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Environmental effect on the exeroeconomic performance of combined cycle power plant for hot climate (Mosul Climate)

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Abastract

The rise of air temperature in hot countries to levels exceeding 50 degrees has become one of the most important challenges facing power plants in terms of environmental pollution and low performance. Iraq is among those countries with hot summer. In this work a proposed combined cycle gas turbine power plant is studied. Energy, exergy, economic, exergoeconomic and exergoenvironmental analysis were conducted, using Fortran software. In this paper we propose to add triple pressure HRSG and three pressure steam turbines to the existing gas turbine in Qayyarah power plant and repowering it to become combined cycle. The objective of this work is to estimate the effect of hot environment on exergoeconomic and exergoenvironmental performance, the estimations are done in three parts, first one is the effect of variation ambient temperature and compressor pressure ratio PR) on the performance of proposed combined cycle gas turbine power plant. The performance parameters of the plant considered are exergy destruction and exergy efficiency. The second part is the extent to which this increases in ambient temperature harms the environment, by calculating the exergoenvironmental parameters. The third case: Adding a supplementary firing at the inlet of the heat recovery steam generator. The effect of supplementary firing degree on the exergoenvironmental factors were considered.

The result indicates that the effect of increasing ambient temperature and pressure ratio on the negatively affects the performance and environment for the HRSG, while there is an improvement in the performance and the exergoenvironmental factors for CCGT. Adding the supplementary firing increases the power output of the plant, but negatively affects the environment.

***Keywords**: Exergoeconomic; Exergoenvironmental; Ambient temperature; Supplementary firing*

Introduction

Despite the increase in the participation of power plants that operate on renewable energy in industrialized countries, the largest proportion of the energy consumed remains dependent on thermal power plants, which operate on the consumption of fossil fuels. Consuming this type of fuel contributes significantly to harming the environment. As the air temperature increases, the need for electrical energy increases. Which means, an increase in environmental pollution on the one hand and on the other hand an increase in air temperature leads to a decrease in the efficiency of thermal plants. Therefore, increasing the air temperature has a negative effect from several aspects. Industrial processes that require thermal or chemical energy and other power plants in general, and inefficient processes in particular, contribute significantly to greenhouse gas emissions, including carbon dioxide(Soltanieh, Azar, and Saber 2012) *and* (Soltani, Fennell, and Mac Dowell 2017). *One of the many attempts to improve the performance of gas turbines is to study the effect of ambient air temperature T_0 at the compressor inlet. Dozens of these researches can be found in gas turbine and thermodynamics literature* (Alhazmy and Najjar 2004). *The combustion of fossil fuels leads to the emission of carbon dioxide and other greenhouse gases, and it is considered the number one responsible for global warming* (Ferrara et al. 2017).

In the literature we find an unspecified number of studies. These studies dealt with the impact of climate on the performance of power plants, and other studies dealt with the impact of power plants on the environment. We review here some studies that we considered as a reference for comparison with the results obtained. Malik et al. studied exergoeconomic of steam turbine, they concluded that boiler have a highest exergy destruction. They stated that the exergoeconomic factor decrease for 11% by increasing ambient temperature from 15 ºC to 35ºC(Radwan 2019). *Ratlamwala et. al. they carried out a comparison of two systems, The effect of weather on the exergoenvironmental performance exergoenvironmental factor, coefficient of exergoenvironmental impact and effectiveness factor of environmental damage of the system from energy, exergy, environment, and sustainable perspective is studied* (Ratlamwala, Dincer, and Gadalla 2013). *For gas turbine combustion chamber is considered as a significant part for the exergy destruction, and the inlet temperature of turbine has an impact on exergy destruction and exergy efficiency* (Al Doori 2012) . *The Exergy destruction in the boiler for steam power plant is larger than all other irreversibility's in the cycle. Boiler can count alone for 82.72% of the plant while the condenser destruction losses are only 4.21%* (Shamet, Ahmed, and Nasreldin Abdalla n.d.). *The combined cycle power plant outperforms the conventional cycles gas turbine and steam turbine in all respects - the generation capacity, the efficiency, and the environmental impact, in terms of fuel consumption, which reduces emissions* (Choi, Ahn, and Kim 2014) *and* (Ehyaei et al. 2012).

