مجلة أكاديمية الجبل للعلوم الأساسية والتطبيقية

Al-Jabal Academy Journal of Pure and Applied Sciences

01 (01): 10-18, 2022

pISSN: 2958-857X; eISSN: 2958-8588

Journal Homepage: https://lajak.edu.ly/journals/index.php/aajpas/index

Energy and exergy analysis of Derna steam power plant and the impact of varying the different parameters on exergy destruction

Adel Bojeldain[1]*, Yasser Aldali [2]*, and Moftah Alshaikh [2]

[1]Department of Mechanical Engineering, University of Omar Al-mokhtar, Al Bayda, Libya[2]
[2] Department of Mechanical Engineering, University of Derna, Derna, Libya

DOI: https://doi.org/10.58309/aajpas.v1i1.9

KEYWORDS:
Energy and exergy analysis, exergy destruction, steam power plant

ABSTRACT:

In this study, an energy and exergy analysis of the Derna steam power plant in Libya is presented. This study aims to identify the components with high energy and exergy losses which are leading to a decrease in the performance of the power plant. The largest place losses can be figured out hence to subsequently ensure where the greatest margin for improvement would be incurred. The influence of different parameters, such as temperatures and pressure values, on this analysis, is also conducted via the so-called Engineering Equation Solver software (EES). In terms of energy, the condenser is found to majorly have the highest energy losses of approximately 103MW which is received by the environment whilst the boiler losses are recorded to be about 24MW. As far as exergy is concerned, the boiler system is found to have the highest percentage ratio of exergy destruction to overall exergy destruction of 88 %, followed by the turbine of 8% and then the condenser of 3%. In addition, the thermal efficiency is also calculated based on the lower heating value of fuel and found to be 29% whereas the exergy efficiency of the power cycle is then computed to be 27.19%. The study is further concluded the significant effect of the live steam temperature changes concerning the design value, the high pressure heater (HPH) pressure as well as the condenser pressure on exergy destruction.

تحليل الطاقة والأكسيرجي لمحطة درنة البخارية لتوليد الطاقة وتأثير تغيير البارامترات المختلفة على تدمير الطاقة

عادل بوجلدين[1]، ياسر الدالي[2]، مفتاح الشيخ[2]

[1] قسم الهندسة الميكانيكية، جامعة عمر المختار، البيضاء، ليبيا؛[2] قسم الهندسة الميكانيكية، جامعة درنة، درنة، ليبيا*

الملخص:

أُجريت هذه الدراسة لتحليل الطاقة والإكسيرجي لمحطة درنة البخارية، ليبيا. الهدف الرئيس من المحاولة الحالية هو تحديد معظم خسائر الطاقة والطاقة الخارجية لجميع مكونات الوحدة. تأتي معرفة ذلك من خلال تقييم كفاءة كل مكوِّن وكفاءة المحطة بشكل عام. يمكن معرفة الأماكن التي بها أكبر هدر للطاقة وبناءً عليه التأكد لاحقًا من المكان الذي سيحصل على أكبر هامش من التحسين. يجري تأثير المَعْلَمَات المختلفة– مثل درجات الحرارة والضغوط– على هذا التحليل أيضًا عبر ما يسمى برنامج حل المعادلات الهندسية (EES). من حيث الطاقة، وُجد أن المكثِّف لديه أعلى خسائر في الطاقة، إذ بلغت حوالي 103 ميجاوات تستقبلها البيئة، في حين سُجِّلت خسائر الغلاية فبلغت حوالي 24 ميجاوات. فيما يتعلق بتحليل الإكسيرجي، وُجد أن نظام الغلايات يحتوي على أعلى نسبة مئوية من تدمير الطاقة يصل إلى نسبة 88 %، تليها التوربينات بنسبة 8 % ثم المكثف بنسبة 3 %. فضلً عن ذلك كانت الكفاءة الحرارية المحسوبة على أساس قيمة التسخين المنخفضة للوقود 29 %، وكانت الكفاءة الحرارية على أساس القانون الثاني لدورة الطاقة 27.19 %. كما خلصت الدراسة إلى التأثير الكبير للتغيرات في درجة حرارة البخار الحي فيما يتعلق بقيمة التصميم، وضغط مسخِّن الضغط العالي (HPH) وضغط المكثِّف على تدمير الطاقة.

