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Modelling of Combined Cycle Gas Turbine Power Plant and Reduction of CO_2 Emissions by using Absorption Chiller Technology

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Abstract—**The main purpose of this study is to propose a technical solution for all these issues (increasing demand for electric power, urgent need to reduce air pollution and global warming and the need to improve the combined cycle gas turbine power plant efficiency and prevent the effects of severe ambient conditions). The combined cycle gas turbine power plant is enhanced by utilizing the rejected heat obtained from the condenser to drive an absorption chiller to cool the gas turbine compressor inlet air to a temperature less than the ISO temperature.**

The waste heat from the gas turbine exhaust gases may be utilized to produce hot water via double-pipe heat exchanger. The hot water produced could then be used to drive a single-effect lithium-bromide absorption chiller machine which in turn could be used for air conditioning and food storage requirements with cooling capacity of 1375 refrigeration tonne.

This study has shown that the combined cycle gas turbine power plant integrated with absorption chiller attains output power by 10% when operated at ambient temperature of 47 °C with pre-cooling temperature of 10 °C applied to the compressor inlet air. The amount of carbon dioxide emissions reduced by the absorption chiller was 7%.

The simulation program IPSEpro has been used to do the modelling and simulation of the combined cycle in this study.

Keywords—Li-Br absorption chiller; Combined cycle power plant; IPSEpro software; Global warming.

1. INTRODUCTION

The growing demand for electric power and the rising cost of energy as well as the environmental restrictions on thermal pollution and the depletion of the ozone layer by the global warming and chlorofluorocarbon (CFC) refrigerants, together with the need for energy conservation have created an increasing interest in heat recovery technologies.

Recently, the international society has been increasingly concerned about environmental issues such as global warming and ozone layer depletion in the earth's atmosphere. Various attempts have been made, based on further utilization of waste heat rejected from conventional power cycles, to conserve the available energy sources and limit atmospheric pollution. The further use of the rejected waste heat reduces the specific fuel consumption, as the released amount of energy from a fixed amount of burnt fuel is utilized to a further significant extent, which results in saving energy and limits the amount of combustion products emitted to the atmosphere. According to the pre-mentioned concept, recently, the most successful and attractive method for the efficient use of energy is the linking of more than one conventional power cycle. Cogeneration or CHP (combined heat and power) is the simultaneous production of electricity and heat using a single fuel source such as natural gas.

The use of CHP can reduce the fossil fuel consumption and the emissions to the atmosphere. It can result in reductions of up to 50% in CO_2 emissions compared with conventional sources of heat and power as well as reduced emissions of sulphur dioxide (Cred Carbon Reduction [1]).

Maidment & Tozer [2] have studied the theoretical analysis of an application of an integrated combined cooling heat and power cycle in the supermarket. To increase the utilization time, it has been proposed that heat generated by the CHP could be used to power an absorption refrigeration system to provide cooling effect. They have initially described the cooling, heating, and power requirements of a typical supermarket and reviewed a number of combined cooling, heating, and power options with different cooling and engine technologies. Their investigation compared the energy saving and capital costs of the different options against typical conventional supermarket technology. The results indicate that this application could offer significant primary energy and CO_2 saving in the short to medium term. In the longer term CCHP system will have to complete against more efficient grid generated electricity.

The most important consequence of global warming is the rise of the sea level due to glaciers and the South Pole melting. It has been predicted that there will be more extreme weather such as storms, hurricanes, floods and heat waves. The frequency and the power of this weather are going to increase and the consequence could be dramatic. The combustion of coal, oil and natural gas currently contributes about 5.5 to 6 billion metric tons of carbon per year to the atmosphere in the form of carbon dioxide (United Nations [3]).

In another work by Mohanty & Paloso [4], the option of cooling the intake air to the compressor of the gas turbine engine using absorption chiller in order to increase the gas turbine capacity was investigated. Double effect absorption chiller was powered by steam produced from a recovery boiler. An analysis carried out by taking the weather data of Bangkok indicated that reducing the temperature from ambient condition to 15°C could increase the power output up to 13%. Consequently, the plant's energy output could increase by 11%.

Ameri & Hejazi [5] have presented an overview of an intake air-cooling system that uses steam absorption chiller and an air cooler in the Chabahar power plant. The results show the output power can be increased by 11.3%.

G. Mohan et al [6] developed and analyzed an integrated energy system based on the utilization of exhaust waste heat from an existing natural gas fired turbine power plant for the simultaneous production of electricity from a steam Rankine cycle and cooling from an absorption refrigeration cycle. The results showed that for the integrated trigeneration system, energy efficiency was about 85%, normalized CO_2 emission per MWh was reduced by 51.5%. The simulation results also showed that the performance of the thermal cycles were affected by the ambient air intake temperature.