System Direction

The unit used in the Qayyarah station is General Electric GE Frame 9e. The unit operates with a load of 125 MW as design load. The proposed addition to the current plant is evaporative cooling to a gas turbine, HRSG with three sections different pressure, and three steam turbines as shown in Figure1

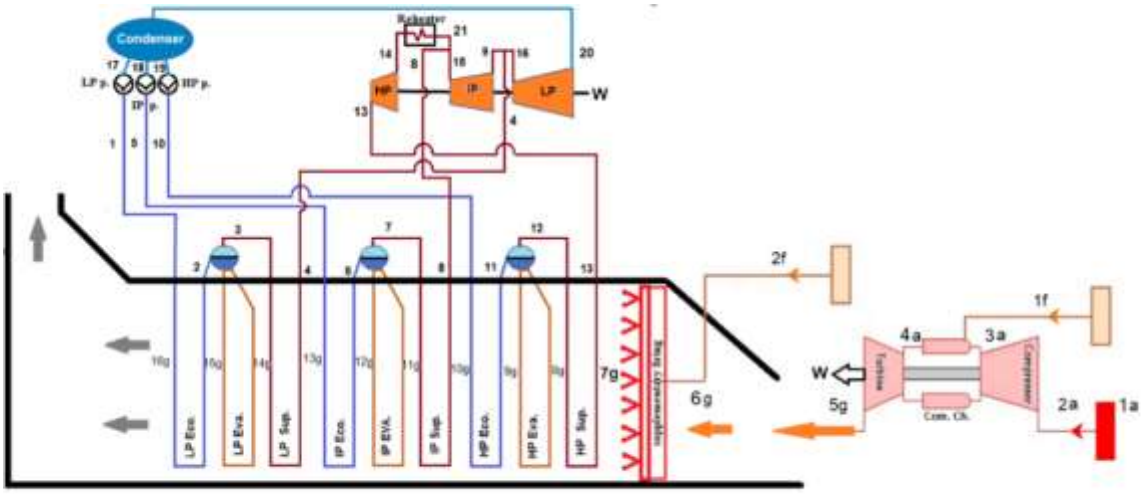

Figure 1 combined cycle power plant

Energy analysis

Simple cycle gas turbine model

The simple gas turbine chosen for this study is the gas turbine used in Qayyarah gas turbine powerplant. It is General Electric GE frame 9E. The unit design with 125 [MW] power output, the schematic diagram illustrated in Figure 2. It consists of conventional parts. Air enters the compressor under standard condition.

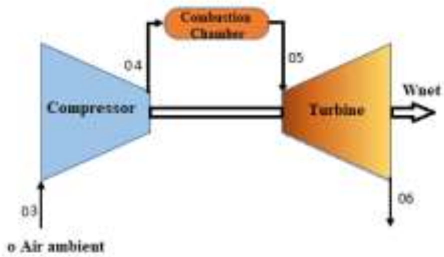

Figure 2 Simple gas turbine

Table 1 summarized the assumptions.(dos Santos, Andrade, and Zaparoli 2012)

1	State 04 figure 2 as ideal gas	2	assuming no pressure drop at air intake and exhaust ducts	3	Ambient pressure $P_0 = 101.3\ kPa$
4	Ambient temp. $T_0 = 15$ ℃	5	Compressor isentropic efficiency 85%	6	Gas turbine power =120MW
7	combustion chamber pressure drops $\Delta P_{cc} = 0.02$				

Thus, the thermodynamic model for gas turbine is presented in the equations (1-4).

The work of the compressor W_C and turbine work W_C are calculated as follows:

$$W_C = m_a . C_{pa} . (T_{04} - T_{03}) \quad (1)$$

$$C_{Pa}(T) = 1.04841 - \left(\frac{3.8371T}{10^4}\right) + \left(\frac{9.4537T^2}{10^7}\right) - \left(\frac{5.490031T^3}{10^{10}}\right) + \left(\frac{7.9298T^4}{10^{14}}\right) \quad (2)$$

$$W_T = m_g . C_{pa} . (T_{05} - T_{06}) \quad (3)$$

$$C_{Pg}(T) = 0.991615 + \left(\frac{6.99703T}{10^5}\right) + \left(\frac{2.7129T^2}{10^7}\right) - \left(\frac{1.2244T^3}{10^{10}}\right) \quad (4)$$

Fuel mass flow rate m_f computed sa:

$$m_f = \frac{Q_{in}}{LHV \times \eta_{com}} = \frac{C_{pg}.(T_{05} - T_{04})}{LHV \times \eta_{com}} \quad (5)$$

Where m_a, C_{pa}, m_g, C_{pg}, and LHV are air mass flow rate, air specific heat capacity, gas mass flow rate, gas specific heat and fuel lower heating value respectively

Supplementary firing (Duct Burner)

For the purposes of increasing the production capacity of combined cycle power plant, several methods are used, one of these methods was used in this research, which is the supplement firing of the HRSG contains additional burners located in the inlet of the HRSG. The working principle of the supplementary firing is to add fuel to the gas turbine exhaust gases, to be reheated before entering the steam generator. The supplementary burner is usually added when the temperature of the exhaust gases increases, and this also happens in countries that have a hot summer, because an increase in the ambient temperature leads to a decrease in the density of air, and the power output of the combined cycle decrease. Additional firing in the duct burner results in make up the decrease in the power output.

