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EXERGY ANALYSIS FOR THE CONDENSER OF A STEAM POWER STATION

Rafea M. Abd El-Maksoud[a], Ahmed T.M. Kotb[a], Mohamed A. Mahmoud[a*], Mahmoud H.Mahmoud [a], Mahmoud R.Abd El-Badei[a], Peter S. Helmy[a], Mostafa S.Gaber [a], Peter E. Sadek [a*], Mina S. Tawfik[a], Abram W. Messiha [a], Hassan Y. Abd Elhamed[a] .

[a] Mechanical Power Engineering Department, Faculty of Engineering - Materia, Helwan University, P.O. 11718, Cairo, Egypt

[a*] Corresponding author E-mail: mohamed.abdo1999.6.6@gmail.com

ABSTRACT:

Steam power station is affected significantly by the performance of the condenser since the condenser determines the back pressure of the station. Accordingly, this paper introduces exergy analyses for the condenser performance. The present work aims to demonstrate the effect of condenser parameters on its exergy and exergy destruction. These parameters are the mass flow rate of cooling water, exit temperature of cooling water, the inlet temperature of steam, and the overall heat transfer coefficient for the condenser. The results of this study illustrate that the second law efficiency is increased, and exergy destruction is reduced with the increase of mass flow rate of cooling water, the reduction of ambient temperature, reduction of inlet steam temperature, and increasing of overall heat transfer coefficient.

1. INTRODUCTION:

Exergy analysis is one of the methods used to evaluate thermal systems. This analysis is utilized to determine available energy, second law efficiency, and exergy destruction. Utilizing this analysis of the condenser is important as it gives a clear vision of the efficiency

Nomenclature

c_p	Specific heat at constant pressure	X	Exergy
h_e	Specific enthalpy out	$\dot{X}_{heat}$	Exergy rate due to heat transfer
h_i	Specific enthalpy in	$\dot{X}_e$	Exergy rate out
$\dot{m}$	Mass flow rate	$\dot{X}_i$	Exergy rate in
$\dot{Q}$	Quantity of heat	$\dot{X}_{destroyed}$	Exergy Destruction
R	Ideal gas constant	**Greek symbol**	
s	Entropy	ψ	Specific exergy
$S_{generation}$	Entropy generation	η_{II}	Second law efficiency
T_0	Dead state temperature	**Abbreviations**	
T_b	Boundary temperature	EES	Engineering Equation Solver

of the condenser. This study concerns improving the performance from the point of view of energy and exergy point of view.

The independent variables are ambient temperature and condenser pressure. It was seen that the increase in Second law efficiency of the plant depends on the combined effect of ambient temperature and condenser pressure as the sole variation of ambient temperature does not have much effect on the performance parameters (Jamali, 2021). Exergy analysis is particularly recommended because it measures process irreversibility (Kowalczyk, 2015). The pressure of the condenser is the most important evaluation index (Zhao, 2013).

Ahmadi, (2016) introduced investigating the steam cycle of Shahid Montazeri Power Plant of Isfahan with an individual power station capacity of 200 MW. The energy analysis shows that 69.8% of the total lost energy in the cycle occurs in the condenser as the main equipment wasting energy, while exergy analysis introduces the boiler as the main equipment wasting exergy where 85.66% of the total exergy entering the cycle is lost.

The exergy balance equations for a system, according to (Dobkiewicz, 2020; Ahmadi, 2016) is very important for completing the analysis of the condenser, how it operates under different conditions, and how to evaluate its performance.

The condenser is important because of its influence on the steam power plant and back pressure. Therefore, this paper deals with the study of the effect of mass flow rate of cooling water, ambient temperature, exit temperature of cooling water, inlet temperature of cooling water, pressure of steam, inlet temperature of steam, and overall heat transfer coefficient on the condenser performance.