الكلمات المفتاحية:
تحليل الطاقة والأكسيرجي، تدمير الطاقة، محطة توليد الطاقة البخارية.

---

*Corresponding author:E-mail addresses: adelbojelain@gmail.com, (Second author) y.aldali@uod.edu.ly

INTRODUCTION

Analysis of power generation systems is of scientific interest and also essential for the efficient utilization of energy resources. The first law of thermodynamics is the most often applied method for analyzing an energy-efficient operation. However, there is growing interest aiming at combining the first and second principles of thermodynamics to assess the efficiency with which available energy is utilized, for instance, exergy and exergy destruction. The exegetic analysis provides a method for distinguishing between energy losses to the environment and internal process irreversibility (Kopac et al. 2007).

Exergy analysis is a method to evaluate the efficiency of devices and processes that involves analyzing the exergy at various stages along with a sequence of energy-conversion operations. With this information in mind, efficiency may be evaluated, and the stages of the process with the largest losses, where the most place for improvement can be identified (Aljundi et al. 2009).

It is worth mentioning here that, the vast majority of the power plants in Libya are of a steam cycle type, so it is necessary to tackle more research work towards optimizing the cycle of these power plants. Using thermodynamics' first and second principles as available and effective tools for assessing energy and power exergy conversion systems would be considered an appropriate method. This allows one to determine the degree of heat loss and the irreversibility of processes. Exergy analysis has played a dominant role in recent years as a useful tool for understanding processes and developing solutions for making better use of existing power plants. Aljundi et al. (2009) presented the energy and exergy analysis of the Al-Hussein power plant in Jordan. They analyzed independently each component of the system using identifying and quantifying the energy and exergy losses. The effect of various reference environment states on the analysis was also presented. Ahmadi et al. (2016) conducted a study on the energy and exergy analysis of the Montazeri Steam Power Plant that was established in Iran. They analyzed each part of the system individually. In addition, the influence of different reference environment states on this analysis was examined. They also proposed a clear procedure related to an increase in cycle efficiency. Therefore, several suggestions were introduced to improve the power plant efficiency and ensure the so-called energy saving. Rashad et al. (2009) carried out an energy and exergy analysis of the Shobra El-Khima power plant in Cairo, Egypt. They analyzed the system components separately by identifying and quantifying the sites having the largest energy and exergy losses at different loads.

The main target of the present paper is to analyze the energy and exergy losses of the Derna power plant. This is mainly assigned by the determination of primary energy loss and exergy destruction locations. This is followed by examining the effect of various parameters on the exergy analysis.

The targeted power plant description

The schematic diagram of one 65MW unit of the Derna power plant is depicted in Fig1. This unit employs a regenerative feed water heating system. Feed water heating is associated with one stage of high pressure heaters (HPH) and one stage of low pressure heaters (LPH) along with one deaerating heat exchanger. Steam is superheated to a temperature of 520 ^{o}C and a pressure of 87 bar inside the boiler, hence the outlet steam enters the turbine. The turbine exhaust steam is then passed to a condenser where the steam is cooled down by the seawater. Then, the cycle starts over again. The operating conditions of the power plant are summarized in Table 1.

© 2022 The Author(s). This open access article is distributed under a CC BY-NC 4.0 license.

Table (1): Operating conditions of the power plant.

Operating condition	Value
Mass flow rate of fuel	5.0 kg/s
Caloric value	44589 kj/kg
Stack gas temperature	130 ºC
Feed water inlet temperature to boiler	216 ºC
Steam flow rater	66.8 kg/s
Steam temperature	520 ºC
Steam pressure	87 bar
Power output	65 MW
Mass flow rate of cooling sea water	3472.2 kg/s

