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Study the Effect of Operational Modifications on the Exergy Efficiency for the Steam Cycle of North Refineries Company (NRC)/ Baiji, Iraq

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ABSTRACT

This work aims to investigate effect of operational modifications on the exergy efficiency of steam cycle. It is based in its calculations on MATLAP codes of the previous study of energy and exergy analysis for a steam cycle of North Refineries Company (NRC)/ Baiji. The results showed that if the steam temperature raised from 374.5 ^{o}C by 15 ^{o}C and by 30 ^{o}C, the exergy efficiency will increase by 0.52 %, and 0.68 %, respectively. Also, increasing the boiler pressure from 22.3 bar by 1.5 bar and by 3 bar will increase the exergy efficiency by 0.89 %, and 1.57 %, respectively. The most efficient modifications concluded by this study is, lowering condenser pressure from 0.8 bar by 0.3 bar, and by 0.6 bar that cause increasing in the exergy efficiency by 9.1 %, and 15.61 %, respectively. In summary, the exergy efficiency can be improved by the above modifications.

KEYWORDS

Energy, Destructions, Petrochemical refinery, Condensers, Second-law efficiency.

INTRODUCTION

The demand on the sources of energy such as oil and gas are increasing in rapid rates around the world, this is due to the population growth that requires more development in the sections that related to the human health, education, transportation, entertainment, and security. All these energy needs are to continue in its objective in serving the human beings. Steam energy is the one form of energy that irreplaceable in the oil and gas sectors, because its flexibility in states and properties that meets the conditions of its productions such as simplicity, availability, and safety[1]. Even in the world's crisis such as COVI-19 Pandemic, which caused a historic decreasing in the prices of the oil, the demand on the fuel and gas around the world is still in the levels that cover the necessary sections for the full lockdown, Iraq has a huge oil and gas resources, Its production to 2030 is set to be third largest contributor to global oil supply[2]. The challenges of population growing, world crisis or pandemic that causing to reduce the oil prices, and world supply/demand are impelled scientific and engineers to find engineering solutions to reduce the energy losses especially in the large sectors such as refineries, the Competitive benchmarking data states that most petroleum refineries can economically improve energy efficiency by a percentage of 10% and 20%.

These valuable improvements are expected to save annual costs of millions to tens of millions of dollars for a refinery, depending on its operational efficiency and size. Improved energy efficiency is expected also, to provide co-benefits that far outcomes the energy cost savings, and may lead to a significant reduction in emissions[3]. to face these challenges, it is preferred to reduce the energy losses in the steam power plants by study its thermodynamics performance and suggest efficient solutions and improvements. A common way to study the performance of the steam generation plant is to study the exergy destructions through the steam cycle based on the second-law of thermodynamics[4]–[12]. Researchers[13]–[16] are presented an exergy analysis to investigate the most effective component that have largest share of exergy destruction, then based on these analysis they suggest modifications such as increasing the inlet pressure to the high pressure turbine (H.P.T), increasing the inlet temperature to (H.P.T), and lowering condenser pressure in the purpose of cycle improvements. Mohamed Elhelw, et al [17] utilized the exergy analysis to investigate the thermal performance for a steam power plant 650 MW.

Then investigated the effect of decreasing the condenser pressure, inlet pressure to intermediate pressure turbine, and increasing the temperature of inlet super-heated steam to the high and intermediate pressure steam turbines, the results showed that decreasing the condenser pressure from 0.067 bar to 0.049 bar will save energy by 0.5878 % at half load and 0.5725 % at full load. Decreasing the inlet pressure to the intermediate pressure turbines by 4.5 bar also, will save the power by 1.344 % at half load and 0.709 % at full load. Furthermore, increasing the temperature of inlet super-heated steam to the high-pressure turbine by 45 ^{o}C will save power by 8.906 % and 10.383 % at half and full load, respectively. The effect of the same increasing in the temperature of the inlet super-heated steam to the intermediate-pressure steam turbine will save power by 6.736 % and 7.285 % at half and full load, respectively. M.N.Eke et al [18] conducted energy and exergy evaluation of A 220 MW thermal power plant, they concluded that increasing the high pressure turbine inlet temperature will enhance the increasing of exergy efficiency for the cycle.