Applying Energy balance cross the burner control volume boundary, gas temperature after burner can be determined

$$h_{6g}.\dot{m}_t + \dot{m}_{2f}.LHV.\eta_{burner} = h_{7g}.(\dot{m}_t + \dot{m}_{2f}) \quad (6)$$

HRSG

Mass and energy rate balances for HRSG components are illustrated in (Mohammed and Petrović 2015)

$$m_{w,LP}(h_4 - h_1) = m_g(h_{13g} - h_{16g}) \quad (7)$$

$$m_{w,IP}(h_8 - h_5) = m_g(h_{10g} - h_{13g}) \quad (8)$$

$$m_{w,HP}(h_{13} - h_{10}) = m_g(h_{7g} - h_{10g}) \quad (9)$$

Steam turbine

Steam turbine work and efficiency are given as follows:

$$W_{ST,total} = W_{ST,LP} + W_{ST,IP} + W_{ST,HP} \quad (10)$$

$$W_{ST,total} = (m_{w,LP} + m_{w,IP} + m_{w,HP}).(h_{16} - h_{20}) + (m_{w,IP} + m_{w,HP}).(h_{15} - h_9) + m_{w,HP}.(h_{13} - h_{14}) \quad (11)$$

$$\eta_{ST} = \frac{W_{ST,total}}{(h_4 - h_1) + (h_8 - h_5) + (h_{13} - h_{10}) + (h_{14} - h_{15})} \quad (12)$$

CCGT efficiency $\eta_{th,CCGT}$

$$\eta_{th,CCGT} = \frac{W_T + W_{ST,total} - W_C - W_{pumps}}{\dot{m}_{1f}LHV_f + \dot{m}_{2f}LHV_f} \quad (13)$$

Exergy $\dot{E}_x$ analysis

Exergy destruction $\dot{E}_D$ and exergy efficiency ε

When the highest available work cannot be found using energy analysis, then exergy analysis is capable to calculate the irreversibility closer to the real process (Mohammed and Petrović 2015). *exergy destruction $\dot{E}_D$, exergy efficiency ε and exergy destruction rate y_D for each component of the system are calculated by equations (26 and 27) and illustrated in table (2)*

$$\dot{E}_D = \dot{E}_{in} - \dot{E}_{out} \quad (14)$$

$$\varepsilon = \frac{\dot{E}_{out}}{\dot{E}_{in}} = 1 - \frac{\dot{E}_D}{\dot{E}_{in}} \quad (15)$$

$$y_D = \frac{\dot{E}_D}{\dot{E}_{F,TOT}} \quad (16)$$

No.	Component	Exergy efficiency	Exergy destruction $\dot{E}x_D$
1	Gas turbine	$\frac{\dot{W}_{\mathrm{GT}}, net}{\dot{m}_{3a}ex_{3a}+\dot{m}_{1\mathrm{f}}ex_{1f}}$	$\dot{m}_{3a}ex_{3a}+\dot{m}_{1f}ex_{1f}-\dot{W}_{\mathrm{GT,net}}-\dot{m}_{6\mathrm{g}}ex_{6\mathrm{g}}$
2	HRSG	$\frac{\dot{m}_1(ex_4-ex_1)+\dot{m}_5(ex_8-ex_5}{\dot{m}_{6\mathrm{g}}ex_{6\mathrm{g}}-\dot{m}_{16\mathrm{g}}ex_{16\mathrm{g}}+\dot{m}_{2f}ex_{2f}}+\frac{\dot{m}_{10}(ex_{13}-ex_{10})}{\dot{m}_{6\mathrm{g}}ex_{6\mathrm{g}}-\dot{m}_{16\mathrm{g}}ex_{16\mathrm{g}}+\dot{m}_{2f}ex_{2f}}$	$\dot{m}_{6\mathrm{g}}ex_{6\mathrm{g}}+\dot{m}_{2f}ex_{2f}+\dot{m}_1ex_1+\dot{m}_5ex_5+\dot{m}_{10}ex_{10}-\dot{m}_1ex_4-\dot{m}_5ex_8-\dot{m}_5ex_8-\dot{m}_{16\mathrm{g}}ex_{16\mathrm{g}}$
3	Steam turbine	$\frac{\dot{W}_{\mathrm{ST}}, net}{\dot{m}_{13}ex_{13}+\dot{m}_{15}ex_{15}+\dot{m}_{16}ex_{16}}$	$\dot{m}_{13}ex_{13}+\dot{m}_{15}ex_{15}+\dot{m}_{16}ex_{16}-\dot{m}_{14}ex_{14}-\dot{m}_{20}ex_{20}-\dot{W}_{ST,net}$
4	pumps	$\frac{\dot{m}_1ex_{17}+\dot{m}_5ex_{18}+\dot{m}_{10}ex_{19}}{(\dot{m}_1+\dot{m}_5+\dot{m}_{10})ex_{20}}$	$(\dot{m}_1+\dot{m}_5+\dot{m}_{10})ex_{20}-\dot{m}_1ex_{17}-\dot{m}_5ex_{18}-\dot{m}_{10}ex_{19}$

CCGT exergy efficency

$$\varepsilon_{CCGT}=\frac{\dot{W}_{ST,net}+\dot{W}_{GT,net}}{\dot{m}_{1a}ex_{1a}+\dot{m}_{1w}ex_{1w}+\dot{m}_{1f}LHV_f+\dot{m}_{2f}LHV_f} \quad (17)$$

Exergoeconomic Model

Exergoeconomic is a relatively new branch of engineering. It was developed to enable engineers to combine economic and thermodynamics of the system at the level of the part, in this composition, thermodynamics are studied on the basis of exergy analysis (Dr. Mohammed Saleh Mohammed et al., 2019).