2. ENERGY & EXERGY METHODOLOGY:

The following thermodynamic analysis of the condenser considers the balances of mass, energy, entropy, and exergy. The exergy balance equation for a system, according to (Dobkiewicz, 2020; Ahmadi, 2016). 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 the energy effectiveness of the condenser is written as:

$$\varepsilon = \frac{(T_{c,o} - T_{c,i})}{(T_{h,i} - Tc_{,}i)} \qquad \mathbf{1}$$

$T_{c,o}$, $T_{c,i}$ is temperature of outlet and inlet cooling water and $T_{h,i}$ is temperature of inlet steam. For an adiabatic heat exchanger with two unmixed fluids (figure (1)), the exergy expended is the decrease in the exergy of the steam, and the exergy recovered is the increase in the exergy of the cooling water, provided that the cooling water is not at a lower temperature than the surroundings. So that the second-law efficiency of the heat exchanger becomes:

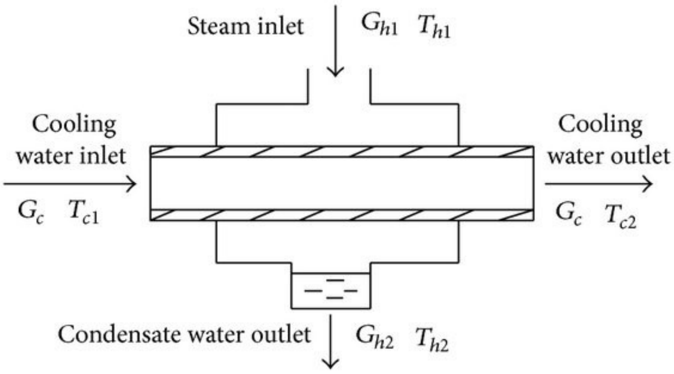

Figure 1:schematic diagram of condenser

$$\eta_{\|} HE = \frac{(Exergy\ recoverd)}{(Exergy\ expended)} = \frac{\dot{m}_{cold\ (\psi_4-\psi_3)}}{\dot{m}_{hot\ (\psi_1-\psi_2)}} = 1 - \frac{T_0\, S_{gen}}{\dot{m}_{hot\ (\psi_1-\psi_2)}} \quad 2$$

$$Where\ S_{gen} = \dot{m}_{hot\ (S_2-S_1)} + \dot{m}_{cold\ (S_4-S_3)}$$

Where the subscripts 1 and 2 represent inlet and exit states, $\dot{m}$ is the mass flow rate.

The change in the exergy flow rate is given by

$$\psi_1 - \psi_2 = (h_1 - h_2) - T_0(S_1 - S_2) \quad 3$$

The relationship between river-water temperature (T_{river}) and ambient air dry-bulb temperature (T_a) throughout the year

$$T_{river} = 1.0349 T_a - 2.0888 \quad 4$$

3. RESULT AND DISCUSSION:

This section is Based upon the methodology developed and the thermodynamic equations shown, the operating performance of the condenser Has been discussed in this section. Accordingly, four subsections are Presented as follows: effect of mass flow rate of the cooling water, effect of temperature of exit cooling water, effect of temperature of inlet cooling water, effect of inlet temperature of the steam, and effect of overall heat transfer coefficient. The following figures show the change the performance of the condenser.

3.1.Effect of mass flow rate of the cooling water:

The mass flow rate of the cooling water affects the exergy flow rate, which affects exergy destruction, and both affect second law efficiency. Mass flow rate is proportional to second law efficiency. The rising mass flow rate of cooling water increases second law efficiency. Raising the steam pressure leads to a decrease in second law efficiency. The results in this operation range stated that the mass flow rate of cooling water = 265 kg /s and steam pressure = 0.037 bar give a value of second law efficiency = 62.3 %.

