- More exergy losses occur in the combustion chamber due to combustion irreversibility and this must be reduced with the aid of advanced in new technology as combustion process is necessary.

C- There are clear effects in the exergy losses when changing pressure ratio, maximum temperature and boiler pressure.

D- Leads to best understanding of losses by knowing the ambient temperature only.

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Table (1) the description data of the 125 MW combined power plant

Pt.	Mass (kg/s)	Pressure (bar)	Temperature (^oC)	Enthalpy (kJ/kg)	Entropy (kJ/kg K)
1	350	1.01	15	-	-
2	350	10.1	330	-	-
3	363	9.5	900	-	-
4	363	1.5	491	-	-
5	363	1.1	105	-	-
6	43.2	4.4	145	620	1.81
7	43.2	33.2	433	3300	7.02
8	7.9	4.4	210	2880	7.18
9	2.5	0.163	55	2490	7.24
10	48.6	0.07	40	2300	7.38
11	48.6	0.07	26	120	0.381
12	48.6	0.163	28	127.6	0.409
13	51.1	0.163	56	233	0.78

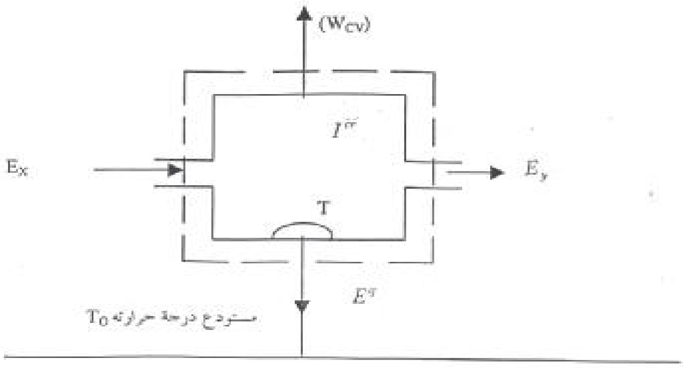

Fig. (1) Control volume

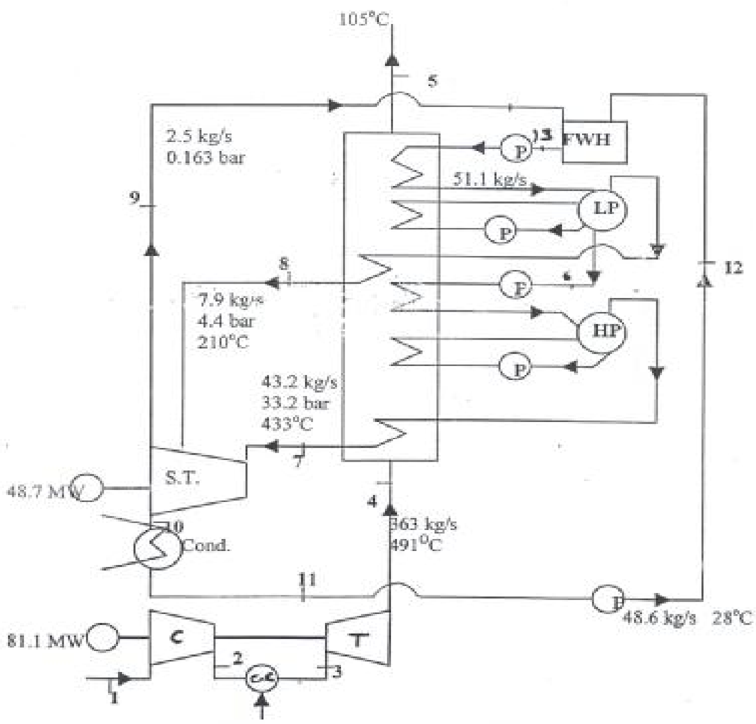

Fig. (2) The flow diagram of the combined plant

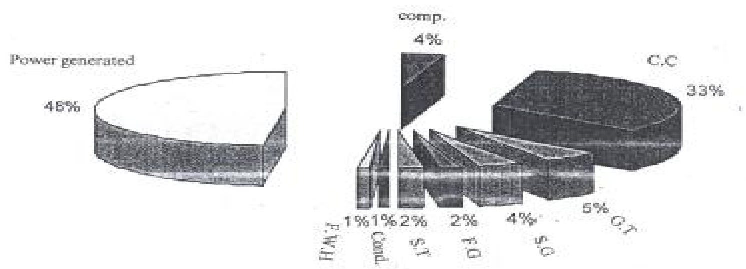

Fig. (3) Exergy analysis of the combined plant

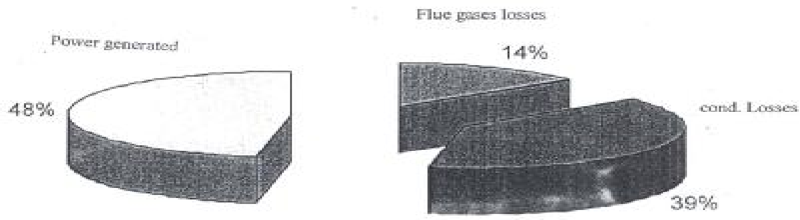

Fig. (4) Energy analysis of the combined plant

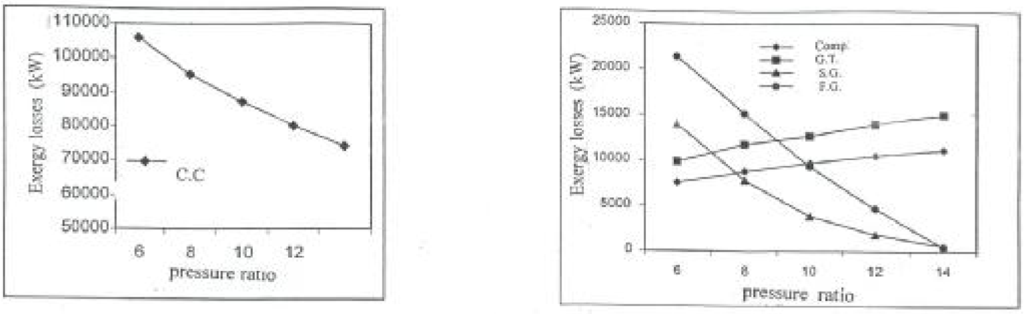

Fig. (5) Effect of pressure ratio on the exergy losses

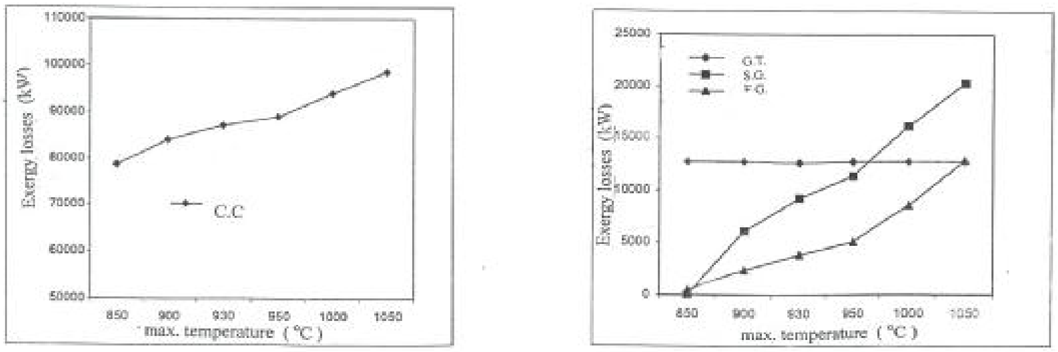

Fig. (6) Effect of maximum temperature on the exergy losses

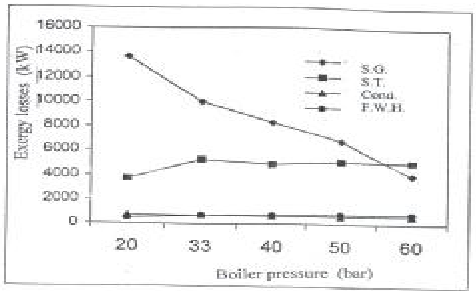

Fig. (7) Effect of boiler pressure on the exergy losses

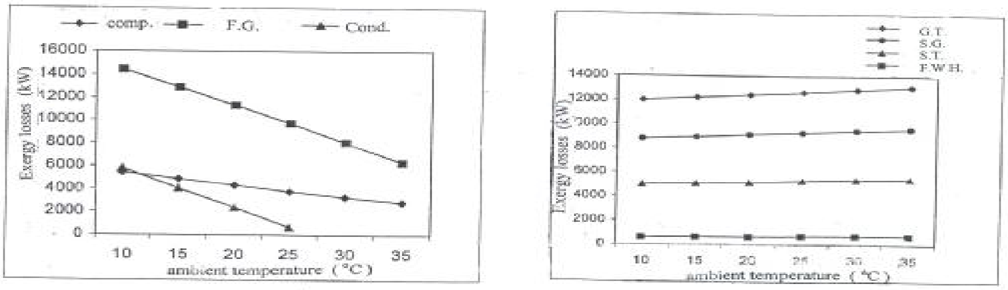

Fig (8) Variation of exergy losses with ambient temperature