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Energy And Exergy Assessment of North Refineries Company (NRC) Steam Cycle Based on Air Mass Flowrate of Main Condenser

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A B S T R A C T

The present work depends on the previous energy and exergy analysis study for a steam cycle of North Refineries Company (NRC)/Baiji, Iraq, which was conducted at real and rated operating loads. After the results of that study are presented, this current study is conducted and aimed to produce the engineering solutions for improving the cycle performance through studying the operational choices that are actually available in the plant as investigating the effect of increasing the air mass flow rate in the main condenser of the cycle. The calculations were done by using the MATLAB program. The results showed that increasing the air mass flow rate or increasing the number of fans in service from 8 to 14 fans will reduce the energy losses in the main condenser and in the cycle. The energy loss reduction can be enhanced in the improvement of the energy efficiency by raising it from 30.11 % to 48.61 % at real load and from 33.49 % to 48.93 % at rated load. On the other hand, the exergy analysis showed that the exergy destructions for the main condenser and for the cycle would decrease if the number of fans increased. This decreasing of exergy destruction in the main condenser will raise the exergy efficiency from 21.95 to 27.06 % at real load and from 21.18 % to 25.45 % at rated load.

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تقييم الطاقة والطاقة المتاحة لشبكة البخار في شركة مصافي الشمال / بيجي استناداً الى تغيير معدل جريان الهواء للمكثف الرئيسي

وعد احمد صالح شركة مصافي الشمال / بيجي ، وعادل عبدالرزاق الكميت وحميد جاسم خلف قسم الهندسة الميكانيكية / جامعة تكريت

الخلاصة

تعتمد الدراسة الحالية على دراسة سابقة لتحليل الطاقة والطاقة المتاحة لشبكة البخار في شركة مصافي الشمال / بيجي , العراق . والتي اجريت عند الحمل الحقيقي والحمل الترددي للمحطة. بعد ان اكتملت نتائج تلك الدراسة تم تقديم هذه الدراسة والتي تهدف الى تقديم حلول هندسية لتحسين اداء دورة البخار من خلال دراسة الخيارات التشغيلية المتوفرة فعلياً في المحطة كدراسة تأثير زيادة معدل جريان الهواء في المكثف الرئيسي في الدورة. تم اجراء الحسابات الرياضية بواسطة برنامج الماتلاب واظهرت النتائج إن زيادة معدل الجريان للهواء او عدد المرواح المستخدمة من 8 مراوح الى 14 مروحة يؤدي الى تقليل خسائر الطاقة في المكثف الرئيسي وفي الدورة وهذا بدوره يحسن من كفاءة الطاقة للدورة وزيادتها من 30.11 % الى 48.61 % 33.49 % الى 48.93 % عند الحمل الترددي . من جانب اخر, فان نتائج تحليل الاتاحية أظهرت إن خسائر الإتاحية % عند الحمل الحقيقي ومن للمكثف وللدورة تنخفض عند زيادة عدد المراوح المستخدمة من 8 الى 14 حيث يؤدي الى زيادة كفاءة الاتاحية للدورة من 21.95 % الى 27.06 % عند الحمل الحقيقي ومن 21.18 % الى 25.45 % عند الحمل الترددي .

الكلمات الدالة: المكثف ، خسائر الطاقة، خسائر الاتاحية ، المصافي النفطية .

NOMENCLATOR

Terms	Description	Units
$\dot{E}_{in}, \dot{E}_{out}$	Energy in/out the cycle	MW
$\dot{E}_{losses}$	Energy losses	MW
COND1	Main condenser in the cycle	/
$\dot{Q}_{rej,cond1}$	Heat rejected from the condenser	MW
n	Number of fans in service	/
$\dot{m}_{air,cond1}$	Air mass flowrate	Kg/s
$\dot{m}_4$	Steam mass flowrate	Kg/s
ψ	Exergy rate	MW
$\dot{I}_{destroyed}$	Exergy destruction rate	MW
$\dot{X}_{input,cycle}$	Exergy input to the cycle	MW
η_I	First-law or Energy efficiency	/
η_{II}	Second-law or exergy efficiency	/