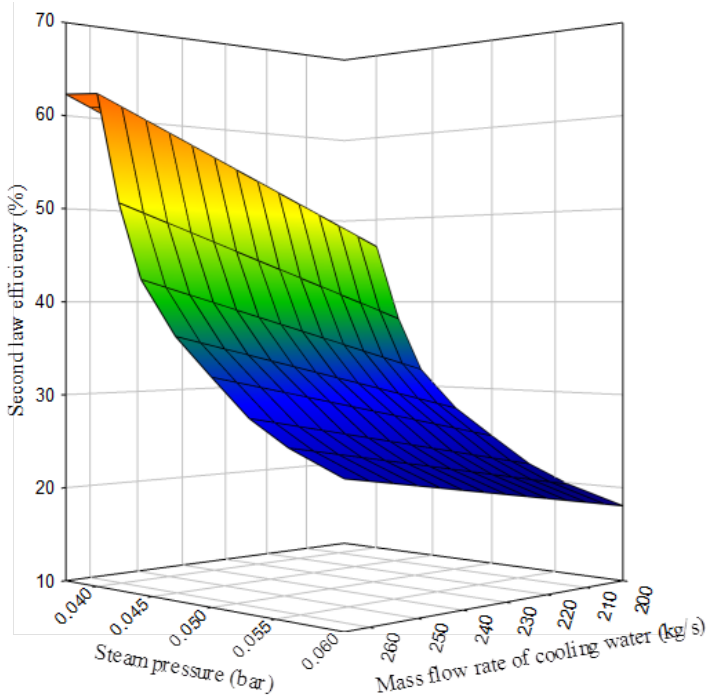

Figure 2: Effect of mass flow rate and pressure on second law efficiency

Figure (3) describes the 3D relationship between two factors (steam pressure and cold-water mass flow) and how they affect each other on exergy destruction. In the accompanying graph, the pressure ranges from 1 bar to 5 bar, and mass flow rates range from 200 kg/s to 265 kg/s. The findings indicate that a steam pressure of 0.037 bar and a mass flow rate of cooling water of 265 kg/s give a minimum value of energy destruction of 1875 kW.

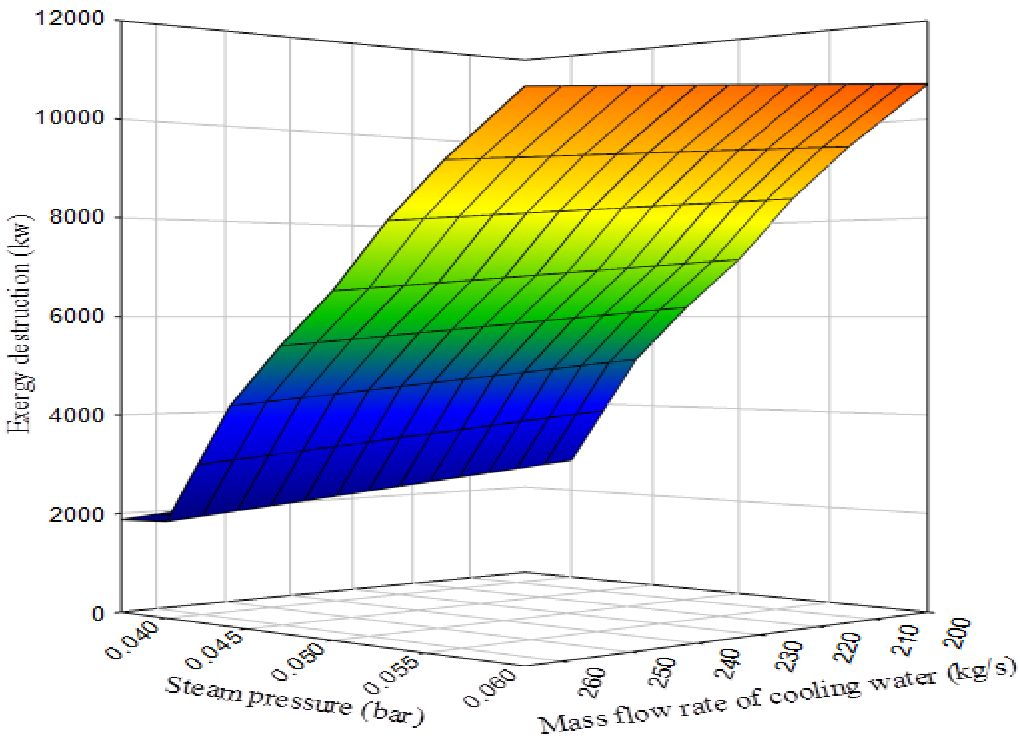

Figure 3: mass flow rate vs pressure and exergy destruction

3.2.Effect of temperature of exit cooling water:

Exergy of the cooling-water flow rate, exergy destruction, the efficiency of the condenser, and the second law of efficiency are all impacted by the exit cooling water temperature.