1.1. Economic analysis

The economic model requires finding the cost of the components of the system in terms of thermodynamic parameters, and these functions were found by researchers and manufacturers. In this paper, the functions used by the researcher will be used. The total cost of the system includes the amortization and maintenance and the cost of fuel combustion, The cost function of components that are accepted here are similar (Dr. Mohammed Saleh Mohammed et al., 2019).

1.2. General cost balance equations:

Cost balance is the stage that follows the exergetic and economic analysis. The cost balance equation is applied to each j^{th} part of the system, and the equation stipulates equality between the cost of exergy streams entering and exiting to and from the system plus the cost rate associated with the capital investment and operating maintenance costs [13].

$$\sum_e \dot{C}_{ej}+\dot{C}_{w,j}=\sum_i \dot{C}_{i,j}+\dot{C}_{q,j}+\dot{Z}_j\dot{C}_j=c_j\dot{E}x_j \quad (18)$$

where $\dot{C}_j$, $\dot{C}_{w,j}$ and $\dot{Z}_j$are the exergy costs of the streams, exergy cost of the power and total cost of the equipment (include investment, operating and maintenance costs); c_j is the unit exergy costs of stream and power; $\dot{E}x_j$ is the exergy of stream, i, e, q indicate the entering, exiting, heat and work streams for component j

1.3. Total cost rate $\dot{C}Z_{total}$

The total cost rate $\dot{C}Z_{total}$ is defined as the sum of the cost rate of exergy destruction $\dot{C}_{D,j}$ and total cost of the equipment $\dot{Z}_j$. Total cost rate $\dot{C}Z_{total}$ is one of the important exergoeconomic indicators in the comparative assessment of alternative options. The higher this indicator, the lower exergoeconomic performance of the system

1.4. Exergoeconomic Factor

The Exergoeconomic factor f_j enables us to know the relationship between the total cost (the purchase, maintenance, and operation cost) and the cost of the exergy destroyed in the system as in the following equation:

$$f_j = \frac{\dot{Z}_j}{\dot{Z}_j + \dot{C}_{D,j}} \quad (19)$$

Where an increase in this factor indicates that the total cost has a greater weight than the destroyed exergy costs, and vice versa

Exergoenvironmental Analysis

The relationship between the Exergy Destruction $\dot{E}_D$ *and the environment can be determined by conducting an Exergoenvironmental analysis, some of the researchers used another factor to know the effect of the irreversibility of the thermal system on the environment. Exergoenvironmental factor* f_{ei} *illustrates that relationship* (Ratlamwala, Dincer, Gadalla, 2013) *and* (Midilli and Dincer 2009)

$$f_{ei} = \frac{\dot{E}_{D,total}}{\sum \dot{E}x_{in}} \quad (20)$$

As for assessing the effectiveness of damage to the environment resulting from inefficiency of thermal systems, the effectiveness factor of environmental damage θ_{ei} *is used. This factor can be evaluated as* (Fiaschi et al. 2017)

$$\theta_{ei} = f_{ei} . C_{ei} \quad (21)$$

where C_{ei} *is the coefficient of Exergoenvironmental impact, this coefficient can be calculated as:*

$$C_{ei} = \frac{1}{\varepsilon_{CCGT}} \quad (22)$$

This coefficient is a measure of damage to the environment caused by a system (Hashemian and Noorpoor 2019), (Ratlamwala, Dincer, and Reddy 2013)

Result and Discussion

The influence of parameters in terms of theT_0*, PR, and degree of supplementary firing* SFD *on the performance of CCGT and on environmental parameters are presented in this section. The effects of operating conditions on the exergy destruction* Ex_D *and exergy efficiency* ε *are obtained from the exergy-balance, utilizing Fortran 90 software*

1.5. Result of Exergy and Exergoeconomic Analysis

Results of the effects of gas turbine parameters and the weather conditions, represented by the PR and the T_0 *, on the performance of the CCGT and HRSG. In this paper, Exergy efficiency* ε*, exergy destruction rate* $\dot{E}x_D$ *and total cost rate* $\dot{\boldsymbol{C}}\boldsymbol{Z}_{total}$ *as a result of exergoeconomic analysis will be considered as affected parameters. Figure 3 and 4 shows that the* ε_{CCGT} *will be increased with increasing of* T_0*, and PR, while reduces with increasing of* SFD*. Figure 5 and 6 shows the variation of* ε_{CCGT} *of HRSG* ε_{HRSG} *with* T_0*, PR and SFD. The efficiency of the HRSG reduces with increasing of* T_0*, PR and* SFD*.*