1. INTRODUCTION

Petrochemical refining is a complicated industry that produces fuel products, from gasoline to asphalt. Processes of refining requiring a range of operation steps, including crude distilling, reforming, and treating. Most of those processes are highly dependent on heating by steam energy. Steam energy is a simple, safe, and continued source of energy for the refineries. Even with the development in the energy sectors around the world, such as nuclear, renewable, and geothermal energies, steam energy is still the source that is inexhaustible and has fewer operational costs. Even with the world's crisis, such as the COVID-19 pandemic that hits the oil and gas industry around the world, this sector is still at its level because it's essential to block down daily life for heating, cooling, health, and food productions. It's true that this pandemic closed some sectors such as transportation and educations, but it caused a high demand on other sectors, such as sectors that are serving the lockdown necessities[1]. The cost of exploration and production of Oil has also impact on the energy sectors as before COVID-19, and the prices are crashing. Most oil industries had considered an oil price to be $70-80/bbl, which opened the doors to investing in higher-cost projects. After the prices are decreased and with continued uncertainty around the future of oil demand, companies have reduced price considerations to be $55-70/bbl, making high-cost projects undesired at these times[2]. All these challenges around the Oil and gas affect the energy sectors and make the scientist and researchers reconsidering the energy costs related to oil and gas industries by studying the energy systems to locate the sites that consume or dissipate high energy in order to reduce or conserve it and suggest the modifications to increase its thermal performance.

The best technique for analyzing the thermal systems is the energy and exergy analysis, which is based on the first and second law of thermodynamics. Researchers [3]–[13] had conducted an energy and exergy analysis for a steam cycle for power plants; they concluded from energy analysis that the maximum energy loss occurs in the condensers, and from the exergy analysis that the maximum exergy destructions occur in the boilers because of the finite temperature difference which causes the largest destructions in the exergy supplied to the boilers. Omar et al. [14] assessed the energy and exergy performance of coal-fired plants based on the condenser pressure. They found that increasing the pressure of the condenser from 0.03 bar to 0.2 bar will decrease the energy and exergy efficiencies of the plant cycle. Hisham [15] conducted a study for increasing the thermal and internal efficiencies for a steam power plant by using the best economical method. The calculations were done by using a computer program (Fortran 90). He concluded that reducing the condenser pressure from 0.45 bar to 0.25 bar will increase thermal efficiency by 4.3 % and the internal efficiency by 2.1 %. Mohammed et al. [16] studied the energy and exergy analysis of a 200 MW steam power plant based on the effect of feedwater heater numbers. Based on the results, they found that the energy and exergy efficiencies to be 37.52 % and 41.70 %, respectively. The boilers contribute 48 % of the exergy destructions of the cycle; they concluded that the optimum number of feedwater heaters is nine heaters as increasing the heaters will increase the boiler temperature and decrease the fuel consumption used for the boiler. Mrzljak V et al. [17] conducted an exergy analysis for a steam condenser with an ambient temperature change range of 5 ^{o}C and 20 ^{o}C at three different rating loads. They found that the highest exergy efficiencies for the steam condenser occur at the lowest ambient temperature, 5 ^{o}C, which were 81.47 % at low load, 76.1 % at middle load, and 74.54 % at a high load of the condenser. And they conclude that the optimal operation condition is at a lower load of the condenser and lowest ambient temperature. Aadel et al. [18] studied the effect of operational modifications, such as lowering main condenser pressure on the exergy efficiency of the North Refineries Company (NRC) steam cycle; they concluded that lowering the main condenser pressure from 0.8 bar by 0.3 and by 0.6 bar will increase the exergy efficiency by 9.1% and by 15.61%, respectively. This modification provides the best choice that can be applied in the steam plant, if the exergy efficiency for the cycle is desired without need for any changing in the plant design. Recently, the energy and exergy analysis become a widely range usages, Mohamad et al. [19] used it to study the energy, exergy, exergoeconomic, and exergoenvironmental (4E) impact for a large steam power plant. The result showed that the maximum exergy destruction is by the boiler and by the turbines, were about 86 % and 8 % from the total exergy destructions of the cycle, respectively. And they conclude that the optimum operation values of energy and exergy efficiencies are increased by 9.7 %, and 16.8%, respectively. Also, the costs of environmental effect and electricity generation were reduced by 49.6%, and 20.25 %, respectively.

Based on the literature reviews that are relevant to energy and exergy analysis around the world, which showed that the condensers are the biggest energy losers in each steam cycle, and based on the gab of these reviews, of studying the effect of mass air flowrate of condensers on the energy and exergy efficiencies. The objective of this study is to show the effect of increasing the air mass flow rate of the main condenser on the energy and exergy efficiencies for the steam cycle of North Refineries

Company (NRC)/ Baiji, Iraq. Based on the results, it aims to recommend the best-operating conditions and instructions for the engineer's plant.

