The impact of fouling on the steam condenser and cooling tower performance – Sabiya power station a case study in Kuwait

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Abstract

The purpose of this research is to study the impact of the development of mud deposits and marine organisms in the combined cycle power plants inside the steam condenser tubes and the cooling tower. The research was carried out on the station of Sabiya as a model of the stations of the State of Kuwait. This study showed that after 8 months of intensive annual maintenance and cleaning of steam condenser tubes and the cooling tower, the highest concentration of mud deposits and marine organisms was, and the results also showed that the condenser's highest efficiency is 96.99 percent and the vacuum efficiency is 99.95 percent and it was immediately after cleaning, while it reached the condenser's highest efficiency. A condenser efficiency and vacuum efficiency value of 68.66 percent and 88.14 percent, respectively, and it was after 8 months of cleaning the tubes inside the condenser and the cooling tower, and the analysis also showed that the steam condenser cooling water flow rate increased, the more mud and marine sediments, to maintain the vacuum pressure inside the condenser. Based on this report, it was concluded that recommendations were made to improve the efficiency of the steam condenser and cooling tower by operating the combined cycle units throughout the year.

Introduction

Electricity generation is the cornerstone of infrastructure for other industries, economic growth, and industrial development. With this rapid growth and economic development in Kuwait, the demand for electricity is increasing, which has prompted Kuwait to press for large investments in new power plants in the short term. Combined cycle power plants are the main best option, as they are characterized by high efficiency that reaches more than 58% [1], which is higher than the efficiency we get from steam turbine units or gas turbine units. Therefore, the Sabiya plant was established in 2016 with eight combined units, each with a capacity of 250 MW. The cooling tower and the steam condenser is one of the most important parts of the power plant that greatly affects the efficiency and performance of the power plant. The deterioration in the thermal performance of the capacitor not only affects the power generation, but also the thermal performance of the unit other factors. The mode of operation of the cooling tower is the same as that of the evaporative condenser. About 1% of the total water comes out in the air in the form of water vapor, thus losing part of its latent heat from the remaining water, causing a decrease in the water temperature [2]. The cooling tower is used when the source of cooling water is limited, and there is a need to recycle the water through the condenser. A cooling tower is an equipment used to more effectively cool the hot cooling water discharged from the condenser. In this research, the focus was on studying the performance of the condenser and the cooling tower on the performance of the combined cycle unit, where the effects of mud or dirt forming inside or around the cooling tubes in the cooling tower and in the condenser were studied, and the effect of that on the lifting of the combined cycle unit's load and its efficiency. The case that was taken as a model for the study is the Sabiya station due to the frequent formation of mud and dirt in the cooling tower and the steam condenser.

Literature review

The concept of exergy destruction was studied by many of research, who studied the balancing of exergy variation in power plants. Some researchers estimated the impact of compressor pressure ratio and the gas power cycle temperature ratio on the performance of the combined cycle power plant. Polyzakiset (2008) concluded the concept of reheat is viable for combined cycle power plants after detailed first low analysis of gas turbines [3] , also Venkata & TVK Bhanu Prakash presented a case study of exergy analysis of Gautame combined cycle power plant [4].

Methods and Materials

Data and readings from the Sabiya electric power plant were obtained in this study from a combined cycle power generation unit consisting of gas turbine No. 3 and producing 250 megawatts and gas turbine No. 4 producing 250 megawatts and heat is applied to the waste gases coming from them to run steam turbine No. 2. As shown in Figure No.1, with a power of 250 megawatts, data and readings were obtained from the operating records of the combined cycle unit over a period of 12 months, as shown in Table No. 1, and the average readings were taken over a period of one month[5]. In this analysis, the combined cycle power plant simulator was used .