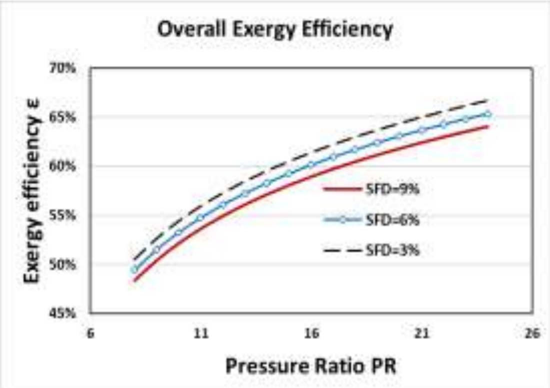

Figure 3 Effect of PR and SFD on the ε_{CCGT}

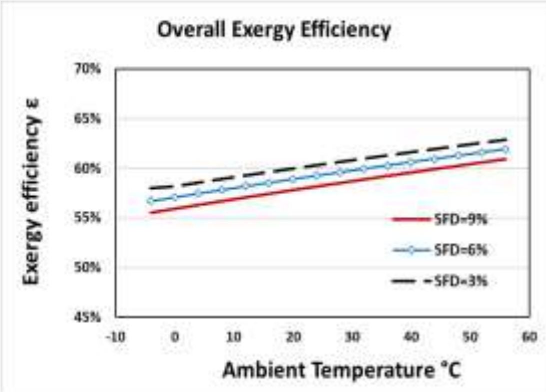

Figure 4 Effect of aT_0*, e and* SFD *on the* ε_{CCGT}

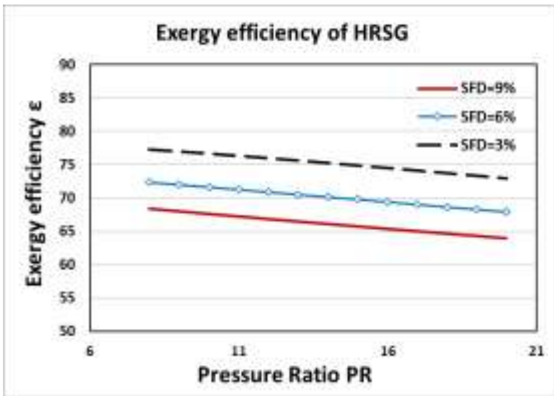

Figure 5 Effect of PR and SFD on the ε_{HRSG}

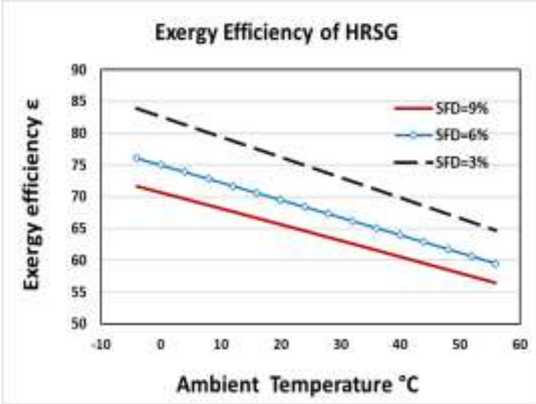

Figure 6 Effect of T_0 and SFD on the ε_{HRSG}

It appears from the curve of the relationship between the total cost rate and the ambient temperature Figure 7 that there is a maximum value for, $\dot{C}\boldsymbol{Z}_{total}$ while this factor increases with the increase of SFD. On the other hand, we notice that there is a minimum value of $\dot{C}\boldsymbol{Z}_{total}$ when the pressure ratio increases, as shown in the figure 8.