The results of the analysis presented by I. H. Njoku et al [7] showed that by utilizing the flue gas waste heat of the combined gas- and steam- turbine cycle power plant to power an absorption refrigeration system to cool the inlet air streams to 15°C in the gas turbine plants, additional 51.1 MW of electricity was generated.

M. Elberry et al [8] developed a thermodynamic model which is an integration of a (Lithium Bromide-Water) absorption inlet air cooling scheme to a cooled gas turbine-based combined cycle. The model shows an increase of 11% in the produced electricity when the inlet air was cooled from 30 °C to 10 °C.

This study and many others (Alhamzy & Najjar [9], Kakaras et al [10], Wang et al [11], Hosseini et al [12], MB Bughazem et al [13], Shazly et al [14]) report the same conclusion; that using an absorption chiller to cool the intake air of any gas turbine is economically viable, and can both enhance the plant performance and reduce its impact on the environment.

2. DESCRIPTION OF THE PROPOSED COMBINED POWER SYSTEM

The proposed model as can be seen in Figure (1), comprises of a single shaft combined cycle gas turbine power plant attached to a double-pipe heat exchanger that utilizes the exhaust waste heat of the power plant to produce hot water. The hot water produced will then be used to drive a single-effect lithium-bromide absorption chiller machine (COP = 0.83) which in turn could be used for air conditioning and food storage requirements. The combined cycle gas turbine power plant consists of a gas turbine with a capacity of 46 MW (at ISO), a single pressure level, vertical flow, and a forced circulation heat recovery steam generator (HRSG). The steam turbine has a capacity of 21 MW, and the combined cycle connected with a deaerator that controls the dissolved oxygen level in the makeup water.

The steam turbine condenser has hot stream of water with a temperature of 73 °C that drives an absorption chiller (Figure 2), which produces 1375 RT of cooling capacity at a temperature of 6 °C. Also, the chilled water stream (at a temperature of 6 °C) was circulated between the absorption chiller evaporator and the compressor air intake double-pipe heat exchanger, where it cools the inlet air of the gas turbine from 47 °C to 10 °C with a mass flow rate of 126 kg/s.

3. SIMULATED MODEL RESULTS AND DISCUSSIONS

In this study the proposed power plant was modeled, tested and the results were presented at ISO conditions. Following a parametric study will be performed to evaluate the behavior of the power plant at off-design conditions, including the effect of ambient temperature on power output. Sensitivity analysis will be performed to show the effect of condenser pressure, pinch point temperature and the steam turbine isentropic efficiency on power output.

Reducing carbon dioxide CO_2 emissions to the atmosphere from the generation of electricity can be obtained by improving the efficiency of existing power plants. The benefit of utilizing combined cycle and absorption chiller to reduce CO_2 will be investigated.

3.1 The power plant behavior at ISO conditions

The first set of tests has been performed at ISO conditions (ambient temperature 15°C, relative humidity 60%, and atmospheric pressure 1.01325 bar), with seawater temperature at 25°C. The power plant at this condition was able to produce 67 MW power output with 1375 RT cooling effect for compressor inlet air and another 1375 RT cooling effect for air conditioning and food storage requirements.

Also, the previously defined performance parameters were used to evaluate the power plant performance, such as the overall thermal efficiency and the absorption chiller COP.

Table (1) shows the most important readings and performance parameter results achieved after the first test at ISO conditions for all the systems within the proposed plant. These results indicate that the absorption chiller have not negatively affected after being attached to the power plant, neither has the power plant itself.

The dominant parameters for single effect absorption chillers were chosen to satisfy the gas turbine cooling and air conditioning and food storage requirements; Table (2) states the most important parameters used in this model.