2. METHODOLOGY

This study is based on the results of energy and exergy analysis for the steam cycle of North Refineries Company (NRC)/Baiji, Iraq[20]. First, the mathematical models are built based on the first and second laws of thermodynamics for the cycle and its components. Then, the calculations are solved by using the MATLAB code. Fig. 1 shows the steam cycle for this refinery, and the condenser considered in this study is the main condenser (COND1). It is an air-cooled condenser that uses electrically driven fans for condensing the steam. Its operational specifications are tabulated in Table 1. The range of fans in service (n) included in this study is selected to be from 8 to 14 fans representing the plant's actual situation. The governing equations used in this study are energy balance Eq. (1), including the losses for the control volume [21], the heat energy rejected from the condenser to the air is represented by Eq. (2). Also, the condenser's energy losses and energy efficiency are illustrated by Eq. (3) and Eq. (4). For the cycle, the energy losses are collected in Eq. (5), and energy efficiency is given by Eq. (6). On the other hand, the exergy balance equation for the control volume systems [21] is given by Eq. (7), exergy destructions by the main condenser are given by Eq. (8), and by the cycle are collected by Eq. (10), exergy efficacies for the main condenser and for the cycle is illustrated by Eq. (9) and Eq. (11).

- Energy equations for the main condenser (COND1):

$$\sum \dot{E}_{in} = \sum \dot{E}_{out} + \dot{E}_{loss} \quad (1)$$

$$\dot{Q}_{rej,cond1} = n \,.\, \dot{m}_{air,cond1} * C_{P_{air}} * (\Delta T)_{air,cond1} \quad (2)$$

$$\dot{E}_{loss,cond1} = \dot{m}_4(h_4 - h_5) - \dot{Q}_{rej,cond1} \quad (3)$$

$$\eta_{I,cond1} = \frac{\dot{Q}_{rej,cond1}}{\dot{m}_4(h_4 - h_5)} \quad (4)$$

Energy loss by cycle$=\dot{E}_{loss,Cycle}$

$$\dot{E}_{loss,Cycle} = \dot{E}_{loss,\,Boiler} + \dot{E}_{loss,WHRB1} + \dot{E}_{K,WHRB2} + \dot{E}_{loss,Turbines} + \dot{E}_{loss,Pumps} + \dot{E}_{loss,Condensers} + \dot{E}_{loss,E.V} + \dot{E}_{loss,H.E} + \dot{E}_{loss,L.H} + \dot{E}_{loss,Dea} + \dot{E}_{loss,ADT} + \dot{E}_{loss,FPT} + \dot{E}_{loss,Misc} \quad (5)$$

$$\eta_{I,cycle} = 1 - \frac{Energy\ Loss}{Energy\ in} = 1 - \frac{\dot{E}_{loss,cycle}}{\dot{E}_{in,Cycle}} \quad (6)$$

- Exergy equations for the main condenser (COND1):

$$\sum\left(1 - \frac{T_0}{T_K}\right) Q_K + \sum m^{\cdot}\ \psi_i = \psi_w + \sum m^{\cdot}\ \psi_e + \dot{I}_{destroyed} \quad (7)$$

$$\dot{I}_{des,COND1} = \dot{m}_4(\psi_4 - \psi_5) - \left(1 - \frac{T_0}{T_K}\right)\dot{Q}_{rej,COND1} \quad (8)$$

$$\eta_{II,COND1} = \frac{\left(1 - \frac{T_0}{T_K}\right)\dot{Q}_{rej,COND1}}{\dot{m}_4(\psi_4 - \psi_5)} \quad (9)$$

$$\dot{I}_{des,cycle} = \dot{I}_{des,Boiler} + \dot{I}_{des,WHRB1} + \dot{I}_{des,WHRB2} + \dot{I}_{des\,,Turbines} + \dot{I}_{des,Pumps} + \dot{I}_{des,Condensers} + \dot{I}_{des,E.V} + \dot{I}_{des,H.E} + \dot{I}_{des,L.H} + \dot{I}_{des,Dea} + \dot{I}_{des,ADT} + \dot{I}_{des,FPT} + \dot{I}_{des,MISC} \quad (10)$$

$$\eta_{II,cycle} = 1 - \frac{\dot{I}_{des,cycle}}{\dot{X}_{input,cycle}} \quad (11)$$