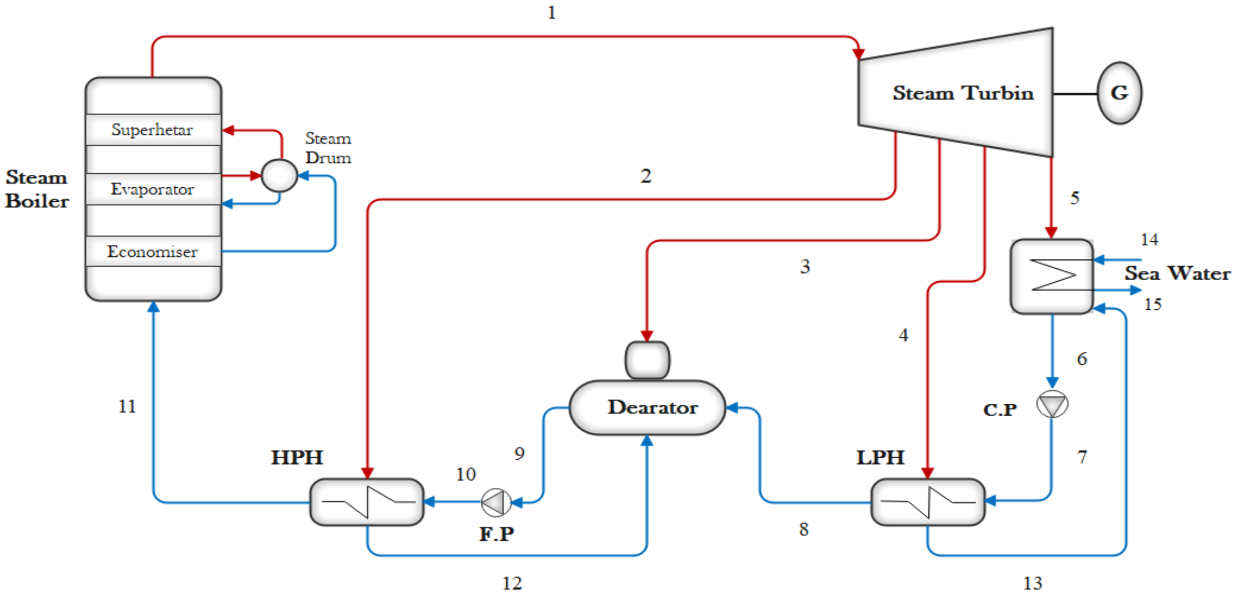

Figure (1): Derna steam power plant.

ENERGY AND EXERGY ANALYSIS

In order to analyze energy and exergy in the water–steam heat cycle of the power plant, thermodynamic parameters required at each point of the current cycle are obtained according to information available in the power plant archive based upon data design. For more detailed information, it is recommended to refer to Table2, where all data and the appropriate standard volume for each piece of equipment are presented. Now, by applying the conservation of mass, energy, and exergy equations for each standard volume, each equipment's status can be then determined. This calculation is performed in terms of energy and exergy efficiency and values of unknown parameters. This is essentially done by using the EES software whose optimal usage of thermodynamic capabilities is available in its library (Ahmadi et al. 2016). Subsequently, optimal values of the main parameters required are obtained accordingly. As a consequence, it can be said that performing energetic and exergetic analysis together can apparently pave our way towards a clear insight into system characteristics (Osueke et al. 2016).

© 2022 The Author(s). This open access article is distributed under a CC BY-NC 4.0 license.

Table (2): Thermodynamic properties of points in cycle when T_o=298 K , P_o=1.013 bar

Point	T (°C)	P (bar)	$\dot{m}$ (kg/s)	h (kJ/kg)	s (kJ/kg K)	ψ (kJ/kg)	$\dot{X}$ (KW)
1	520	87	66.86	3440	6.741	1436	95983
2	332.1	21.8	6.936	3092	6.845	1057	7330
3	195.3	6.02	5.015	2839	6.942	775	3887
4	103.6	1.15	5.937	2587	7.06	487.1	2892
5	36.77	0.062	48.97	2239	7.258	81.07	3970
6	36.77	0.062	57.58	154	0.5289	0.8803	50.69
7	36.83	6.02	57.58	154.8	0.5295	1.488	85.66
8	103.6	6.02	57.58	434.2	1.347	37.24	2144
9	159	6.02	69.53	671.3	1.933	99.79	6938
10	160.6	87	69.53	683.2	1.94	109.6	7622
11	216.8	87	69.53	928.8	2.488	191.9	13344
12	160	21.8	6.936	676.5	1.941	102.6	711.8
13	103.6	1.15	5.937	493.4	1.347	96.44	572.5
14	20	1.75	3472.22	84	0.2965	0.1486	517
15	27	1.5	3472.22	113.4	0.3959	0.01327	46.07