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Figure (4) illustrates the effect of steam pressure and temperature of exit cooling water on exergy destruction by increasing the pressure and decreasing the temperature of exit cooling water, that effect exergy destruction by increasing. The cold-water exit temperature ranges from 340 K to 344 K, and the pressure ranges from 0.037 bar to 0.06 bar in the following figure. The steam pressure of 1 bar and the cooling water's exit temperature of 344 ◦k produce a minimum amount of energy destruction of 3814 kW.

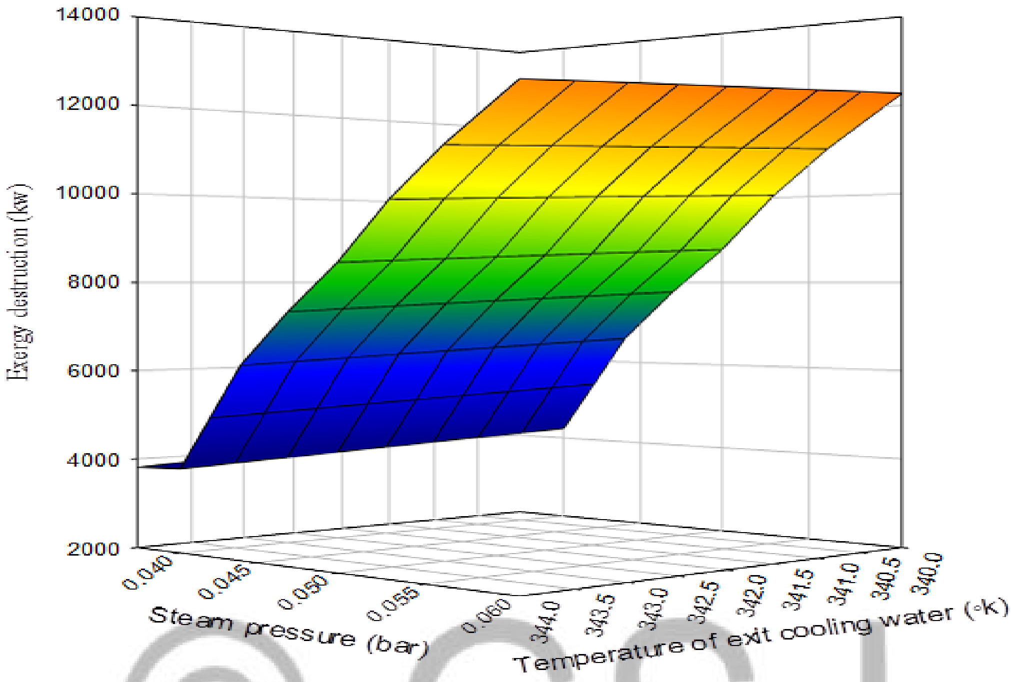

Figure 4: temperature of exit cooling water vs pressure and exergy destruction

Exit temperature of the cooling water affects the enthalpy and entropy, which both affect the exergy flow rate and second law efficiency.

When the exit temperature of the cold-water increases, the exergy cooling water flow rate increases, and the increased exergy cooling water flow rate affects the exergy destruction by decreasing and increasing the second law efficiency. Figure (5) represents the effect steam pressure and exit temperature of cooling water) on second law efficiency.