Combined cycle power plant simulator

The combined station simulator is one of the most important means of training combined gas turbine unit operators to simulate reality and to provide the operators with the requisite operational skills. At the Higher Institute of Energy, the simulator of the station with a combined cycle was developed by the American company, SIMTRONICS-SPM-5601-combined cycle power plant-DSS-100 100. The combined cycle power plant simulator of Simtroncs is a standard combined cycle for producing electrical power, version 7.0 figure No. 2. The plant consists of the following section:

- Boiler feed water system.
- Natural gas fired gas turbine with generator.
- Heat recovery steam generator (HRSG).
- Steam turbine with generator.
- Cooling tower

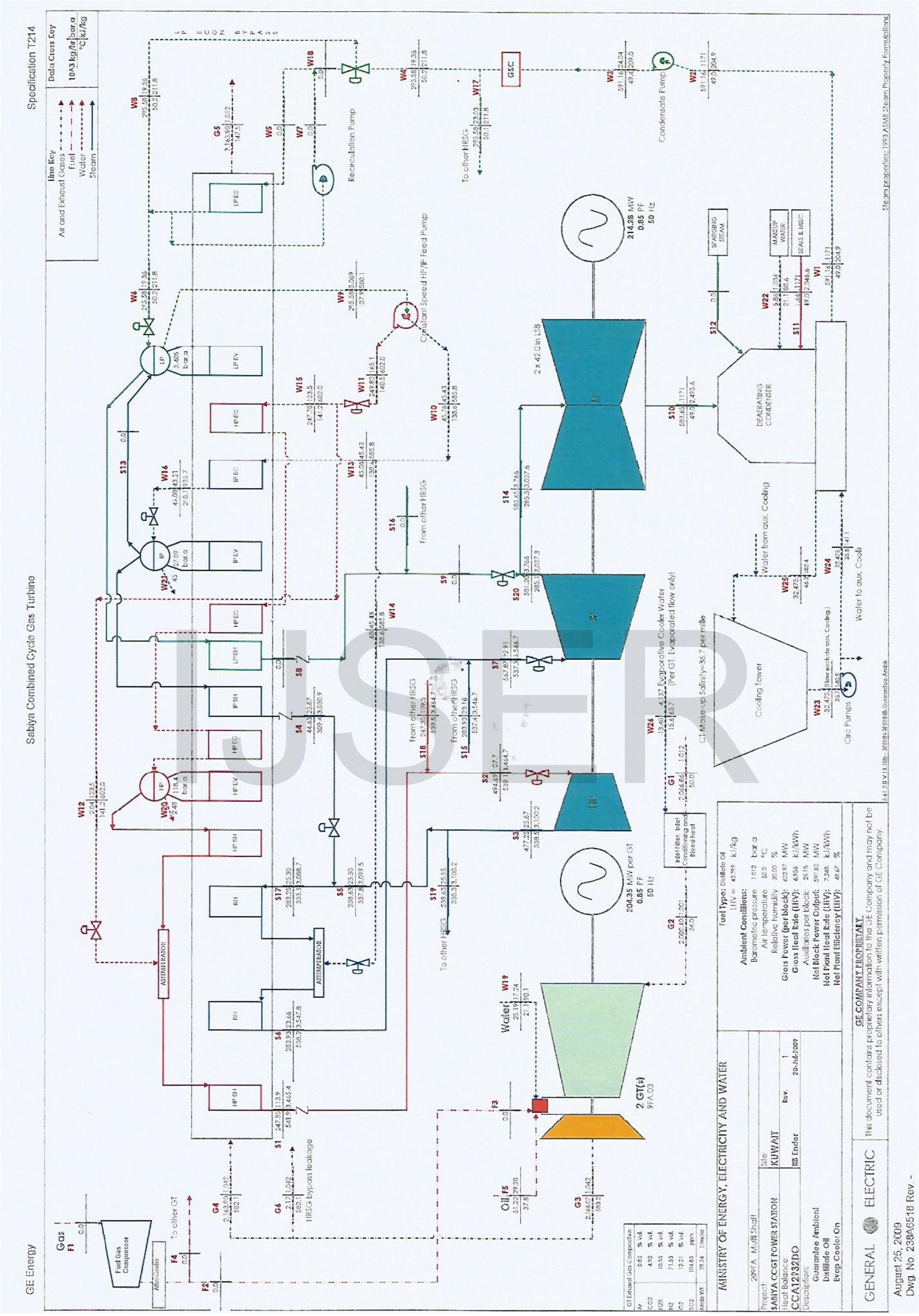

Figure 1- Sabiya power station Overview

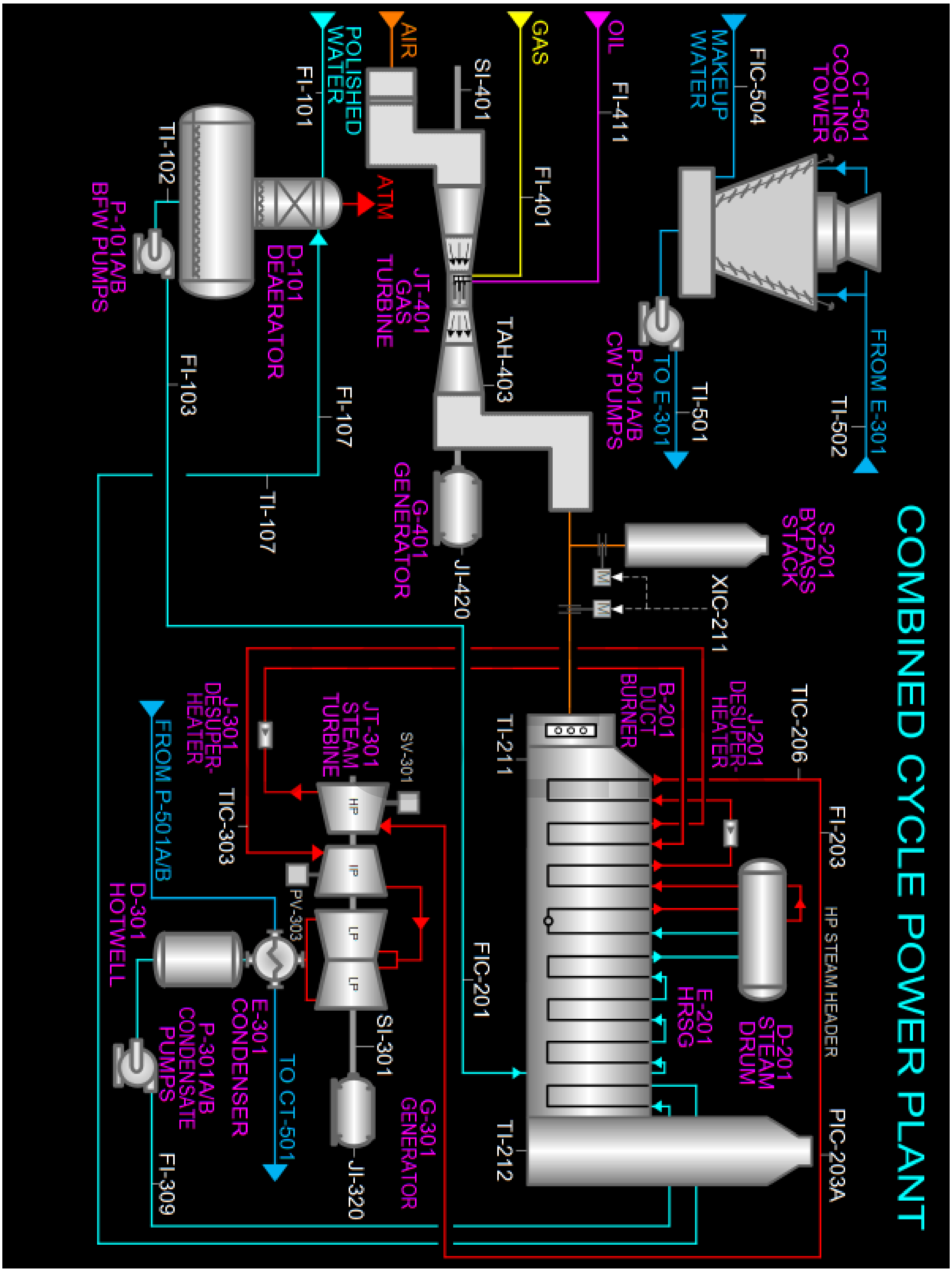

Figure 2-Combined cycle power plant simulator

Table 1- Operation record for six months

Description	Time						
	Unit	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20
Gas Turbine Generator(GT3)	MW	218.12	219.85	215.68	212.07	185.16	207.74
Gas Turbine Generator(GT4)	MW	218.28	219.65	215.42	211.95	185.02	215.59
Steam Turbine Generator(ST4)	MW	223.05	217.66	213.96	211.83	190.64	199.28
Gas Fuel Flow	kg/s	12.22	12.53	12.67	12.31	11.14	12.12