The subsequent procedure is outlined to clearly exhibit calculations and descriptions with respect to the application of first and second laws of thermodynamics in accordance with the equipment. The first law of thermodynamics and the main exergy balance equation are formulated based on eq.(1) and eq.(2), respectively(Kaushik et al. 2007):

$$\sum\dot{Q}+\sum\dot{m}_i h_i=\sum\dot{W}+\sum\dot{m}_e h_e \qquad (1)$$

$$\sum\left(1-\frac{T_o}{T_k}\right)\dot{Q}_k-\dot{W}+\sum_{in}\dot{m}\psi-\sum_{out}\dot{m}\psi=\dot{X}_{destroyed} \qquad (2)$$

For a standard volume in steady state, the mass, energy, and exergy balance equations are, respectively, expressed as follows:

$$\sum\dot{m}_i=\sum\dot{m}_e \qquad (3)$$

$$\dot{Q}-\dot{W}=\sum\dot{m}_e h_e-\sum\dot{m}_i h_i \qquad (4)$$

where the net exergy transfer by heat Ψ_Q at the temperature of (T) equals[2]:

$$\psi_Q=\dot{Q}\left(1-\frac{T_o}{T}\right) \qquad (5)$$

Specific flow exergy also equals:

$$\psi=h-h_o-T_o(s-s_o) \qquad (6)$$

Therefore, the total exergy of a flow is given as:

$$\dot{X}=\dot{m}\psi=\dot{m}[h-h_o-T_o(s-s_o)] \qquad (7)$$

Note that the fuel specific exergy is calculated as: $\psi_{fuel}=\gamma_f * LHV$, where γ_f = 1.06, is the exergy factor based on the lower heating value (Aljundi et al. 2009).

The exergy destruction rate and exergy

© 2022 The Author(s). This open access article is distributed under a CC BY-NC 4.0 license.

efficiency are defined in Table 3 for a steady-state operation using each component in Fig. 1 as a control volume.

Table (3): The exergy destruction rate and exergy efficiency equations for plant components.

	Exergy destruction	**Exergy efficiency**
Boiler	$\dot{X}_{d_{boiler}} = \left(1-\frac{T_o}{T_{b_B}}\right)Q_{L_B} + \dot{X}_f + \dot{X}_a + \dot{X}_{11} - \dot{X}_1 - \dot{X}_g$	$\eta_{2_{boiler}} = \frac{\dot{X}_1 - \dot{X}_{11}}{\dot{X}_{fuel}}$
Condenser	$\dot{X}_{d_c} = \left(1-\frac{T_o}{T_{b_C}}\right)Q_{L_C} + \dot{X}_5 + \dot{X}_{14} + \dot{X}_{13} - \dot{X}_6 - \dot{X}_{15}$	$\eta_{2_c} = 1 - \frac{\dot{X}_{d_c}}{(\dot{X}_5 + \dot{X}_{14} + \dot{X}_{13})}$
Turbine	$\dot{X}_{d_T} = \left(1-\frac{T_o}{T_{b_T}}\right)Q_{L_T} + \dot{X}_1 - \dot{X}_2 - \dot{X}_3 - \dot{X}_4 - \dot{X}_5 - \dot{W}_T$	$\eta_{2_T} = 1 - \frac{\dot{X}_{d_T}}{W_{rev}}$
LPH	$\dot{X}_{d_{LPH}} = \left(1-\frac{T_o}{T_{b_{LPH}}}\right)Q_{L_{LPH}} + \dot{X}_4 + \dot{X}_7 - \dot{X}_8 - \dot{X}_{13}$	$\eta_{2_{LPH}} = \frac{\dot{X}_8 - \dot{X}_7}{\dot{X}_4 - \dot{X}_{13}}$
HPH	$\dot{X}_{d_{HPH}} = \left(1-\frac{T_o}{T_{b_{HPH}}}\right)Q_{L_{HPH}} + \dot{X}_2 + \dot{X}_{10} - \dot{X}_{11} - \dot{X}_{12}$	$\eta_{2_{HPH}} = \frac{\dot{X}_{11} - \dot{X}_{10}}{\dot{X}_2 - \dot{X}_{12}}$
Dearator	$\dot{X}_{d_{Dea}} = \left(1-\frac{T_o}{T_{b_{Dea}}}\right)Q_{L_{Dea}} + \dot{X}_3 + \dot{X}_8 + \dot{X}_{12} - \dot{X}_9$	$\eta_{2_{Dea}} = 1 - \frac{\dot{X}_{d\,Dea}}{\dot{X}_3 + \dot{X}_8 + \dot{X}_{12}}$
C.P	$\dot{X}_{d_{CP}} = \left(1-\frac{T_o}{T_{b_{CP}}}\right)Q_{L_{CP}} + \dot{W}_{P_C} + \dot{X}_6 - \dot{X}_7$	$\eta_{2_{CP}} = \frac{\dot{X}_7 - \dot{X}_6}{\dot{w}_{P_C}}$
F.P	$\dot{X}_{d_{FP}} = \left(1-\frac{T_o}{T_{b_{FP}}}\right)Q_{L_{FP}} + \dot{W}_{P_F} + \dot{X}_9 - \dot{X}_{10}$	$\eta_{2_{FP}} = \frac{\dot{X}_{10} - \dot{X}_9}{\dot{w}_{P_F}}$
Cycle	$\dot{X}_{d_{cycle}} = \sum \dot{X}_{d_{component}}$	$\eta_{2_{cycle}} = \frac{\dot{W}_{Net}}{\dot{X}_{fuel}}$