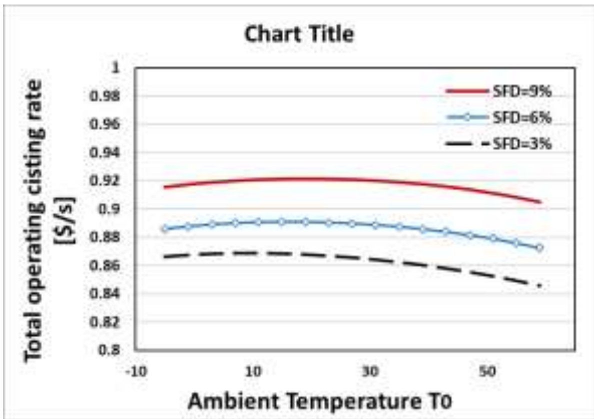

Figure 7 Effect of T_0 and SFD on $\dot{C}\boldsymbol{Z}_{total}$

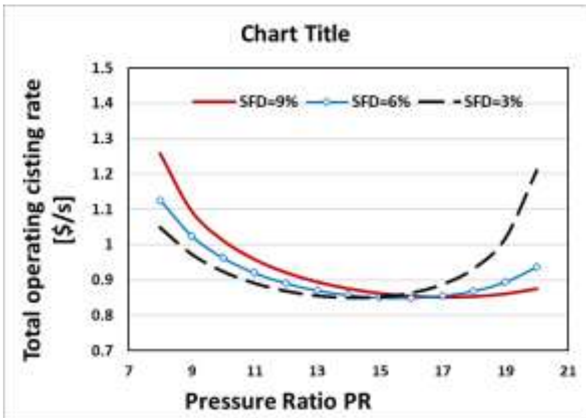

Figure 8 Effect of PR and SFD on $\dot{C}\boldsymbol{Z}_{total}$

1.6. Result of Exergoenvironmental analysis

The Exergoenvironmental analysis was carried out in two parts.

1.6.1. The first one is the effect of gas turbine parameters on the exergoenvironmental performance of the CCGT and HRSG. Figures (9-14)

Figures 9, 10 displays the effect of T_0 on the exergoenvironmental performance exergoenvironmental factor f_{ei}, coefficient of exergoenvironmental impact C_{ei} and effectiveness factor of environmental damage θei of the CCGT and HRSG. Figures 9 shows that the increase of ambient temperature leads to reduce in all three factors (f_{ei}, C_{ei} and θei). Increasing f_{ei} is undesirable because the reference value of this factor is "zero" at this value the best exergy is obtained. Also, second factor C_{ei} decrease, the ideal case for this factor should be one, because C_{ei} is related to exergy efficiency of the system. The effectiveness factor of environmental damage θei is very important factor, because the value of parameter gives an indicate whether or not the combined cycle damage environment due to exergy losses (exergy destruction and exergy west). Figures 10 shows the variation of HRSG exergoenvironmental factors (f_{ei}, C_{ei} and θei) as a result of variation of gas turbine ambient. The figures shows that the behaviors of the exergoenvironmental factors of HRSG, with increasing of ambient temperature completely opposite to the behaviors of the exergoenvironmental parameters of the whole plant, but with different values.

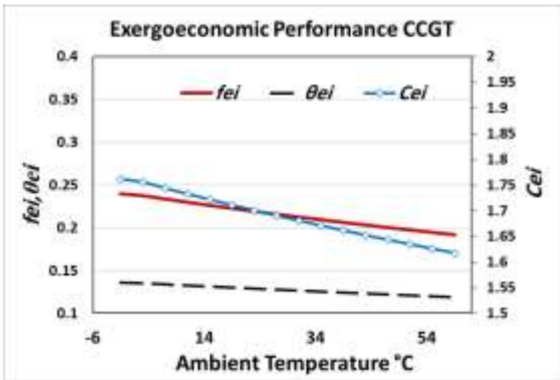

Figure 9 Effect of ambient temperature on CCGT exergoenvironmental factors

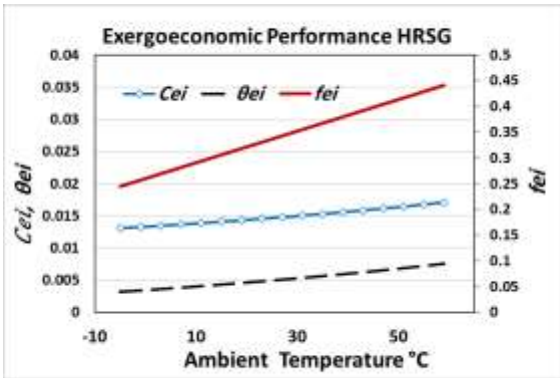

Figure 10 Effect of ambient temperature on HRSG exergoenvironmental factors

Figures 12 and 13 shows the range in which the exergoenvironmental parameters change with the PR of the compressor in gas turbine. If we compare the shape of the curves in the previous relationships, we will find that there is a similarity in the shape of the change in terms of the increase in the factors in the HRSG and their decrease in the CCGT with the increasing in the pressure factor, but with different values and gradients.