Gas Fuel Flow	kg/s	12.10	12.63	12.57	12.37	11.02	12.34
AMBIENT TEMP	°C	42.07	43.08	47.37	46.46	36.84	31.95
Exhaust Temp Median Corrected By Average	°C	628.11	627.63	629.91	632.92	647.94	632.87
Exhaust Temp Median Corrected By Average	°C	624.15	621.61	623.61	627.28	648.04	629.92
BAROMETRIC PRESSURE	mbar	978.15	971.79	971.43	974.19	983.24	984.45
Turbine Exhaust Mass Flow (GT3)	kg/s	568.64	574.24	564.27	560.98	510.51	550.90
Turbine Exhaust Mass Flow (GT4)	kg/s	579.65	590.12	583.91	577.02	511.69	571.24
Compressor Inlet Pressure Transducers (GT3)	mmH2O	156.26	170.57	178.19	180.58	148.01	174.95
Compressor Inlet Pressure Transducers (GT4)	mmH2O	169.10	183.69	186.43	175.95	125.33	160.20
Compressor Discharge Press	kg/cm2	13.43	13.57	13.33	13.25	11.93	12.96
Compressor Discharge Press	kg/cm2	13.75	14.04	13.88	13.74	11.99	13.54
Exhaust Duct Pressure	mmH2O	177.70	186.62	181.42	175.99	107.95	172.74
Exhaust Duct Pressure	mmH2O	184.58	193.50	190.11	182.85	108.07	175.18
HP Steam Pres	barg	116.18	117.47	117.93	119.52	106.84	117.51
HP Steam Pres	barg	115.02	118.15	118.31	119.52	107.05	117.67
RH Outlet Steam Pressure	barg	23.00	23.04	23.03	23.23	21.44	21.48
RH Outlet Steam Pressure	barg	23.01	23.01	23.07	23.31	21.31	21.57
LP STEAM PRES	barg	4.16	1.97	1.98	2.00	1.81	1.95
LP STEAM PRES	barg	1.98	1.96	2.02	2.04	1.81	1.94
HP Steam Flow	t/hr	271.05	273.36	271.04	272.19	248.45	265.04