Mansur Aliyu, et al [19] presented energy, exergy, and parametric analysis for a combined power plant cycle and they find that decreasing the superheated steam pressure will decrease in the exergy efficiency of the cycle. Omar J Khalil, et al [20], studied energy and exergy assessment of the coal-fired power plant based on the effect of condenser pressure, they conclude that by raising the pressure of the condenser, the both thermal and exergy efficacies are decrease. Nowadays, the energy and exergy analysis has a wide range benefits, it is expanded to include the exergoeconomic analysis [21] and the four effect (4E) of energy, exergy, economic, and environmental impacts on the performance of steam generation plant [22]. Most researches [23], [24] that they are interested in the energy and exergy analysis are suggest some modifications for improvement the exergy efficiency. This prompt study is to show the effect of some operational modifications such as increasing the super-heated steam (S.H.S) temperature, increasing the boiler pressure, and lowering the condenser pressure on the exergy efficiency of a refinery steam cycle to suggest and recommended the proper operational trends for the energy commission in this refinery.

METHODOLOGY

The flow diagram of the steam cycle of the North Refineries Company (NRC)/Baiji is shown in **Figure 1**. The calculations of this study are based on the mathematical models and MATLAB codes that build for the previous study of energy and exergy analysis for a steam cycle of North Refineries Company (NRC), Baiji / Iraq [25], which involve the full analysis for the cycle. In order to seek for improvement ways for the cycle, the operational modifications such as superheating the steam, increasing the boilers pressure, and lowering the main condenser (COND1) pressure are selected in this paper. Their effects on the cycle exergy efficiency are studied actually and separately by recording the readings for each modification at real operating load for each component included in the cycle, at this operating load the super-heated steam (S.H.S) that generated in the boilers have temperature of 374.5 oC, pressure of 22.3 bar, and condenser pressure of 0.8 bar. Also, the exergy efficiency of the cycle at real load was 23.65 %.

The superheating steam can be done actually in the plant by increasing the heat input to the boilers (Boilers), Waste heat recovery boilers WHRB1 and WHRB2 by a 15 ^{o}C and then by 30 ^{o}C. The increasing of the boiler pressure also can be done actually in the plant through increasing the heat input process to the boilers which also increase the inlet pressure to turbines, the pressure range selected is increasing by 1.5 bar and 3 bar. Finally, lowering main condenser (COND1) pressure by 0.3 bar and 0.6 bar will decrease the saturated temperature at which the heat rejected from the cycle. After tabulating the readings of pressure and temperature of the cycle components which collected during testing the above modifications, the readings are supplied to the MATLAB code in order to run the calculations and present the results of total exergy in and total exergy destructions of the cycle to compute the second low efficiency or the exergy efficiency which can be defined as a useful tool for evaluating the potential improvement in the given cycle [26]. The calculations of the exergy were based on dead state of temperature 25 ^{o}C and pressure 1.0132 Bar. The equations of exergy efficiency can be in the form of exergy as below [24]:

$$\boldsymbol{\eta_{II}} = \frac{\textbf{Exergy recovered}}{\textbf{Exergy expanded}} = \mathbf{1} - \frac{\textbf{Exergy destroyed}}{\textbf{Exergy expanded}} \quad (1)$$

For the steam cycle, the modeling equations of the exergy efficiency are based on the total exergy destructions in the cycle as illustrated in equations (2-4).