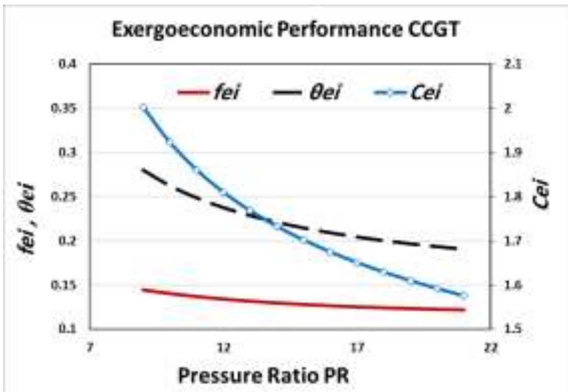

Figure 11 Effect of PR on CCGT exergoenvironmental factors

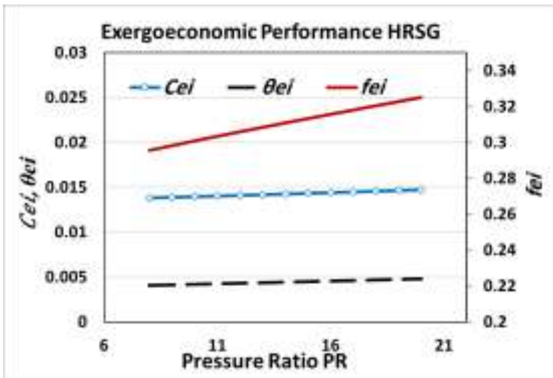

Figure 12 Effect of PR on HRSG exergoenvironmental factors

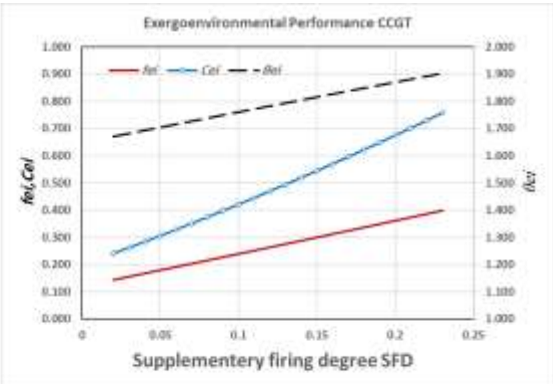

Figure 13 Effect of SFD on CCGT exergoenvironmental factors

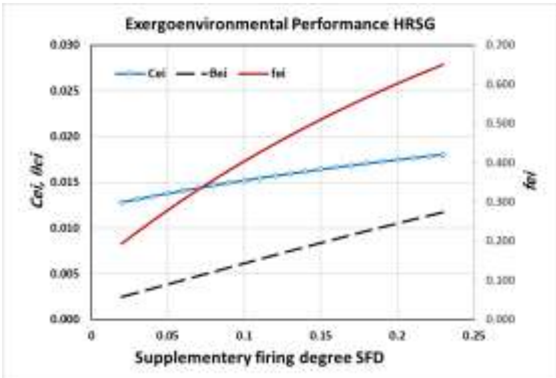

Figure 14 Effect of SFD on HRSG exergoenvironmental factors

1.6.2. The second is the effect of SFD on the Exergoenvironmental performance of CCGT and HHRG

The results of adding additional burning to the HRSG are presented in figures 13 and 14. The situation seems undesirable from an environmental point of view in the HRSG performance as well as the CCGT as a whole. Figures shows that by increasing supplementary firing degree SFD all factors are increases.

Conclusion

In this paper, exergoeconomic and exergoenvironmental analyzes of the proposed combined cycle power plant were performed. The combined cycle consists of an existing gas turbine (currently in Qayyarah) plus the proposed units to be added. These units are HRSG and a steam turbine. This process is called complete full repowering. These analyzes aims to estimate the expected *impact on the environment as a result of the harsh conditions in Iraq (Mosul city) in terms of high temperatures, as well as the impact of high temperatures on the performance of proposed CCGT. For these purposes, a Fortran program was developed to calculate these effects. In this model, the net output of the gas turbine is fixed at 120 [MW].*

Many previous researches, some of which were mentioned in the introduction, concluded that the boiler in the steam turbine power plant is responsible for the highest value of exergy distribution, as well as the combustion chamber in the gas turbine power plant, and that increasing the ambient temperature leads to an increase in the exergy destruction in the traditional power plant. Studies also indicate that all indicators of environmental damage are getting worse in these power plant.

The conclusions are summarized as follow

1. Exergy Analysis

a. by increasing the ambient temperature from 15 ºC t0 60 º, the total exergy efficiency increases for 4 %, while the exergy efficiency of the HRSG reduces 15%.

b. By increasing pressure ratio from 8 to 24, the total exergy efficiency increases for 15%, while the exergy efficiency of HRSG reduces for 2%

c. By increasing supplementary firing degree from 0.3% to 9%, the total exergy efficiency reduced by 2%, while the exergy efficiency of HRSG reduces for 3.5%

2. Exergoeconomic Analysis, the total operating cost rate for bottoming cycle has a maximum at $T_0 = 11{,}15\ and\ 19\ for\ SFD = 3\%, 6\%\ and 9\%$ *respectively with a variation of ambient temperature, and minimum for the variation of pressure ratio at* $PR = 17{,}16\ \ and 14\ \ for\ SFD = (3\%, 6\%\ and\ 9\%)$ *respectively*

3. Exergoenvironmental analysis:

a. The result that we observed from the increases in all three factors with the increase in the ambient temperature and pressure coefficient in the HRSG, at the same time there is a decrease for all factors in the CCGT as a whole. We note that these increases at HRSG negatively affect the environment. But it is much less than the positive effect obtained from increases of these factors in the station as a whole

b. With the increase of SFD, all the exergoenvironmental factors in the HRSG and the CCGT increases, so adding the supplementary burner and increasing the SFD negatively affects the environment.