HP Steam Flow	t/hr	280.28	283.10	281.41	280.58	248.72	276.29
IP Steam Flow	t/hr	37.19	33.75	34.06	34.79	28.81	34.55
IP Steam Flow	t/hr	32.99	34.52	35.13	35.30	28.84	35.28
LP STEAM FLOW	t/hr	32.31	0.00	0.01	0.01	0.01	0.01
Exhaust Vacuum Feedback	mmHg	120.75	125.71	137.30	159.56	158.36	150.31
Condenser pressure	barg	-0.84	-0.83	-0.81	-0.79	-0.79	-0.80
Exhaust Steam Temperature	°C	54.38	55.54	57.02	61.90	61.27	62.29
Condenser Hot well Temperature	°C	55.02	56.14	57.99	61.22	61.36	59.54
Cooling Water flow rate heat balance	kg/s	9631.85	9635.98	99999.04	9364.84	8751.60	10072.55
Condenser Water BOX Inlet TEMP	°C	32.72	32.52	33.50	34.00	32.97	31.98
CONDENSER WATER BOX OUTLET TEMP	°C	43.39	42.89	43.85	44.49	43.13	41.86
CONDENSATE HEADER FLOW	t/hr	666.81	635.81	638.74	651.35	610.51	638.32

Cooling tower performance measurement

The efficiency of the cooling tower is assessed to achieve current approach levels against its design principles, to identify areas for energy wastage and to recommend improvements. The readings taken during the service of the combined cycle unit during the 12 months of 2020 and the readings for the following parameters when assessing the results -Wet and dry bulb temperature of air.

- Exhaust air temperature.
- Air flow rate
- Cooling tower inlet and outlet water temperature.
- Water flow rate.
- Electrical readings of pumps and fan motors.