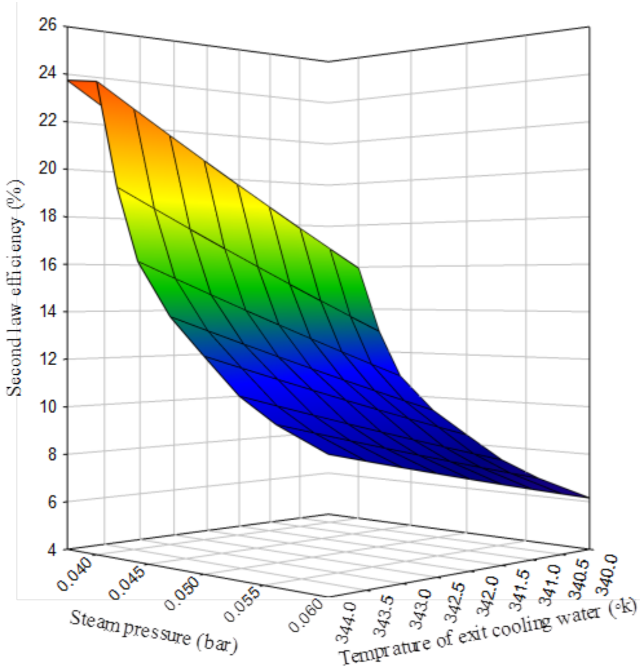

Figure 5: temperature of exit cooling water vs pressure and second law efficiency

3.3.Effect of temperature of inlet cooling water:

The temperature of inlet cooling water has multi-effects exergy of cooling water flow rate, exergy destruction, the effectiveness of condenser, and the second law of efficiency. Figure (6) shows that decreasing the inlet water temperatures to the condenser leads to an increase in the available energy in a sufficient way, so it is recommended to use a cooling water system to have sufficiently high exergy destruction at all inlet temperatures, even though it is of an additional cost. However, it is of increasing demand and efficiency for the system.

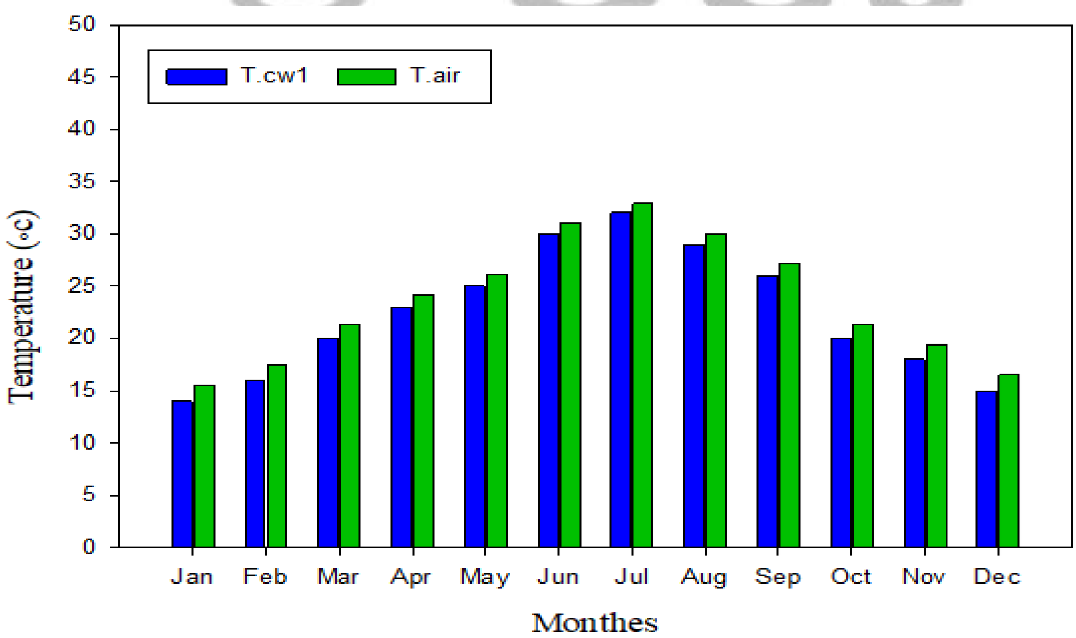

Figure 6: The relationship between river-water temperature (Triver) and ambient air dry-bulb temperature (Ta) throughout the year

The table 1 summarizes the change in temperature of inlet cooling water and it is impact on second law efficiency, effectiveness, and exergy distraction. The highest second law efficiency = 39% occurring at the lowest temperature of inlet cooling water = 14 ◦c at january.