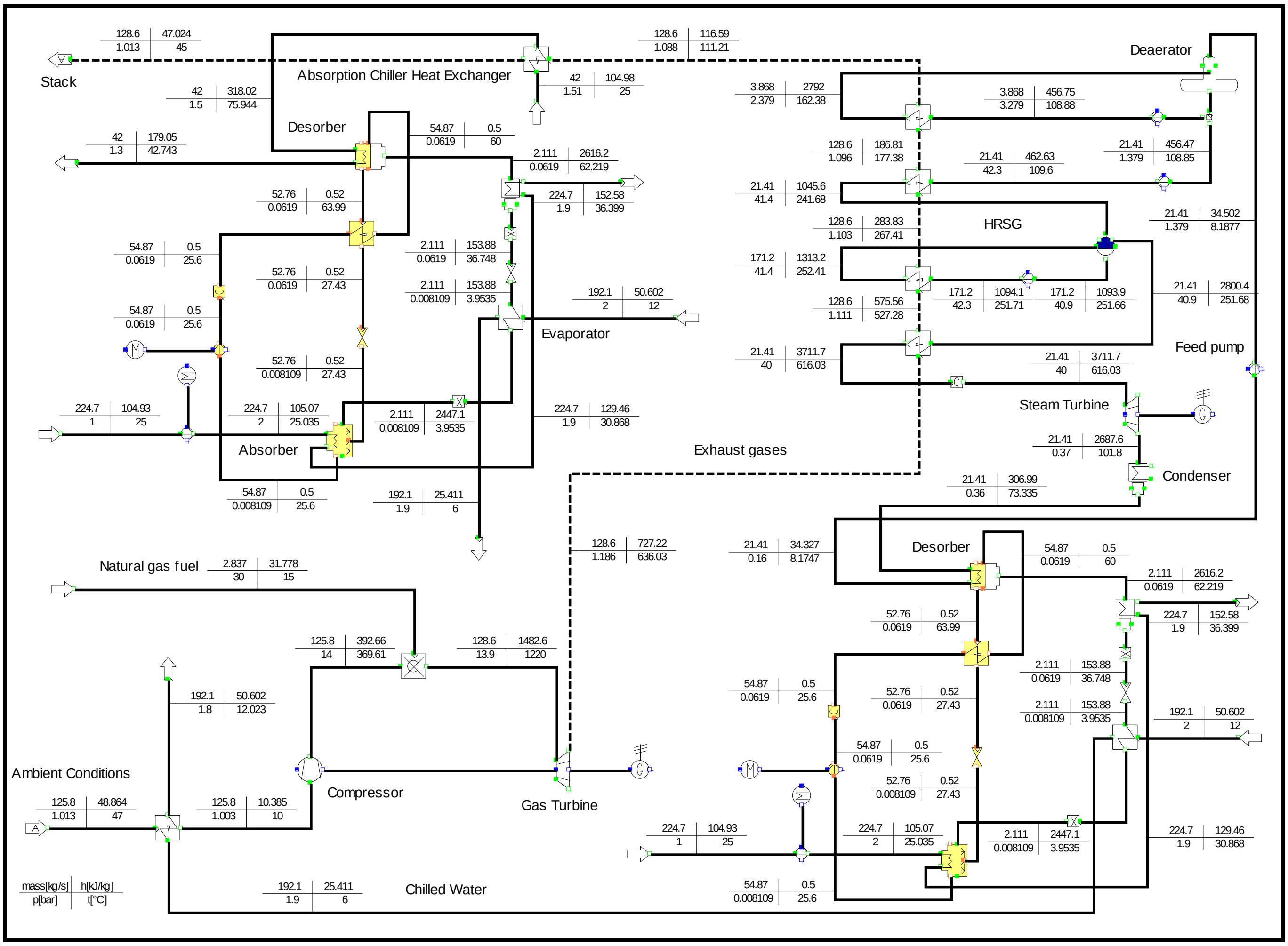

Figure (1) Single-shaft combined cycle power plant connected with single effect absorption chillers modelled by IPSEpro

3.2 The power plant behavior at off-design conditions

Combined cycle gas turbine power plants often run under off-design situations due to change of the load or ambient conditions or both. Particular attention therefore should be given to analyze the behavior of the proposed power plant used in this study.

This topic is set to investigate the proposed power plant performance under the fluctuating weather conditions i.e. ambient temperature only. The maximum and minimum values will be considered from the weather data in Libya, to ensure the power plant stability at all extreme weather conditions that may take place.

The IPSEpro process simulator [15] has been used to perform this study, while the PSExcel module has been used to create the required variation and to exchange the input values and results between the IPSEpro process simulator and MS Excel spreadsheet.

3.2.1 Ambient temperature

During the last decades, gas turbines have been widely used to produce electric power. Despite their numerous applications, one of the most important shortcomings affecting gas turbines behavior is their power output decrease at higher air ambient temperatures.

The ambient temperature fluctuation is greatly affects the gas turbine performance. Hence a parametric study have been done to monitor the gas turbine, which defines the whole power plant performance. The weather data presented in this study states that the maximum temperature expected in Libya during summer season is about 47 °C; therefore a variation from 11 °C to 47 °C will be introduced to the power plant.

The study was performed at the following conditions (relative humidity 60% and atmospheric pressure 1.01325 bar), with seawater (cooling water) temperature at 25°C and the gas turbine set at the full load. The proposed power plant results were compared with those of the power plant without cooling the gas turbine air intake, but counting all the cooling effect generated from the absorption chiller as a product.