RESULTS AND DISCUSSION

This section is mainly devoted to presenting the main findings of the current study. Thus the steam cycle of Derna Power Plant and all its equipment are analyzed in terms of energy and exergy. In doing so, values of heat loss, exergy loss, energy efficiency and exergy efficiency are then calculated for the targeted equipment. Besides, the effect of different parameters on exergy loss and exergy efficiency are also presented for boiler, condenser and turbine. The following explanation is presented according to figures and tables that would fundamentally illustrate the difference between energy and exergy analysis.

Table 4 shows the energy balance of the power plant components and the percent ratio to fuel energy input. In the performed analysis, the condenser is found to have the largest heat loss in the cycle, whose value is 74.75 % of the total heat loss. According to this value and the first

© 2022 The Author(s). This open access article is distributed under a CC BY-NC 4.0 license.

law of thermodynamics, it should be considered as a high potential for optimization and would eventually increase the outcomes. To conclude, the table shows that the condenser has the most energy losses in a power plant.

Table (4): Energy balance of the power plant components and percent ratio to fuel energy input.

Component	Heat loss (MW)	Percent ratio %
Boiler	24.11	17.38
Turbine	4.27	3.07
Condenser	103.724	74.75
Feed Pump	0.024	0.017
C. Pump	0.001	0.0007
HPH	0.326	0.23
Deaerator	2.626	1.89
LPH	3.66	2.63
Power Cycle	138.747	100

Table 5 shows **the e**xergy destruction and exergy efficiency of the power plant components. In exergy analysis, the condenser is found to have only 3 % of the total lost exergy which has almost no potential for optimization and subsequently has no effect on the increasing outcomes. Exergy analysis shows that the targeted boiler has 88.2 % of the total lost exergy but only 17.38 % of the total heat loss. The table shows that the boiler has the most exergy losses in the power plant. In other words, this introduces the boiler as the main equipment destroying the exergy.

In energy analysis, efficiency of the first law of thermodynamics is calculated to be 29%. Energy analysis shows that although the energy lost through the condenser includes the major part of the lost energy, it will have no benefit to be further investigated. Exergetic efficiency obtained is 28.8%. The turbine is introduced as the second piece of equipment destroying the exergy with 7.8 % of the total lost exergy. Applying different parameters via the current analysis would ensure clear variation in percentages of exergy loss an exergy efficiency for all equipment ereas the boiler still covers the major part of exergy loss.

It has been found that exergy analysis has enabled the identification of the causes of process inefficiencies in detail when compared to energy analysis.