Table 1 : effect the temperature of inlet cooling water on second law efficiency, effectiveness, and exergy destruction

Months	$Tc_{,}i$ (◦c)	ε	$\eta_{\|}HE$	$Xdestroyed$ (kw)
Jan	14	80.76	39.05	4257.45
Feb	16	79.16	35.22	4525.41
Mar	20	75.00	27.62	5056.12
Apr	23	70.58	21.99	5449.66
May	25	66.66	18.26	5709.89
Jun	30	50.00	9.05	6353.12
Jul	32	37.50	5.41	6607.51
Aug	29	54.54	10.88	6225.31
Sep	26	64.28	16.41	5839.37
Oct	20	75.00	27.62	5056.12
Nov	18	77.27	31.41	4791.63
Dec	15	80.00	37.13	4391.65

Figure (7) shows that decreasing the inlet cooling water temperatures in the condenser leads to an increase of the available energy in a sufficient way, which is the required operation, but the main challenge here is to limit the exergy destruction, which will be discussed in the following part.

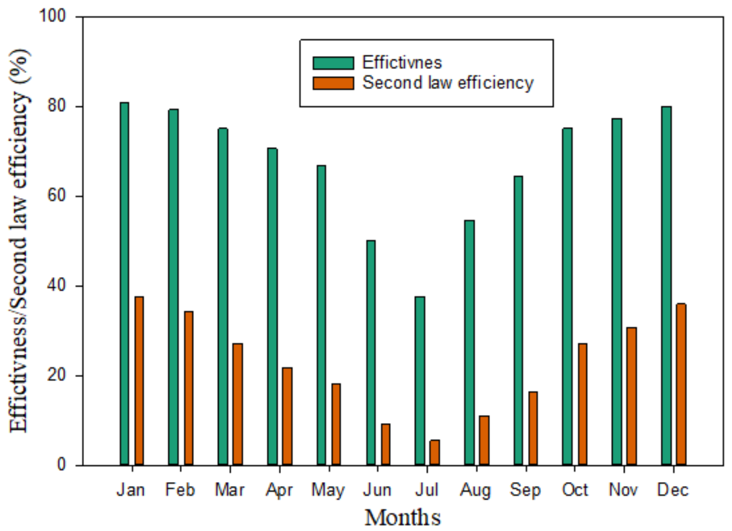

Figure 7 the temperature main parameter affects the exergy destruction and second law efficiency by the change in the temperature of the climate.

The graph (8) illustrates the relationship between temperature of inlet cooling water and exergy destruction which exergy destruction increasing by increasing of inlet cooling water. On the other side, temperature of inlet cooling water decreases the second law efficiency.