As mentioned previously, the absorption chiller succeeded in stabilizing the compressor intake air temperature at 10 °C, which stabilized if not enhanced the performance of the whole power plant. The combined cycle gas turbine power plant with the absorption chiller presents a significant opportunity for improving the power output. The power output was increased by 10% (Figure 3).

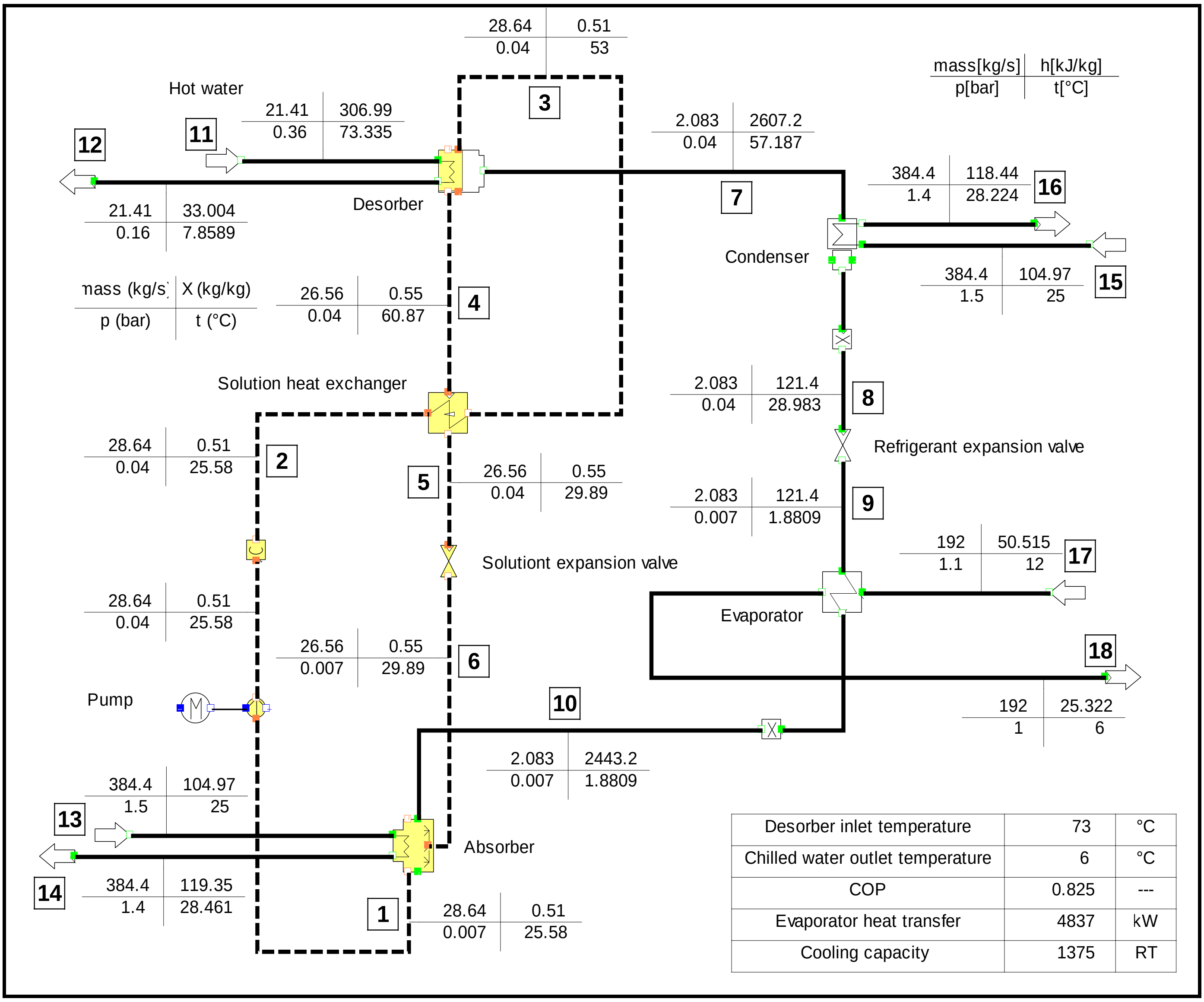

Figure (2) Single effect water-lithium bromide absorption chiller modelled by IPSEpro

Table (1) The proposed power plant performance parameters (at ISO conditions)