Table (5): Exergy destruction and exergy efficiency of the power plant components.

Component	Exergy destruction (MW)	Percent exergy destruction %	exergy efficiency %
Boiler	143.9	88.2	36.99
Turbine	12.742	7.8	83.44
Condenser	4.89	3.0	3.1
Feed Pump	0.125	0.078	82.7
C. Pump	0.0097	0.0059	75.9
HPH	0.683	0.418	91.19
Deaerator	0.388	0.23	94.27
LPH	0.400	0.24	88.7
Power Cycle	163.200	100	27.19

Figure 2 shows the detailed energy and exergy balance of the considered power plant at full operating load. There is a noticeable difference between components in terms of both represented energy and exergy balances. As can be seen from the figure, the highest value of exergy is recorded for the boiler whilst the highest energy is shown in the condenser.

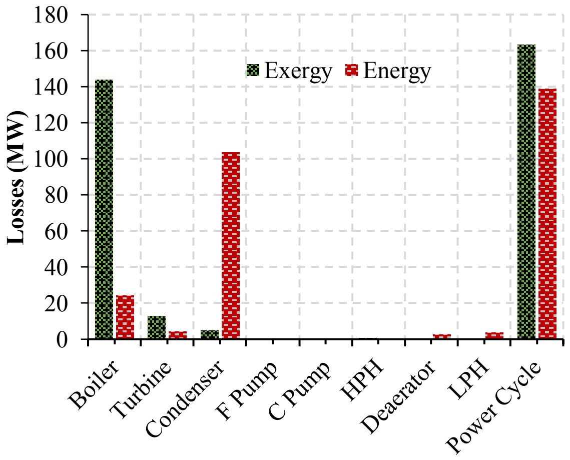

Figure (2): Amount of energy and exergy losses in power plant and main equipment.

© 2022 The Author(s). This open access article is distributed under a CC BY-NC 4.0 license.

To investigate the significant influence of different parameters on exergy destruction, parameter values have been changed frequently and the impact of these parameters on the exergy destruction of plant components is determined accordingly.

Figure 3 presents the effect of various temperatures of superheated steam from 470 °C to 570°C where a lack of exergy destruction is observed as the temperature of the live steam increases particularly in the boiler. However, there is a small effect in both condenser and turbine.

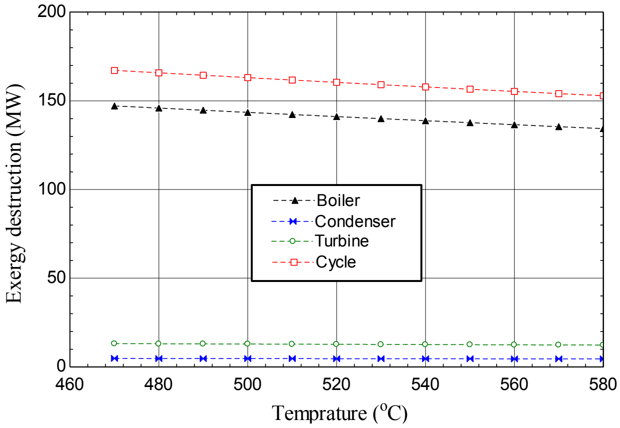

Figure (3): Effect of live steam temperature on total exergy destruction rate in major plant components.

Figure 4 dipects the effect of the pressure of live steam, ranging between 70 bar and 115 bar, on exergy destruction. As can be noted, there is a slight variation of exergy destruction with an increase in the live steam pressure. It can be also concluded that there is no obvious effect on both condenser and turbine with regard to energy destruction.

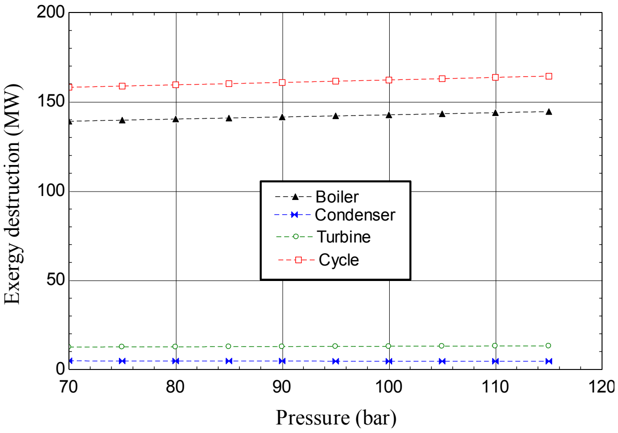

Figure (4): Effect of live steam pressure on total exergy destruction rate in major plant components.