– **Approach** is the difference between the cooling tower water outlet temperature and ambient wet bulb temperature. [4]

– **Range** is the difference between the cooling tower water inlet and outlet temperature. [4]

$$\eta_{CT} = \frac{Range}{Range + Approach} * 100 \qquad \{1\}$$

$$\eta_{CT} = \frac{T_{THW} - T_{TCW}}{T_{THW} - T_{wb}} * 100 \qquad \{2\}$$

Where; η_{CT} is cooling tower efficiency,
T_{THW} is cooling tower hot water temperature, T_{TCW} is cooling tower cold water temperature and T_{wb} is air wet bulb temperature.

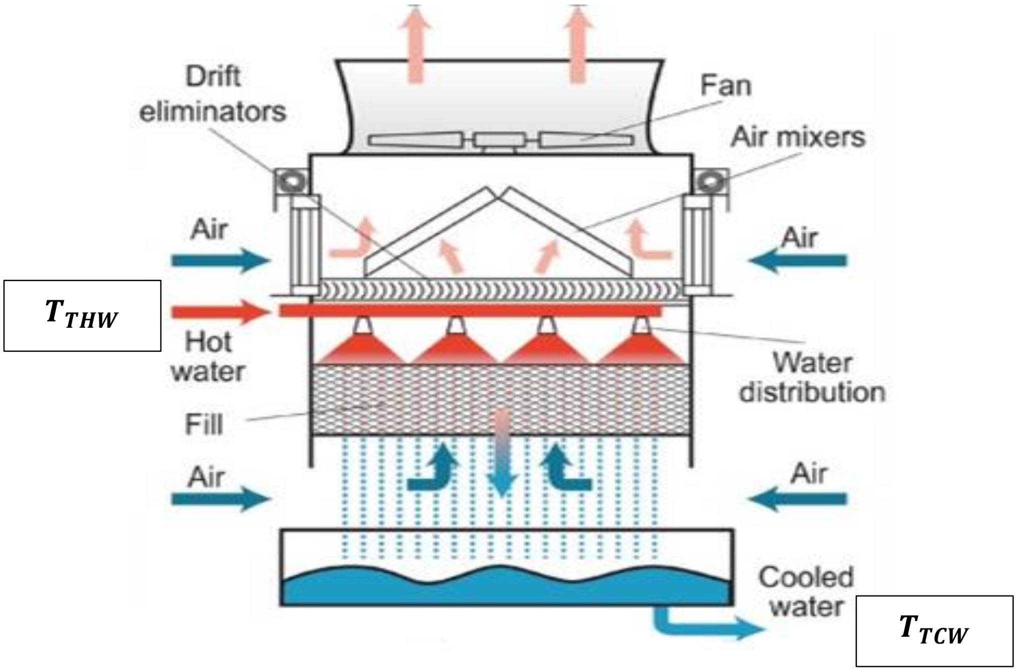

Figure 3 -Cooling tower - heat balance

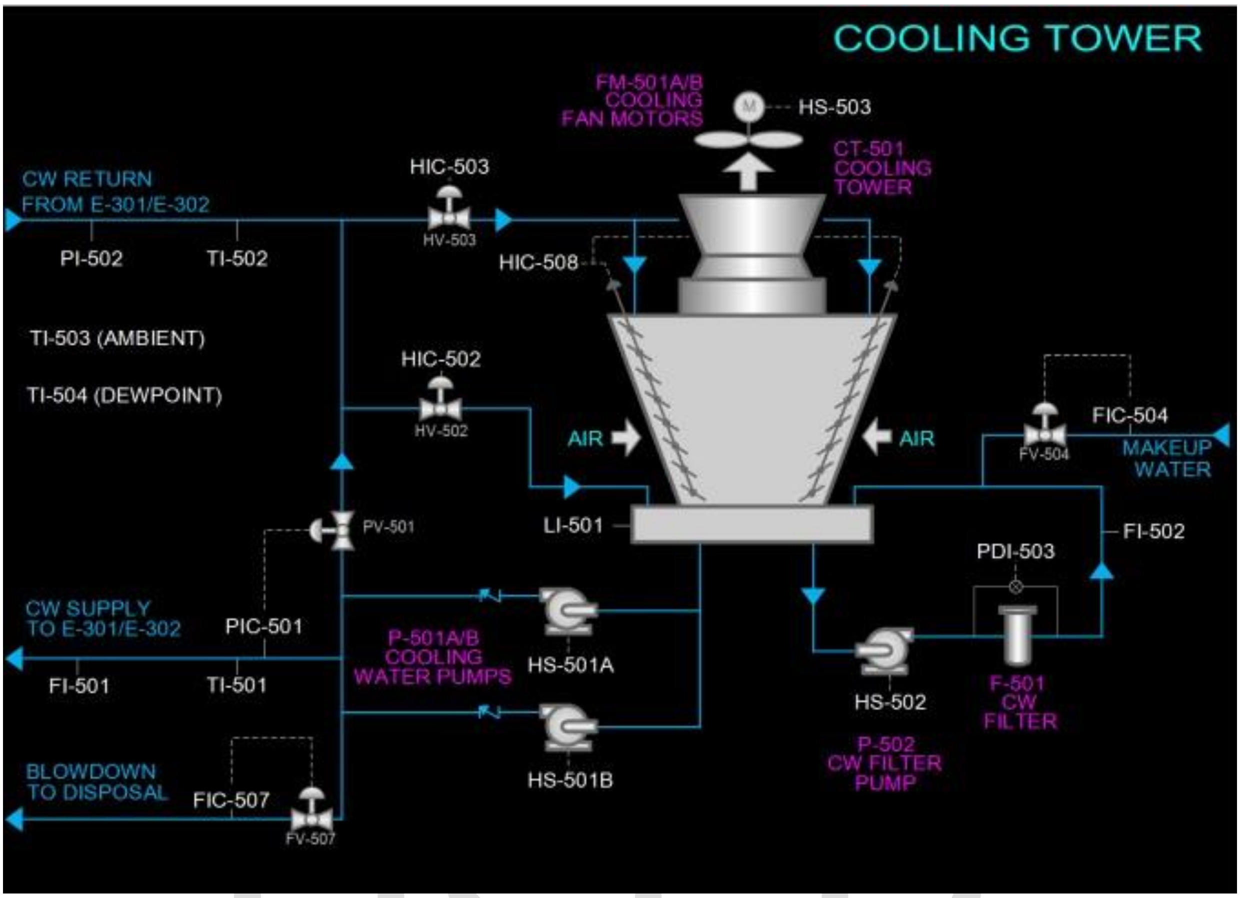

Figure 4- combined cycle power plant simulator overview

Condenser performance measurement