System	Parameters	Value	Unit
Combined cycle gas turbine power plant	Gas turbine power	46	MW
	Steam turbine power	21	MW
	Steam turbine condenser pressure	0.37	bar
	Gas turbine exhaust waste energy	93.54	MW
	Ambient temperature	15	°C
	Natural gas heat input	141.17	MW
	Cooling water temperature	25	°C
	Fuel lower heating value	49767	kJ/kg
Absorption chiller	COP	0.8245	---
	Cooling capacity	4837	kW
	Chilled water temperature	6	°C
	Desorber inlet temperature	73	°C
	Desorber heat transfer	5866	kW
	Electricity consumption	0.120	kW
Net power output		67	MW
Overall thermal efficiency		47	%
Energy utilization factor		54.15	%
Heat energy emitted to atmosphere		6.05	MW
CO_2 emissions rate		448	kg of CO_2/MW.h
Fuel mass flow rate		2.84	kg/s

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Table (2) Operating conditions for a single effect water-lithium bromide absorption chiller (Figure 2)

i	Enthalpy (i) kJ/kg	Mass flow rate (i) kg/s	Pressure (i) bar	Temperature (i) °C	Mass fraction (i) (% LiBr)
1	52.276369	28.64	0.007	25.58	51
2	52.279429	28.64	0.04	25.58	51
3	111.7	28.64	0.04	53	51
4	136.83	26.56	0.04	60.87	55
5	72.75	26.56	0.04	29.89	55
6	72.75	26.56	0.007	29.89	55
7	2607	2.083	0.04	57.19	0
8	121.40	2.083	0.04	28.98	0
9	121.40	2.083	0.007	1.88	0
10	2443.18	2.083	0.007	1.88	0

COP = 0.8245 $Q_{Absorber}$ = 5.524 MW

High pressure = 0.04 bar $Q_{Condenser}$ = 5.178 MW

Low pressure = 0.007 bar $Q_{Evaporator}$ = 4.837 MW

$Q_{Desorber}$ = 5.866 MW Electric power input = 0.120 kW

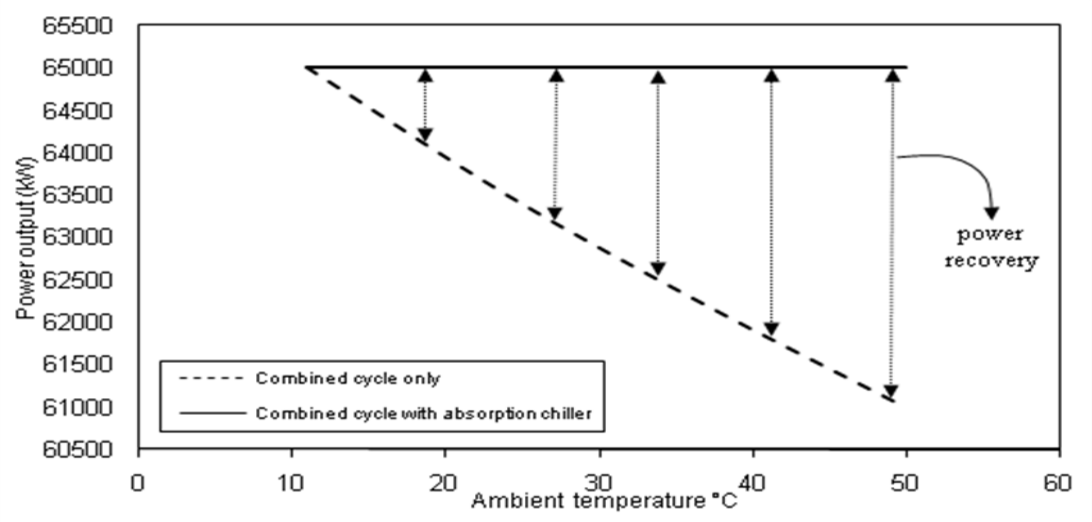

Figure (3) Effect of ambient temperature on power output for single shaft combined cycle gas turbine power plant with and without absorption chiller

Furthermore, the carbon dioxide CO_2 emissions rate are directly influenced by the utilization of the absorption chiller which reduces the emissions rate by 7% (Figure 4).