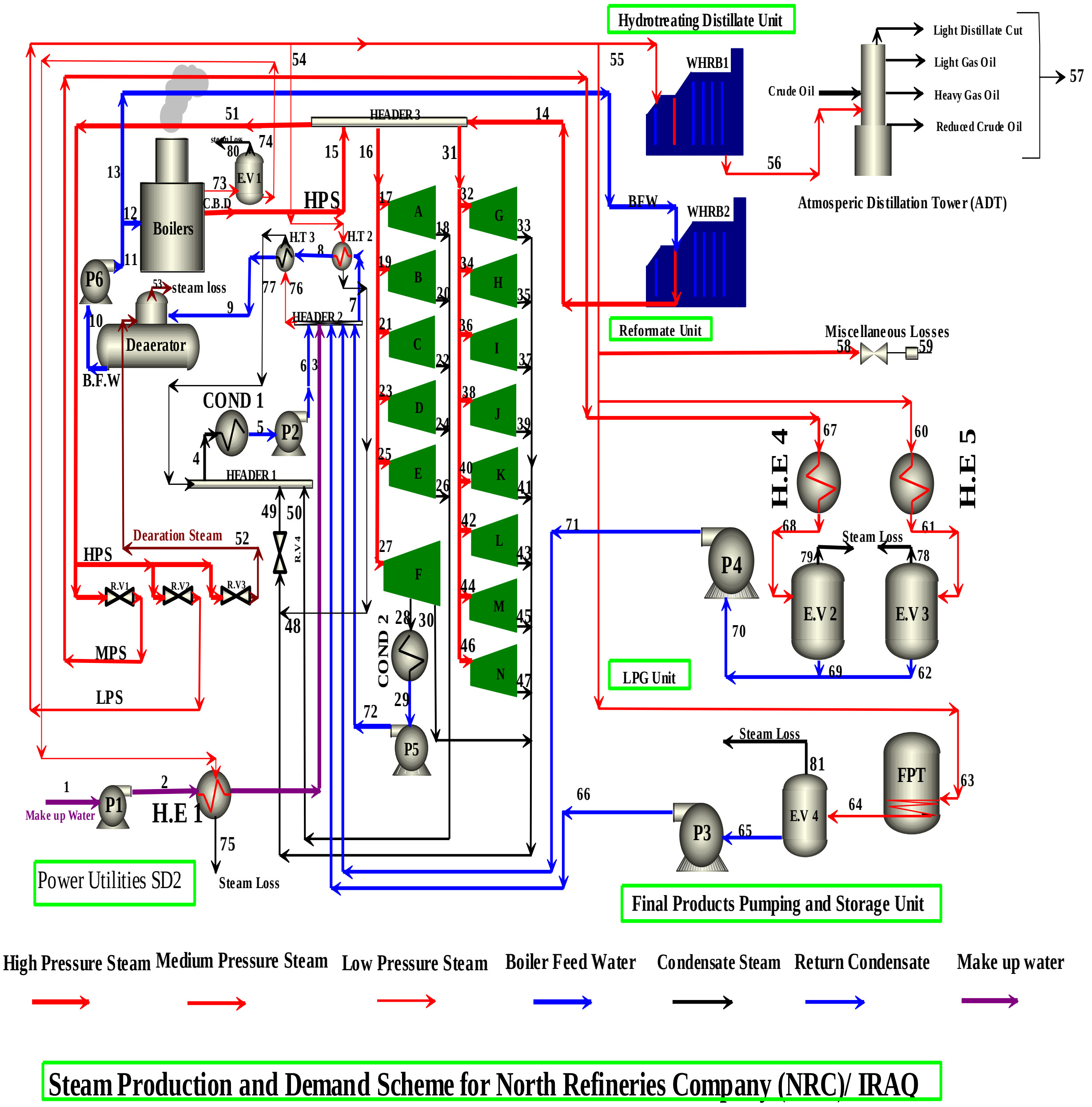

Fig. 1. Steam flow diagram

Table 1.

Operational conditions for the main condenser

Operational Parameter	Value	Unit
Total number of fans in the main condenser	16	Fans
Air mass flowrate ($m_{air,cond1}$)	884.7	Kg/s. fan
$C_{P_{air}}$	1.005	KJ/Kg. K
T_0, P_0	25 °C , 1.0132 Bar	/

3. RESULTS AND DISCUSSION

The calculations are conducted by using the MATLAB program as it has the ability to solve all the equations and showing the results. The air mass flow rate in the condenser depends on the number of fans (n) that in service. These fans provide a constant air mass flow rate for the condenser. When it is required to increase the mass flow rate of the air in the condenser, the operation engineer should operate more fans and vice versa. Since the meaning of increasing the mass flow rate of air is the same as the meaning of increasing the number of fans in service, it is preferred to use the term of a number of fans in service to be more useful for the operation staff in the plant.