Figure 5 represents the effect of HPH pressure varying in the range from 10 bar to 29 bar on the destruction of exergy. It can be seen that there is a clear variation in exergy destruction linked to the boiler. There is no obvious effect in both condenser or turbine regarding the exergy destruction.

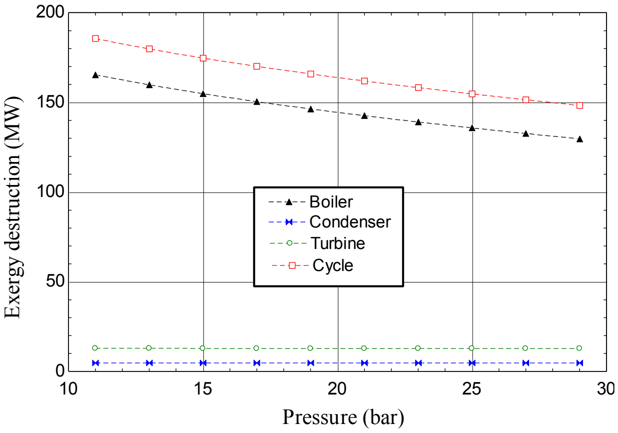

Figure (5) Effect of HPH pressure on total exergy destruction rate in major plant components.

Figure 6 illustrates the effect of Dearator pressure changes from 4 bar to 10 bar on exergy destruction. The figure shows no obvious effect of energy waste across all components of the plant.

© 2022 The Author(s). This open access article is distributed under a CC BY-NC 4.0 license.

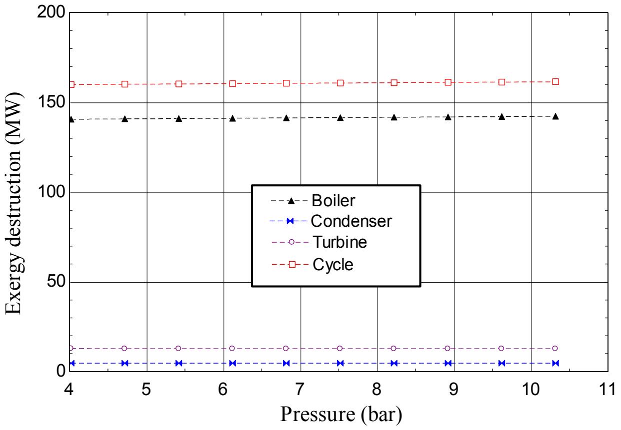

Figure (6): Effect of Dearator pressure on total exergy destruction rate in major plant components.

Figure 7 shows the influence of LPH pressure alternates from 0.4 bar to 2 bar on exergy destruction. It is observed that there is a slight exergy waste effect on the boiler in the case of LPH pressure deficiency and no apparent effect on both condenser and turbine.

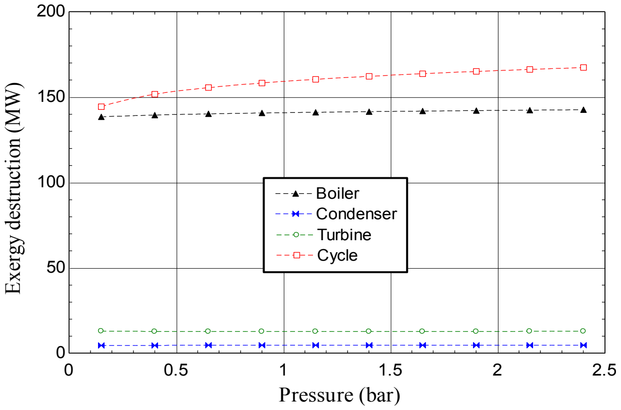

Figure (7): Effect of LPH pressure on total exergy destruction rate in major plant components.