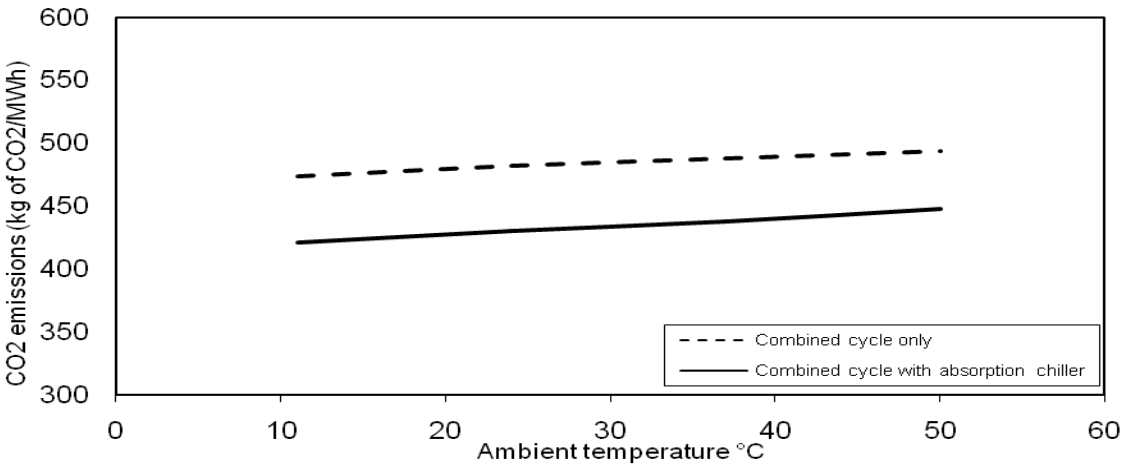

Figure (4) Effect of ambient temperature on CO_2 emissions for single shaft combined cycle gas turbine power plant with and without absorption chiller

3.3 Sensitivity analysis of the proposed energy system

In this section, sensitivity analysis is performed. The purpose of sensitivity analysis is to evaluate whether the model appropriately responds to changes in its inputs. This is one approach to help verify the accuracy of the model (Cullen and Frey [16]). The sensitivity analysis focuses on the effects of changes in inputs (condenser pressure, pinch point temperature and steam turbine isentropic efficiency) on the proposed energy system power output.

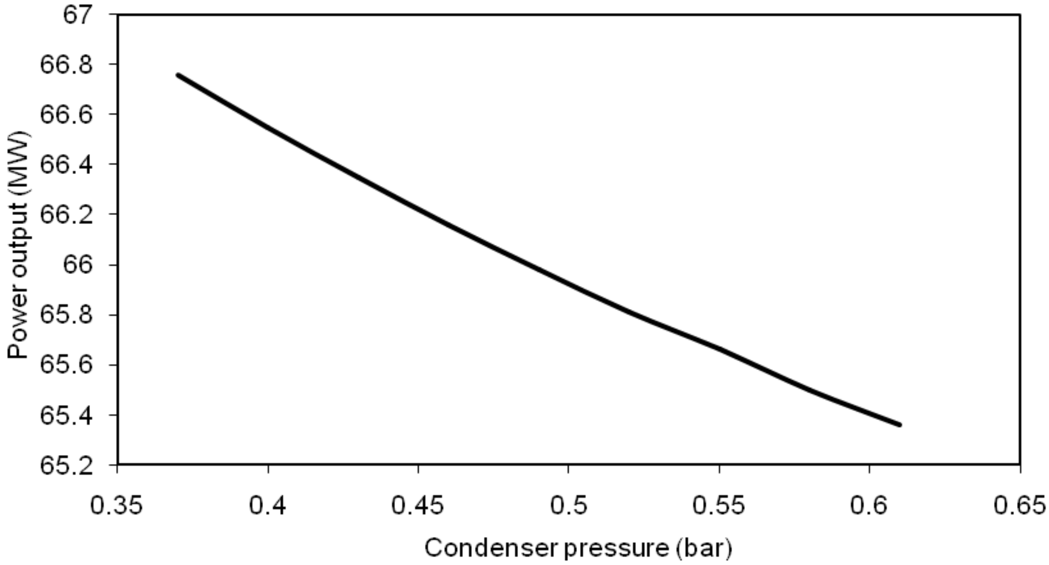

Figure (5) Effect of condenser pressure on power output

The condenser pressure has been varied from 0.37 bar to 0.61 bar at ISO conditions and full gas turbine load, to monitor the net power output of the proposed energy system. The results (Figure 5) indicate that lower condenser pressure boosts the net power output, which contributes to improving the overall plant efficiency as well.

A sensitivity analysis was also carried out to examine the net power output against a variation in the pinch point temperature from 14 ºC to 23 ºC at ISO conditions and the gas turbine was at full load. The results (Figure 6) show an increase in the net power output by 250 kW for each 5 ºC reduced in the pinch point temperature.