Table 2. Shows the results of the energy losses from the main condenser and from the whole cycle, in addition to the exergy destructions by the main condenser and by the whole cycle that affected by increasing the number of fans of the main condenser (COND1). The minimum and maximum number of fans are restricted by the operational conditions of the condenser, which is between 8 to 14 fans of 16 fans. The energy assessment showed that the energy losses from the main condenser are highly affected by increasing the number of fans in service as illustrated in Fig. 2, it decreased from 37.07 MW to 9.33 MW at real load, and from 40.91 MW to 13.16 MW at rated load as the number of fans increased from 8 to 14 fans in service, that because the condenser instead of losing energy, it rejects it to the air when the number of fans is increased. Also, Fig. 3 showed the total energy losses from the cycle, which decreased from 108.16 MW to 80.42 MW at real load, and from 129.13 MW to 101.39 MW at rated load. This large quantity of decreasing is because one of the previous study results [19], which this current study is based on, is showed that the maximum energy losses occur in the condensers. i.e., this large decrease is due to the significant effect of the condenser on the cycle in the energy analysis. On the other hand, the exergy assessment results are shown in Fig. 4, that the exergy destructions of the condenser are decreased from 8.51 MW to 4.38 MW at real load and from 9.61 MW to 5.48 MW at rated load when the number of fans is increased. Because the term of exergy destruction of the condenser in Eq. (8) is dependent on two terms. The first one is the term of exergy transferred by the mass, which is basically constant and affected by the rating load of the cycle only. The second term is the term of the exergy transferred by heat which is mainly affected by the energy rejected ($\dot{Q}_{rej,COND1}$)by fans and this term increase when the number of fans is increased and lead to decrease the exergy destructions in the condenser. Also, for the cycle, the exergy results showed a minor decrease as explained in Fig. 5, which were decreased from 62.99 MW to 58.87 MW at real load and from 76.12 MW to 72.00 MW, because the exergy destructions of the cycle are largely affected by boilers and a little bit by the condenser. For the energy efficiency of the cycle as illustrated in Fig. 6, which increased from 30.11 % to 48.61 % at real load and from 33.49 % to 48.93 % at rated load, that is because the total energy losses from the cycle are decreased as the energy losses of the main condenser is decreased Eq. (5) and lead to raising up the energy efficiency Eq. (6). Also, the exergy efficiency, as explained in Fig. 7 which increased from 21.95 to 27.06 % at real load and from 21.18 % to 25.45 % at rated load as the number of fans increased from 8 fans to 14 fans in service. That is because the total exergy destructions of the cycle are decreased as a result of decreasing of the exergy destructions in the main condenser.

Table 2.
Results at real and rated load

Real load							
No. of Fans	8	9	10	11	12	13	14
$\dot{E}_{loss,cond1}$ (MW)	37.07	32.44	31.65	23.20	18.57	13.95	9.33
$\dot{E}_{loss,Cycle}$ (MW)	108.16	103.54	98.89	94.29	89.67	85.04	80.42
$\dot{I}_{des,COND1}$ (MW)	8.51	7.82	7.13	6.45	5.76	5.07	4.38
$\dot{I}_{des,cycle}$ (MW)	62.99	62.30	61.58	60.93	60.24	59.56	58.87
$\eta_{I,cycle}$ (%)	30.11	33.20	36.27	39.36	42.44	45.53	48.61
$\eta_{II,cycle}$ (%)	21.95	22.80	23.65	24.51	25.36	26.21	27.06
Rated load							
No. of Fans	8	9	10	11	12	13	14
$\dot{E}_{loss,cond1}$ (MW)	40.91	36.28	35.70	27.03	22.41	17.79	13.16
$\dot{E}_{loss,Cycle}$ (MW)	129.13	124.50	119.85	115.26	110.63	106.01	101.39
$\dot{I}_{des,COND1}$ (MW)	9.61	8.92	8.23	7.55	6.86	6.17	5.48
$\dot{I}_{des,cycle}$ (MW)	76.12	75.43	75.13	74.06	73.37	72.68	72.00
$\eta_{I,cycle}$ (%)	33.49	36.06	38.63	41.21	43.78	46.36	48.93
$\eta_{II,cycle}$ (%)	21.18	21.89	22.60	23.31	24.02	24.73	25.45