$$\dot{\boldsymbol{I}}_{des,cycle} = \dot{\boldsymbol{I}}_{des,Boiler} + \dot{\boldsymbol{I}}_{des,WHRB1} + \dot{\boldsymbol{I}}_{des,WHRB2} + \dot{\boldsymbol{I}}_{des,Turbines} + \dot{\boldsymbol{I}}_{des,Pumps} + \dot{\boldsymbol{I}}_{des,Condensers} + \dot{\boldsymbol{I}}_{des,E.V} + \dot{\boldsymbol{I}}_{des,H.E} + \dot{\boldsymbol{I}}_{des,L.H} + \dot{\boldsymbol{I}}_{des,Dea} + \dot{\boldsymbol{I}}_{des,ADT} + \dot{\boldsymbol{I}}_{des,FPT} + \dot{\boldsymbol{I}}_{des,MISC} \,. \quad (2)$$

$$\dot{\mathbf{X}}_{\mathbf{input,cycle}} = \dot{\mathbf{X}}_{\mathbf{f,Boiler}} + \dot{\mathbf{X}}_{\mathbf{f,WHRB1}} + \dot{\mathbf{X}}_{\mathbf{f,WHRB2}} + \dot{\mathbf{X}}_{\mathbf{2}} - \dot{\mathbf{X}}_{\mathbf{1}} \quad (3)$$

$$\eta_{II,cycle} = 1 - \frac{\dot{I}_{des,cycle}}{\dot{X}_{input,cycle}} \quad (4)$$