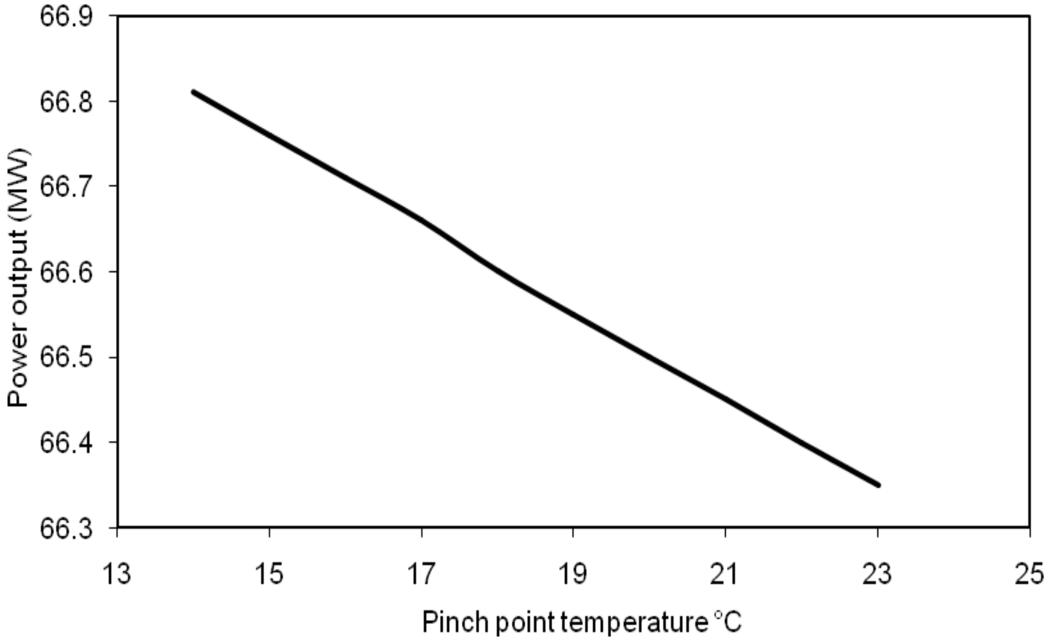

Figure (6) Effect of pinch point temperature on power output

Another sensitivity analysis was investigated on the behavior of the proposed energy system by varying the steam turbine isentropic efficiency from 63% to 87% at ISO conditions and the gas turbine was at full load. The results (Figure 7) indicate that the isentropic efficiency has great effect on the net power output.

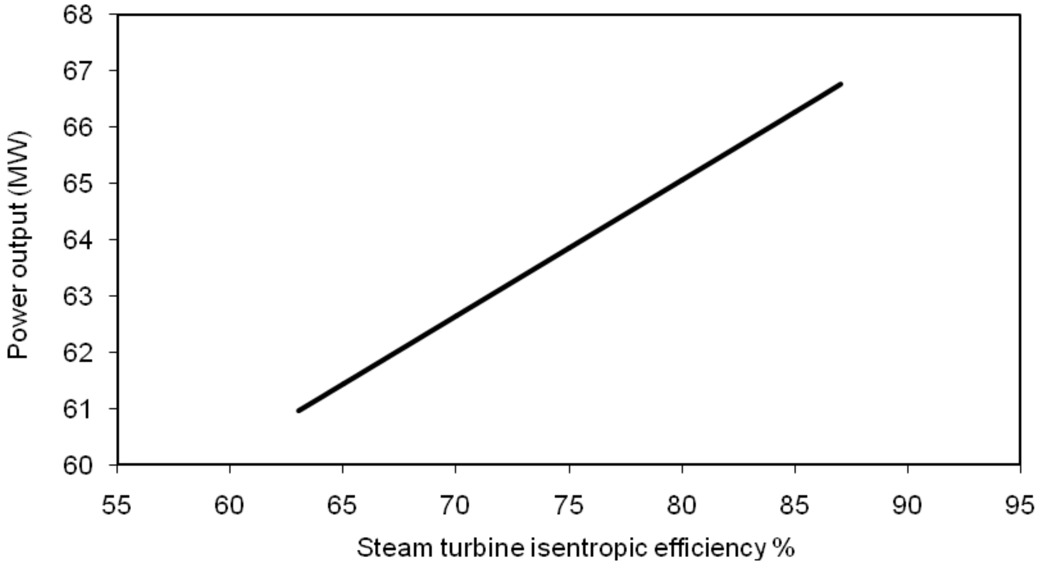

Figure (7) Effect of steam turbine isentropic efficiency on power output

4. CONCLUSION

In conclusion, global warming and improving the energy efficiency were the main motivation behind this study. An approach of solving the two problems at once was proposed by utilizing power plant exhaust heat in an absorption chiller to produce cooling effect, increase the power plant's efficiency and decrease the carbon dioxide emissions to atmosphere.

A new model has been developed and constructed using simulation software called IPSEpro, by which a 67 MW combined cycle gas turbine power plant was successfully configured and attached to a single effect absorption chillers. Running and analyzing the model at off-design conditions showed that the power plant is stable, efficient and profitable producing 9674 kW of cooling effect and improving the power output by 10% and the CO_2 emissions were decreased by 7%.

The most important parameter that affects the performance of a gas turbine is the intake air temperature.