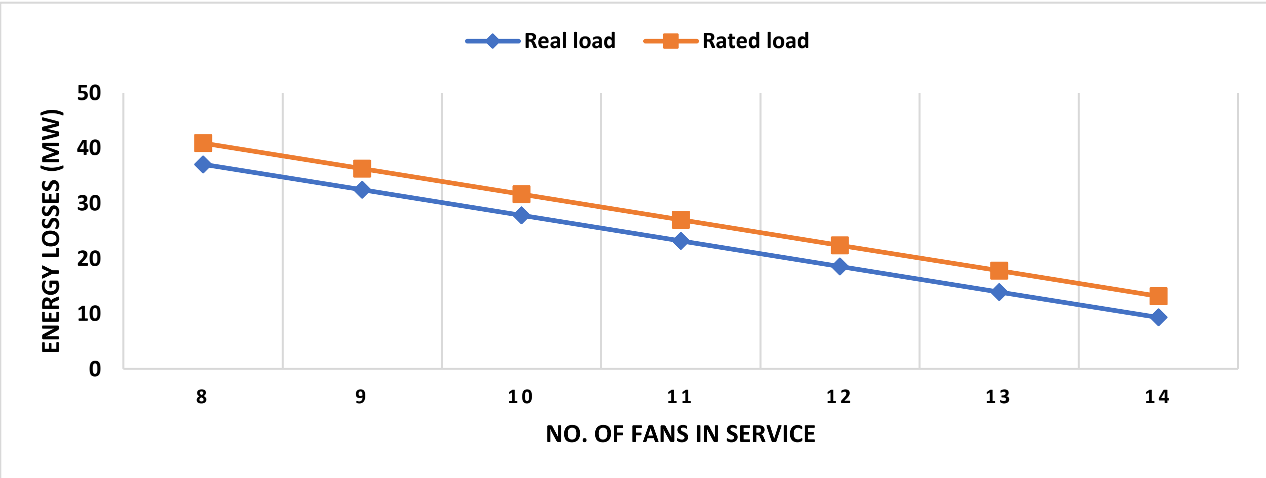

Fig. 2. Energy losses of the main condenser (COND1)