There is no specific procedure for evaluating a condenser 's efficiency. The Parson method is used in this research to measure the efficiency of the steam condenser that is typically used in steam turbines. By applying the condenser heat balance as a figure (5).

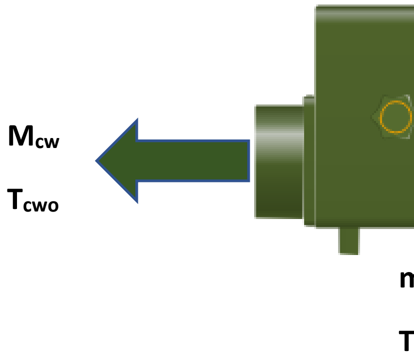

Figure 5-condenser heat balance

Figure 6-The Fouling on condenser tubes

$$\eta_{Co.} = \frac{T_{CWo} - T_{CWi}}{T_s - T_{CWo}} * 100 \quad \{3\}$$

Where; η_{CT} is condenser efficiency,

T_{CWo} is cooling water temperature at outlet and, T_{CWi} is cooling water temperature at outlet of condenser.

T_s is temperature of steam corresponding to the actual absolute pressure in the condenser.

$$\eta_V = \frac{p_{V,act.}}{p_{v,th.}} * 100 \quad \{4\}$$

Where; η_V is the vacuum efficiency,

$p_{V,act}$ is the actual vacuum pressure and, $p_{V,th.}$ is the theoretical vacuum pressure?

$$TTD = T_s - T_{CWo} \quad \{5\}$$

Where:

TTD is terminal temperature difference.

T_s is steam temperature.