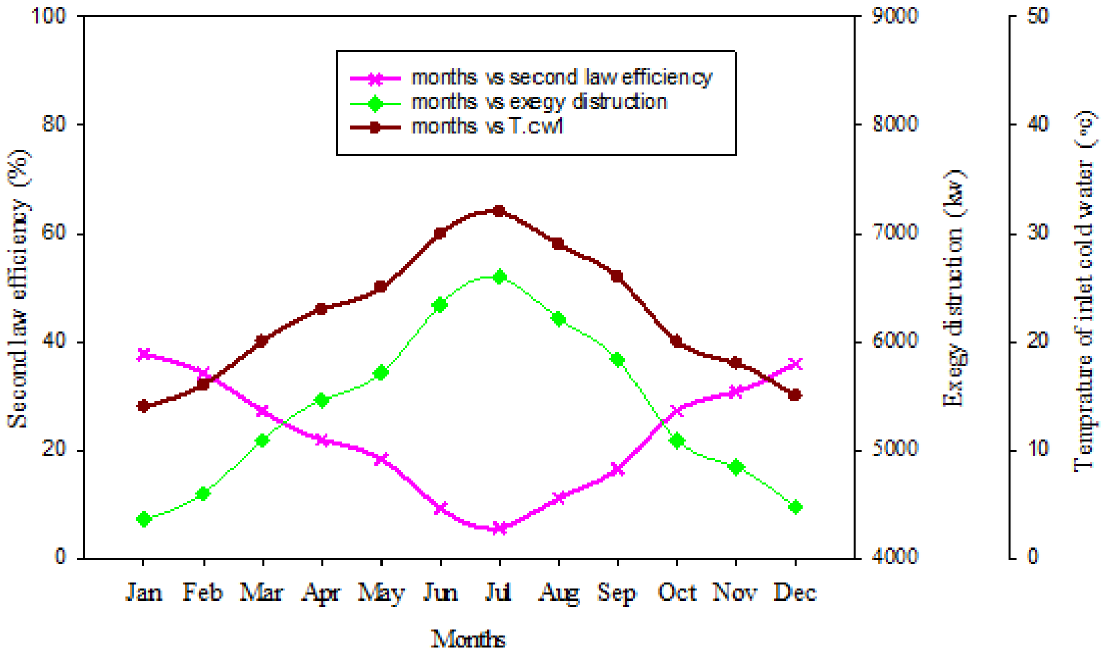

Figure 8: months vs second law efficiency, exergy destruction and temperature of inlet water

3.4.Effect of inlet temperature of the steam:

The steam's temperature has an impact on the enthalpy and entropy, which in turn have an impact on the exergy flow rate and the efficiency of the second law. In Figure (9), when the steam's inlet temperature rises, pressure rises as well, and second law efficiency decreases. Temperature of inlet steam 30 °C has a very significant impact on second law efficiency of 80%.

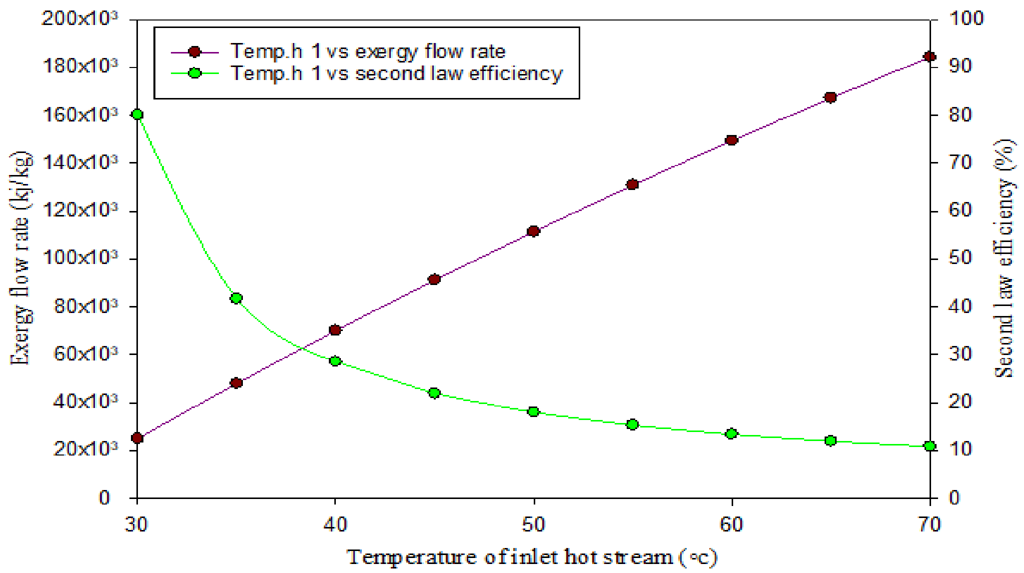

Figure 9: temperature of inlet hot water vs exergy flow rate and second law efficiency

Table 2 shows the variation range of temperature of steam with exergy of inlet steam and second law efficiency. Second law is decreasing with increasing in inlet steam temperature, the exergy of inlet steam is increasing with increasing in temperature of steam. The highest second law efficiency =80.10 % at exergy of inlet steam=24967 kw.

Table 2 : effect of temperature of steam on second law efficiency and exergy of inlet steam

$T_{h,i}$ (°C)	$\dot{m}e_{x,i}$ (kw)	$\eta_{\parallel}HE$
30	24967.68	80.10
35	47973.36	41.68
40	70031.40	28.55
45	91213.32	21.92
50	111417.00	17.95
55	130876.08	15.28
60	149482.08	13.37
65	167295.00	11.95
70	184368.48	10.84

3.5.Effect of overall heat transfer coefficient:

The Overall heat transfer coefficient has effect on exergy destruction and second law efficiency. Figure 10 shows that the overall heat transfer coefficient is inverse proportional with exergy destruction and direct proportional with second law efficiency.