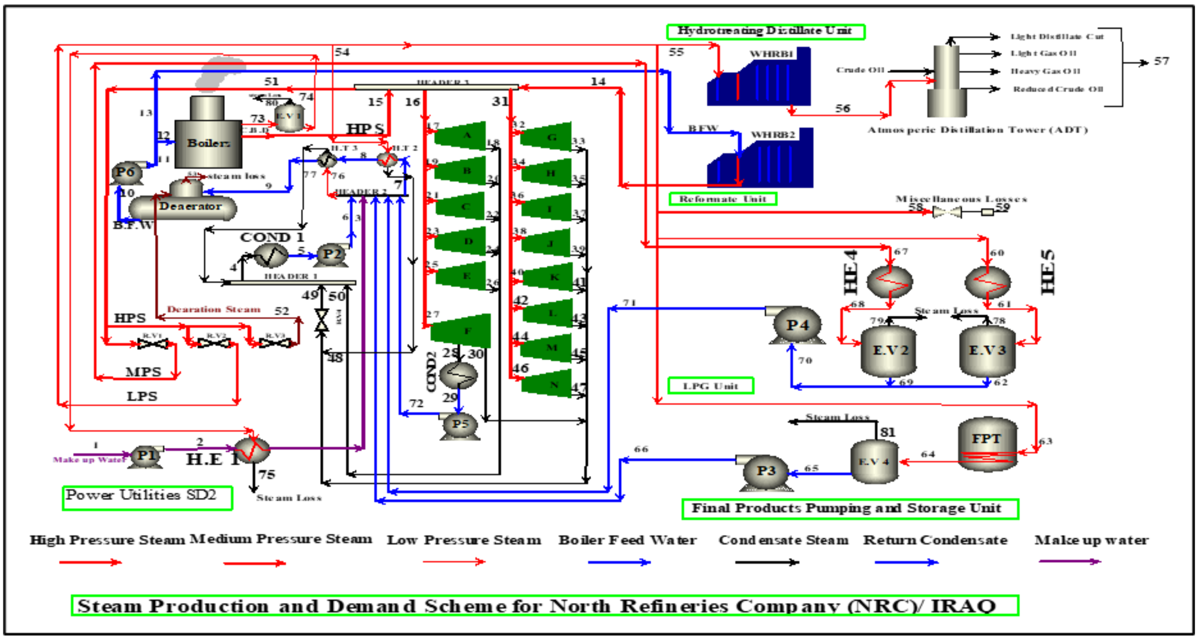

Figure 1. Flow diagram of steam cycle

RESULTS AND DISCUSSIONS

Calculations are conducted by using MATLAB program in order to reduce the work of studying the effect of modifications such as increasing steam temperature / pressure and reducing the main condenser (COND1) pressure. These modifications are indexed in reference book [24] in order to increase the thermal efficiency for steam generation plants working according to Rankin cycle. since exergy analysis is connected to the quality of the steam and the exergy efficiency is a standard measurement for the range of improvements, it is produced here instead of the thermal efficiency to show the effect of these modifications on the exergy efficiency. The results of superheating the steam in boilers, (WHRB1) and (WHRB2) are summarized in Table 1 , it expressed that superheating the steam in constant pressure - heat input process by increasing its temperature from 374.5 oC by 15 oC and then by 30 oC will increase the exergy efficiency by 0.52 %, and 0.68 %, respectively. Increasing the super-heated steam temperature means to increase the exergy input to the cycle and the work produced by the turbines which will lead to reduce in the exergy destructions for the turbines and the cycle at all. Another benefit for superheating the steam is to reduce the moisture content of the steam generated, that will ensure reaching the super-heated steam to all turbines in its best quality and this another reason for reducing the exergy destructions in the cycle and improving the exergy efficiency as illustrated in Figure 2.

Also, Table 2 shows the effect of increasing working pressure of the boilers. it can be concluded from this table, that raising up this pressure from 22.3 bar by 1.5 bar and then by 3 bar will raise the exergy efficiency of the cycle by 0.89 %, and 1.57 %, respectively. Raising up the boilers pressure means increase the temperature of the boiling at which the boiling occurs, this will increase the exergy transferred by mass flowrates that provided to the turbines and will increase the total power produced by the cycle and lowering the total exergy destructions which will improve the exergy efficiency for the cycle as in Figure 3. On the other hand, Table 3 explains the effect of lowering the main condenser (COND1) pressure from 0.8 bar by 0.3 bar and then by 0.6 bar. The results showed that decreasing the main condenser (COND1) pressure by 0.3 bar and 0.6 bar without increasing the exergy input to the cycle will increase the exergy efficiency by 9.1 %,15.61 %. This is because of, lowering condenser pressure leads to lower the back pressure of the turbines and produce further power by the cycle. another reason can be explain this increase which is, since the pressure is connected with the temperature at which the heat energy is rejected by the condenser, decreasing the pressure of the condenser will decrease the temperature of heat rejection to the air and this will reduce the temperature difference between the steam (system) and the air (surroundings) and this will reduce the entropy generated and irreversibilities which means decrease in the exergy destructions of the cycle and cause clearly improvement in the exergy efficiency as in Figure 4. Finally, the above modifications had showed an interested results related to enhancement the exergy efficiency, and the results are matched with the previous studies in [18]–[20].

Table 1. Results of superheating steam on the exergy efficiency of the steam cycle

Modification type	Results			
Superheating steam	S.H.S Temperature (^{o}C)	374.5	389.5	404.5
	Exergy input to the cycle (MW)	80.700	80.810	81.236
	Total exergy destructions (MW)	61.580	61.278	61.471
	Cycle Exergy efficiency (%)	23.65	24.17	24.33

Table 2. Results of increasing pressure of steam on the exergy efficiency of the steam cycle

Modification type	Results			
Increasing boiler pressure	Boiler pressure (bar)	22.3	23.8	25.3
	Exergy input to the cycle (MW)	80.7	81.12	81.482
	Total exergy destructions (MW)	61.580	61.213	60.932
	Exergy efficiency (%)	23.65	24.54	25.22

Table 3. Results of lowering condenser pressure on the exergy efficiency of the steam cycle

Modification type	Results			
Lowering main condenser pressure	Main condenser Pressure (bar)	0.8	0.5	0.2
	Exergy input to the cycle (MW)	80.700	80.700	80.700
	Total exergy destructions (MW)	61.580	54.274	49.017
	Exergy efficiency (%)	23.65	32.75	39.26