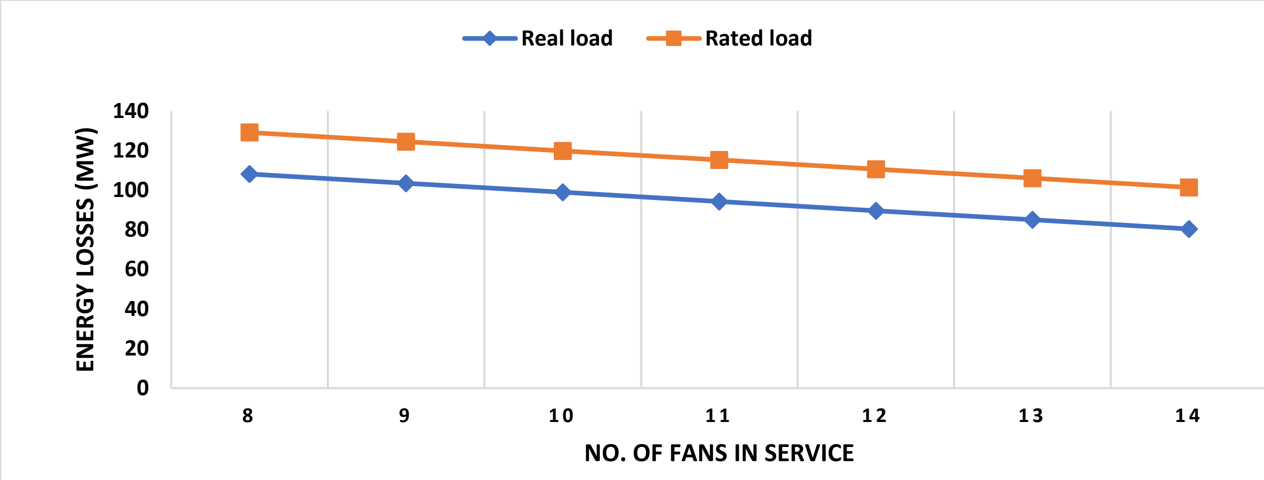

Fig. 3. Energy losses of the cycle

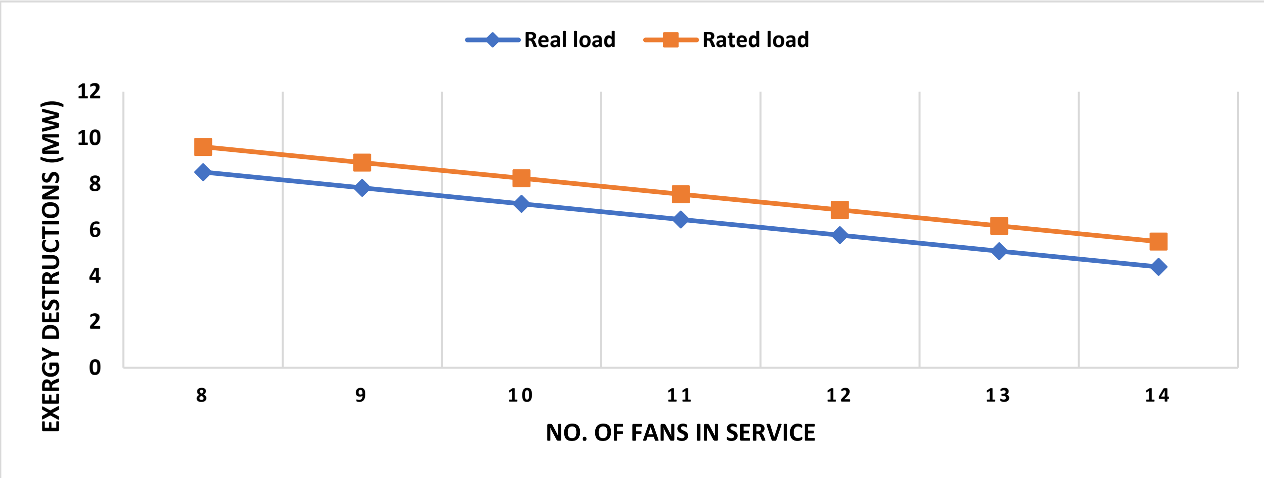

Fig. 4. Exergy destructions of the main condenser (COND1)