References

Alhazmy, M M, and Yousef S H Najjar. 2004. “Augmentation of Gas Turbine Performance Using Air Coolers.” *Applied thermal engineering* 24(2–3): 415–29.

Choi, Ju Hwan, Ji Ho Ahn, and Tong Seop Kim. 2014. “Performance of a Triple Power Generation Cycle Combining Gas/Steam Turbine Combined Cycle and Solid Oxide Fuel Cell and the Influence of Carbon Capture.” *Applied Thermal Engineering* 71(1): 301–9.

Al Doori, WHAR. 2012. “Exergy Analysis of a Gas Turbine Performance with Effect Cycle Temperatures.” *International Journal of Recent Research and Applied Studies* 13: 549–56.

Dr. Mohammed Saleh Mohammed et al., Dr. Mohammed Saleh Mohammed et al.,. 2019. “Specific Exergy Costing Analysis and Optimization of Ccpp Power Plant.” *International Journal of Mechanical and Production Engineering Research and Development* 9(6): 1189–98.

Ehyaei, M A, Sh Hakimzadeh, N Enadi, and P Ahmadi. 2012. “Exergy, Economic and Environment (3E) Analysis of Absorption Chiller Inlet Air Cooler Used in Gas Turbine Power Plants.” *International Journal of Energy Research* 36(4): 486–98.

Ferrara, G et al. 2017. “Exergetic and Exergoeconomic Analysis of Post-Combustion CO2 Capture Using MEA-Solvent Chemical Absorption.” *Energy* 130: 113–28.

Fiaschi, D, G Manfrida, E Rogai, and L Talluri. 2017. “Exergoeconomic Analysis and Comparison between ORC and Kalina Cycles to Exploit Low and Medium-High Temperature Heat from Two Different Geothermal Sites.” *Energy Conversion and Management* 154: 503–16.

Hashemian, Nasim, and Alireza Noorpoor. 2019. “Assessment and Multi-Criteria Optimization of a Solar and Biomass-Based Multi-Generation System: Thermodynamic, Exergoeconomic and Exergoenvironmental Aspects.” *Energy Conversion and Management* 195: 788–97.

Midilli, Adnan, and Ibrahim Dincer. 2009. “Development of Some Exergetic Parameters for PEM Fuel Cells for Measuring Environmental Impact and Sustainability.” *International Journal of Hydrogen Energy* 34(9): 3858–72.

Mohammed, Mohammed S., and Milan V. Petrović. 2015. “Thermoeconomic Optimization of Triple Pressure Heat Recovery Steam Generator Operating Parameters for Combined Cycle Plants.” *Thermal Science* 9(2): 447–60.

Radwan, Elham M. 2019. “Advanced Exergoeconomic and Exergy Cost Sensitivity Analyses Of 350MW Steam Power Plants.”

Ratlamwala, Tahir A H, Ibrahim Dincer, and Mohamed A Gadalla. 2013. "Comparative Environmental Impact and Sustainability Assessments of Hydrogen and Cooling Production Systems." In *Causes, Impacts and Solutions to Global Warming*, Springer, 389–408.

Ratlamwala, Tahir A H, Ibrahim Dincer, and Bale V Reddy. 2013. "Exergetic and Environmental Impact Assessment of an Integrated System for Utilization of Excess Power from Thermal Power Plant." In *Causes, Impacts and Solutions to Global Warming*, Springer, 803–24.

dos Santos, Ana Paula P, Claudia R Andrade, and Edson L Zaparoli. 2012. "Comparison of Different Gas Turbine Inlet Air Cooling Methods." *World academy of science, engineering and technology* 61: 40–45.

Shamet, Osman, Rana Ahmed, and Kamal Nasreldin Abdalla. "Energy and Exergy Analysis of a Steam Power Plant in Suda." *African Journal of Engineering & Technology* 1(1).

Soltani, Salman Masoudi, Paul S Fennell, and Niall Mac Dowell. 2017. "A Parametric Study of CO2 Capture from Gas-Fired Power Plants Using Monoethanolamine (MEA)." *International Journal of Greenhouse Gas Control* 63: 321–28.

Soltanieh, Mohammad, Karwan Mahmoodi Azar, and Mohammad Saber. 2012. "Development of a Zero Emission Integrated System for Co-Production of Electricity and Methanol through Renewable Hydrogen and CO2 Capture." *International Journal of Greenhouse Gas Control* Complete(7): 145–52. https://www.infona.pl//resource/bwmeta1.element.elsevier-494104b4-2d98-3dcf-8c36-a14acec5dbe5 (January 10, 2022).