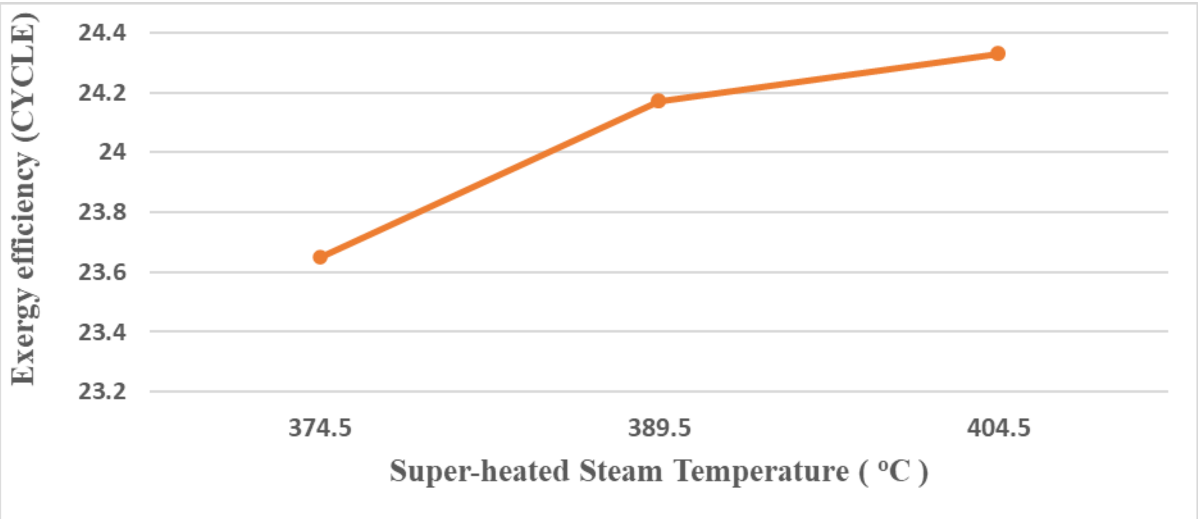

Figure 2. Effect of superheating steam on the exergy efficiency of the steam cycle

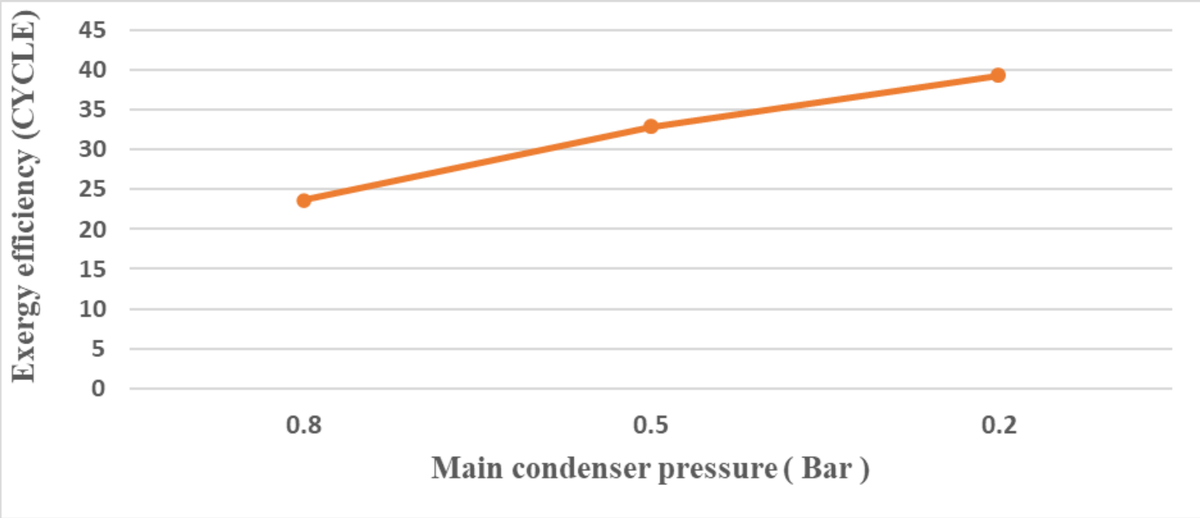

Figure 3. Effect of increasing the boiler pressure on the exergy efficiency of the steam cycle