Figure 8 presents the effect of changing the condenser pressure from 0.03 bar to 0.07 bar on exergy destruction. It is noted that the lower the condenser pressure the less exergy destruction for the boiler and the condenser. There is no obvious effect on the turbine.

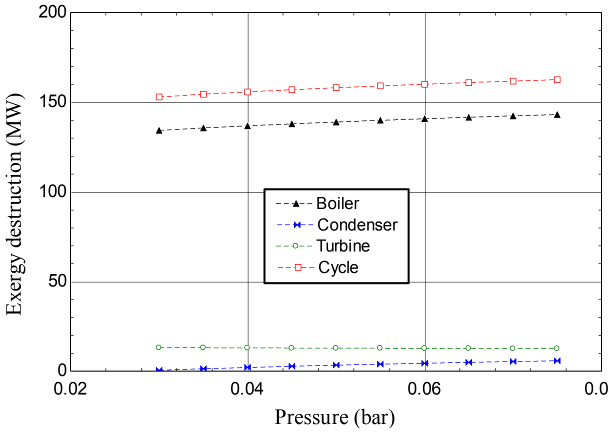

Figure (8): Effect of Condenser pressure on total exergy destruction rate in major plant components.

CONCLUSIONS

In this study, an energy and exergy analysis as well as the effect of varying different parameters on the exergy analysis of an actual power plant has been presented. About 74.7% of the input energy was lost to the environment where the maximum energy loss was found. The boiler system's energy loss was found to be about 17.3% and less than 8% for all other components. The thermal efficiency of the cycle was 29%. The exergy analysis was done on the plant. The amount of lost energy in the condenser is insignificant.

As far as energy destruction is concerned, a major value of approximately 88.2% was recorded in the boiler, which represents the maximum destroyed amount of fuel exergy. This was followed by a 7.8% fuel exergy input to the cycle that would be assigned to12.7MW as exergy being destroyed in the turbine. In addition, an amount of about 3% exergy destruction was found in the condenser, meanwhile, a percentage of less than one was mainly destroyed in all pumps and heaters.

The calculated exergy efficiency of the power cycle was found to be as low value as 27.19% compared to modern power plants. The study concluded that the boiler system was the most significant source of exergy destruction in a combustion chamber, with chemical reaction being the most significant cause of exergy destruction.

Last but not least, the main concluding

© 2022 The Author(s). This open access article is distributed under a CC BY-NC 4.0 license.

remark would be that the boiler is the main source of irreversibilities in the system, even when the exergy destruction of each component in the system is altered with different parameters.

ACKNOWLEDGEMENT

We are very grateful to Omar Almukhtar University, Derna University and the Derna Power Plant.

REFERENCES

Kopac, M., & Hilalci, A. (2007). Effect of ambient temperature on the efficiency of the regenerative and reheat Çatalağzı power plant in Turkey. Applied Thermal Engineering, 27(8-9), 1377-1385.

Aljundi, I. H. (2009). Energy and exergy analysis of a steam power plant in Jordan. *Applied thermal engineering*, *29*(2-3), 324-328.

Ahmadi, G. R., & Toghraie, D. (2016). Energy and exergy analysis of Montazeri steam power plant in Iran. *Renewable and Sustainable Energy Reviews*, 56, 454-463.

Rashad, A., & El Maihy, A. (2009, May). *Energy and exergy analysis of a steam power plant in Egypt.* In 13th international conference on AS AT-13.

Aldali, Y., & Morad, K. (2014). Thermal performance improvement of Derna electric power station (unit5) using solar energy. *Journal of sustainable development*, *7*(1), 60

T. Kotas, The Exergy Method of Thermal Plant Analysis, London Boston Butterworths, London, (1985).

Kaushik, S. C., Reddy, V. S., & Tyagi, S. K. (2011). Energy and exergy analyses of thermal power plants: A review. *Renewable and Sustainable energy reviews*, 15(4), 1857-1872.

Osueke, C. O., Onokwai, A. O., & Adeoye, A. O. (2015). Energy and Exergy analysis of a 75MW Steam Power Plant in Sapele Nigeria. *International Journal of Innovative Research in Advance Engineering*. (6), 2.

© 2022 The Author(s). This open access article is distributed under a CC BY-NC 4.0 license.