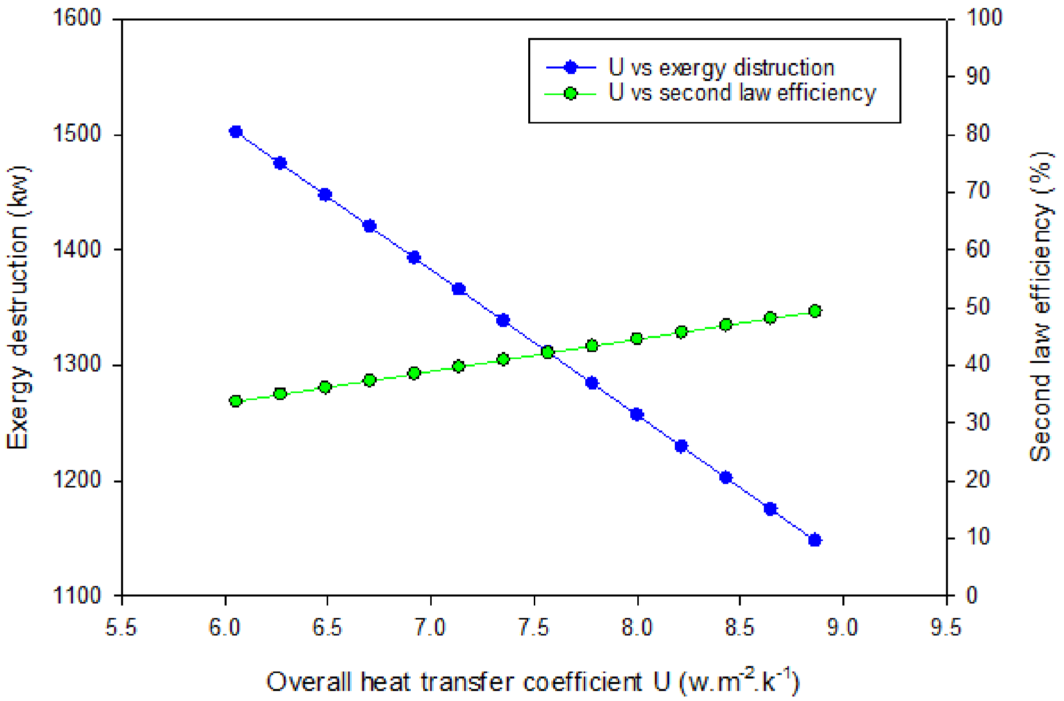

Figure 10: the relation between Overall heat transfer coefficient and exergy destruction and exergy efficiency

Table 3 shows the variation range of overall heat transfer coefficient with exergy destruction and second law efficiency. Second law efficiency is increased with increasing in overall heat transfer coefficient. The maximum second law efficiency = 49.33 % at the overall heat transfer coefficient = 8.86 w.m^{-2}. k^{-1}.

Table 3 : effect of overall heat transfer coefficient on second law efficiency and exergy destruction

U (w.m^{-2}. k^{-1})	$Xdestroyed$ (kw)	$\eta_{\parallel}HE$

6.05	1502.00	33.69
6.27	1474.75	34.89
6.49	1447.50	36.09
6.70	1420.25	37.30
6.92	1393.00	38.50
7.14	1365.75	39.70
7.35	1338.50	40.91
7.57	1311.25	42.11
7.78	1284.00	43.31
8.00	1256.75	44.51
8.22	1229.50	45.72
8.43	1202.25	46.92
8.65	1175.00	48.12
8.86	1147.75	49.33

4. COCLUSION:

The previously discussed results could be summoned in the following points:

- Raising the mass flow rate increases the second law efficiency increases.
- With increasing exit temperature of the cooling water, the exergy of the cooling water flow rate will be raised.
- Increasing the inlet temperature of cooling water till it reaches the maximum in high-temperature months, especially in July, decreases the second low of efficiency and effectiveness and increases exergy destruction.
- When the inlet temperature of the hot stream increases, the pressure also increases, and second law efficiency decrease.
- The system should be operated at the low Inlet temperature of the hot stream to increase system efficiency.
- The highest second law efficiency is achieved at the highest overall heat transfer coefficient

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