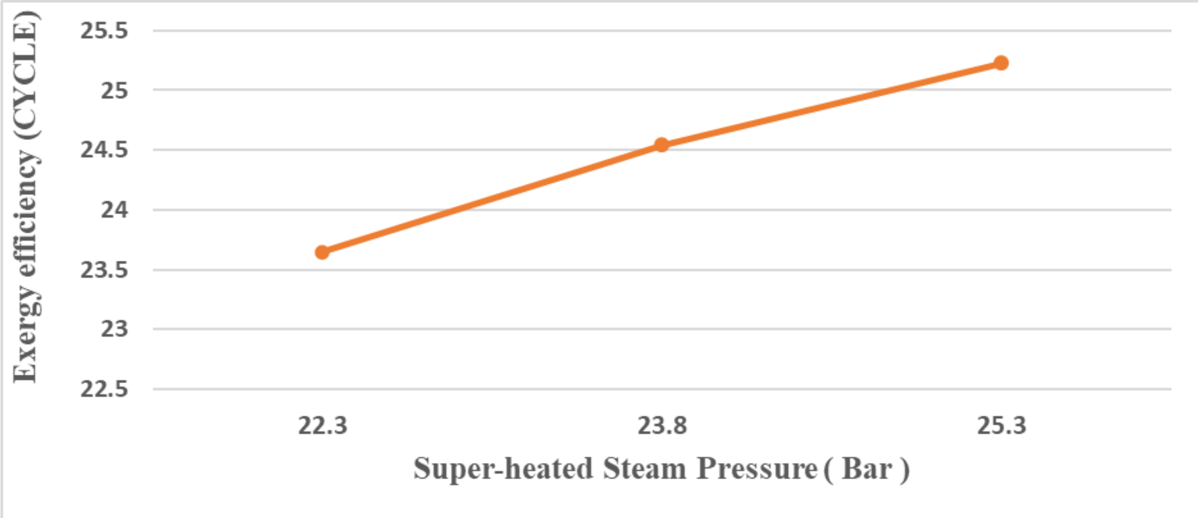

Figure 4. Effect of lowering main condenser pressure on the exergy efficiency of steam cycle

CONCLUSIONS

The following points are concluded from the present study:

1- Superheating the steam or raising its pressure will increase the exergy efficiency of the steam cycle.

2- Lowering the main condenser (COND1) pressure will also raise the exergy efficiency of the steam cycle.

3- The most effective modification in this study is the lowering condenser pressure, this is because its directly responded to the back pressure turbines (see Figure 1) since the exhaust steam of the turbines are collected and passed through main condenser. That explain the reason behind its direct impact on the power producing and raising the exergy efficiency of the cycle.

RECOMMENDATIONS

The author recommended these points for the operational engineers in the steam generation plant in the refinery in order to increase the thermal performance of the plant.

1- If the turbines power desired its recommended to superheating the steam without over-ranges values of the temperatures mentioned in this study. Taking into account this method needs more heat energy supplied by the fuel combustion in the boilers.

2- If the turbines power and cycle efficiency raising are desired without burning more fuel, its recommended to lower the condenser pressure, this method seems more economically as it can be conduct without increasing the fuel combustion in the boilers.

3- Please note, that these modifications are constrained by design limitations for the plant, lines, and component, such as metallurgy limits of the metals of the cycle components. So, in the case of increasing S.H.S temperature/pressure, the increasing should not exceed the maximum design temperature/pressure for the plant and its accessories of the refinery. Also, lowering condenser pressure should be according to the design limits to prevent the condenser from the high-vacuumed pressure which cause a vacuum pressure leakage that makes the air enters inside the condenser. These mentioned constraints are shortcomings this study.

4- For future studies, it is preferred to study the effect of reducing the number of feed water heaters on the exergy efficiency of the cycle.

NOMENCLATURES

Terms	Description	Units
S. H. S	Super-heated steam	/
Boilers	Steam generation boilers	/
COND1	Main condenser in the cycle	/
ψ	Exergy rate	MW
$\dot{I}_{destroyed}$	Exergy destruction rate	MW
$\dot{X}_{input,cycle}$	Exergy input to the cycle	MW
η_{II}	Second- law or exergy efficiency of the cycle	/

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