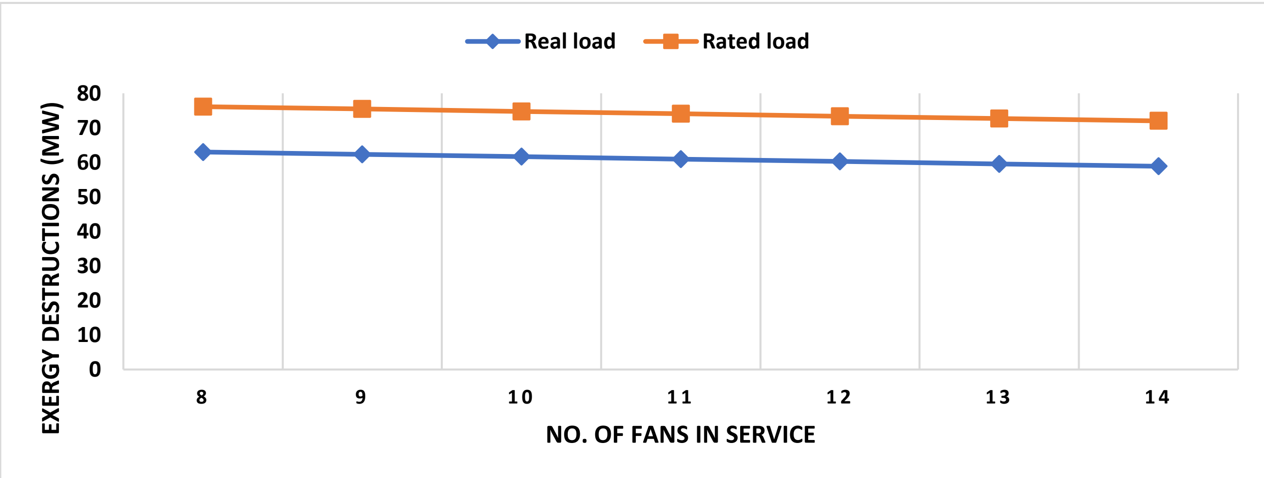

Fig. 5. Exergy destructions of the cycle

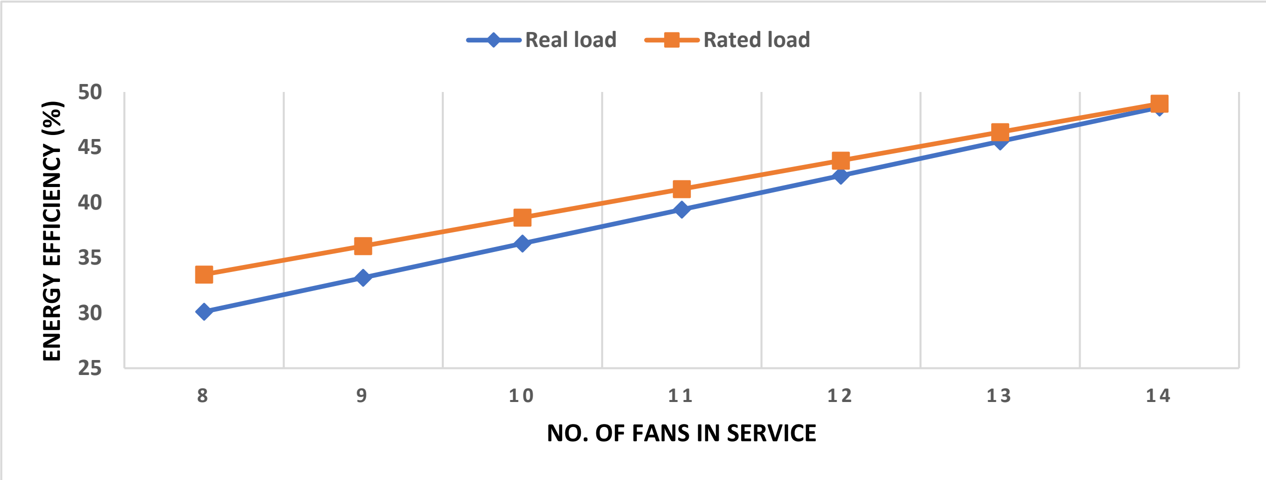

Fig. 6. The energy efficiency of the cycle

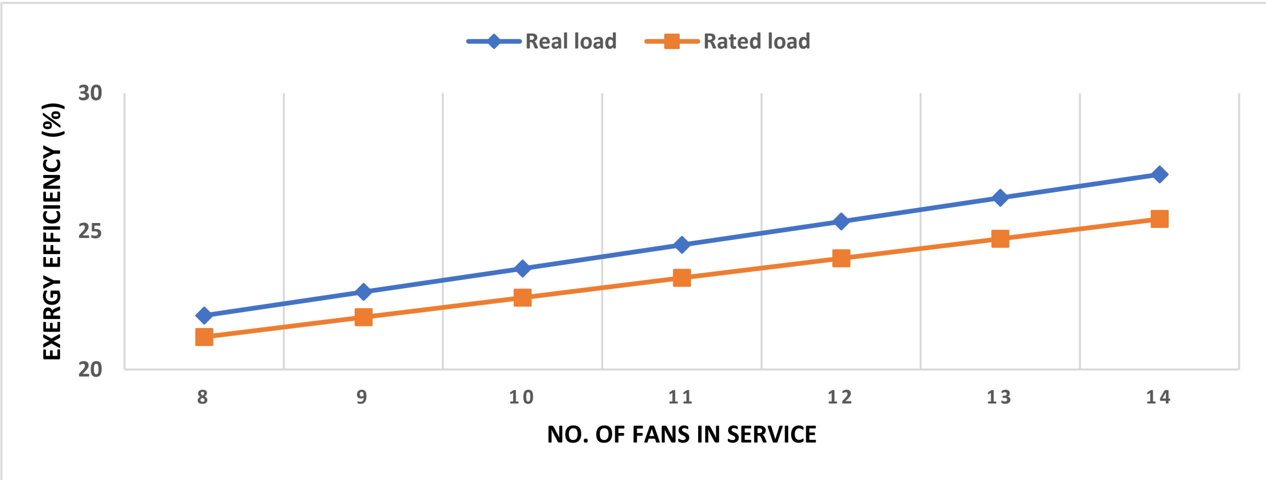

Fig. 7. The exergy efficiency of the cycle

4. CONCLUSIONS

From this study, the following points can be concluded:

- Increasing the number of fans in service (i.e., increasing air mass flow rate) for the main condenser (COND1) will decrease the energy losses from the condenser and the cycle. And this will enhance in improving the energy efficiency of the cycle.
- Increasing the number of fans in service (i.e., increasing air mass flow rate) for the main condenser (COND1) will decrease the condenser's exergy destructions and the cycle. And will lead to improving the exergy efficiency of the cycle.
- As the maximum energy losses occur in the condenser, the effect of increasing the number of fans in the condenser is more significant on the energy assessment (energy losses and energy efficiency) than on the exergy assessment (exergy destructions and exergy efficiency).
- The effect of increasing the number of fans in service in the main condenser will enhance the energy and exergy efficiency of the steam cycle, and this choice will provide simple operational solutions if the cycle efficiencies are required without changing the design of the steam plant.

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