The combined cycle gas turbine power plant behavior under fluctuating ambient temperature has been investigated by varying the ambient temperature from 11 °C to 47 °C with pre-cooling temperature of 10 °C applied to the compressor intake air, in order to find out the effect of extreme weather conditions on the power plant. The combined cycle gas turbine power plant after cooling the hot ambient air entering the compressor by the absorption chiller shows no reaction towards the ambient temperature fluctuation.

The absorption chiller succeeded in stabilizing the compressor intake air temperature at 10 °C and thus enhancing the performance of the whole power plant and producing cooling effect for air conditioning and food storage requirements with a capacity of 1375 refrigeration tonne.

Absorption refrigeration cycles are attracting increasing interest because they can be driven by low-temperature heat sources, and may therefore provide a means of converting waste heat into useful refrigeration. Absorption cooling is a technology that allows cooling to be produced from heat, rather than from electricity and does not use harmful refrigerants.

REFERENCES

[1] Cred Carbon Reduction, (2004), “The Community Carbon Reduction Project at UNC-Chapel Hill”, CRed in Cambridge-Industrial Sector.

[2] Maidment, G. G., Tozer, R. M., (2002), “Combined Cooling Heat and Power in Supermarket”, Applied Thermal Engineering, Vol. 22, Issue 6, pp. 653-665.

[3] United Nations, (1992), “Climate Change and Transnational Corporations: Analysis and Trends”, Centre on Transnational Corporations, ISBN 9211043859, 9789211043853

[4] Mohanty, B. and Paloso, G., (1995) “Enhancing Gas Turbine Performance by Intake Air Cooling Using an Absorption Chiller”, Heat Recovery Systems and CHP; 15(1); pp. 41-50.

[5] Ameri, M. and Hejazi S. H., (2004), “The Study of Capacity Enhancement of the Chabahar Gas Turbine Installation Using an Absorption Chiller”, Applied Thermal Engineering; 24, pp. 59-68.

[6] Mohan, G., Dahal, S., Kumar, U., Martin, A., & Kayal, H., (2014), “Development of Natural Gas Fired Combined Cycle Plant for Tri-generation of Power, Cooling and Clean Water Using Waste Heat Recovery: Techno-economic Analysis”, Energies,7, 6358–6381.

[7] I.H. Njoku, C.O.C. Oko, & J.C. Ofodu, (2018), “Performance Evaluation of a Combined Cycle Power Plant Integrated with Organic Rankine Cycle and Absorption Refrigeration System”, Cogent Engineering, 5:1, 1451426

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[8] Elberry, M., Elsayed, A., Teamah, M., Abdel-Rahman, A., Elsafty, A., (2018), "Performance improvement of power plants using absorption cooling system", Alexandria Engineering Journal, 57 (4), pp. 2679-2686.
[9] Alhamzy, M. M. and Najjar, Y. S., (2004), "Augmentation of Gas Turbine Performance Using Air Coolers", Applied Thermal Engineering, Vol. 24, No. (2-3), pp. 415-429.
[10] Kakaras, E., Doukelis, A., Prelipceanu, A. and Karellas, S., (2006), "Inlet Air Cooling Methods for Gas Turbine Based Power Plants", Journal of Engineering for Gas Turbines and Power, Vo. 128, No. 2, pp. 312-317.
[11] Wang, F. J., Chiou, J. S. and Wu, P. C., (2007), "Economic Feasibility of Waste Heat to Power Conversion", Applied Energy, Vol. 84, No. 4, pp. 442-454.
[12] Hosseini, R., Beshkani, A. and Soltani, M., (2007), "Performance Improvement of Gas Turbines of Fars (Iran) Combined Cycle Power Plant by Intake Air Cooling Using a Media Evaporative Cooler", Energy Conversion and Management, Vol. 48, No. 4, pp. 1055-1064.
[13] MB Bughazem and Agnew B., (2009), "Improvements of the Single Shaft Combined Cycle Gas Turbine Power Plant by Intake Air Cooling Using an Absorption Chiller", Heat Powered Cycles Conference 2009, TU Berlin, 7-9 September 2009, HPC 800.
[14] El-Shazly, A., Elhelw, M., Sorour, M., El-Maghlany, W., (2016),"Gas Turbine Performance Enhancement via Utilizing Different Integrated Turbine Inlet Cooling Techniques", Alexandria Engineering Journal, Vol. 55, No. 3, pp. 1903-1914.
[15] Sim Tech, (1991-2003), IPSEpro Process Simulator, Simulation Technology, System Version 4.0, Manual Version 4.0.001.
[16] Cullen, A. C., and Frey, H. C., (1990), "Probabilistic Techniques in Exposure Assessment: a Handbook for Dealing with Variability and Uncertainty in Models and Inputs", Plenum, New York.