T_{CWo} is cooling water exit temperature.

$$\dot{m}_{CW} = \frac{\dot{m}_s \left(h_f + xh_{fg} - h_c\right)}{Cp_{CW}\left(T_{CWo} - T_{CWi}\right)} \quad \{6\}$$

Where:
$\dot{m}_{CW}$ is the required rate of flow of cooling water in kg / s.
$\dot{m}_s$ is the rate of exhaust steam flow from the turbine in kg/s.
x is the dryness frication.
h_f and h_{fg} are enthalpy from steam table @ saturation steam temperature of exhaust steam turbine.
h_c is enthalpy of condensate @condensate temperature .
Cp_{CW} is specific heat of cooling water in kj/kg.K .

The overall thermal efficiency of the combined cycle power station

$$\eta_{th.} = \frac{P_{GT3} + P_{GT4} + P_{ST2}}{\dot{m}_f * C.V} * 100 \qquad \{7\}$$

Where; η_{th} is the overall efficiency,
P_{GT3} & P_{GT4} is the generated power (KW) of gas turbine No.3 &4.
and P_{ST} is the is generated power (KW) of steam turbine No.2.

$\dot{m}_f$ is the fuel gas flow rate (kg/s)
$C.V$ is the caloric heat value kj/kg

Result

Fouling on condenser tube and cooling tower, decreases heat transfer coefficient when fouling beginning cover tube surface. Low coefficients of heat transfer result in higher steam temperature since it is unable to transfer its energy to cooling water, so pressure rises with respect to temperature figure (7), showing the effect of fouling on the condenser output and cooling tower by cleanliness factor. The outcome represented by the only TTD is significantly modified.

Table 2- Factor for clean lines with temperature change

Cleanliness factor	Temperature change °C	Condenser pressure mm bara
0.9	1	114
0.85	1.1	116
0.8	1.18	118
0.75	1.2	120
0.7	1.35	123
0.65	1.5	125
0.6	1.55	127
0.55	1.6	130
0.5	1.63	132

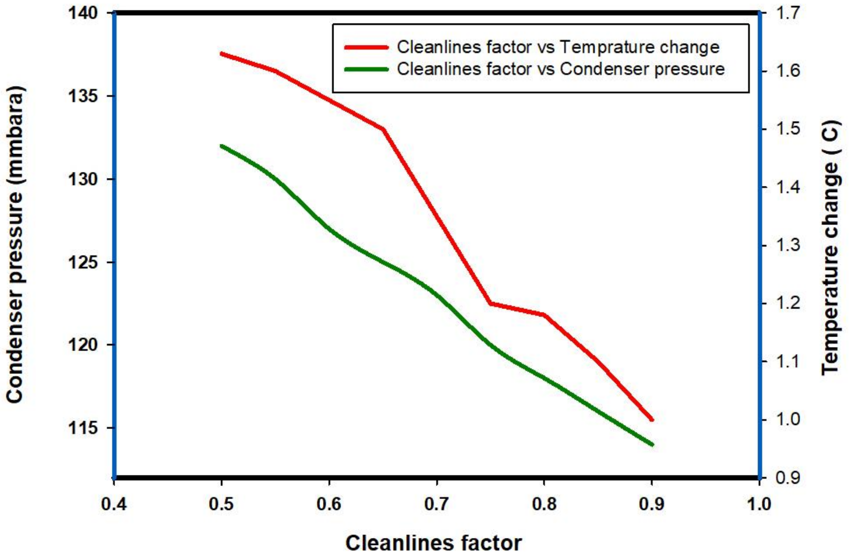

Figure 7- Factor for clean lines with temperature change

Figure No. (8) demonstrates the relationship between the exhaust steam temperature of the steam turbine and the efficiency of the condenser and the efficiency of the vacuum within the steam condenser for a span of 8 months following the full annual maintenance period. The results showed that in the month of May, that is, after cleaning the steam condenser tubes during the annual thorough maintenance, the highest efficiency was. The condenser density was 96.99 % and the steam condenser's vacuum efficiency was 99.95 % . The condenser and vacuum's lowest efficiency was in December, where the steam condenser's efficiency reached 68.66 % and the vacuum efficiency reached 88.14 %.

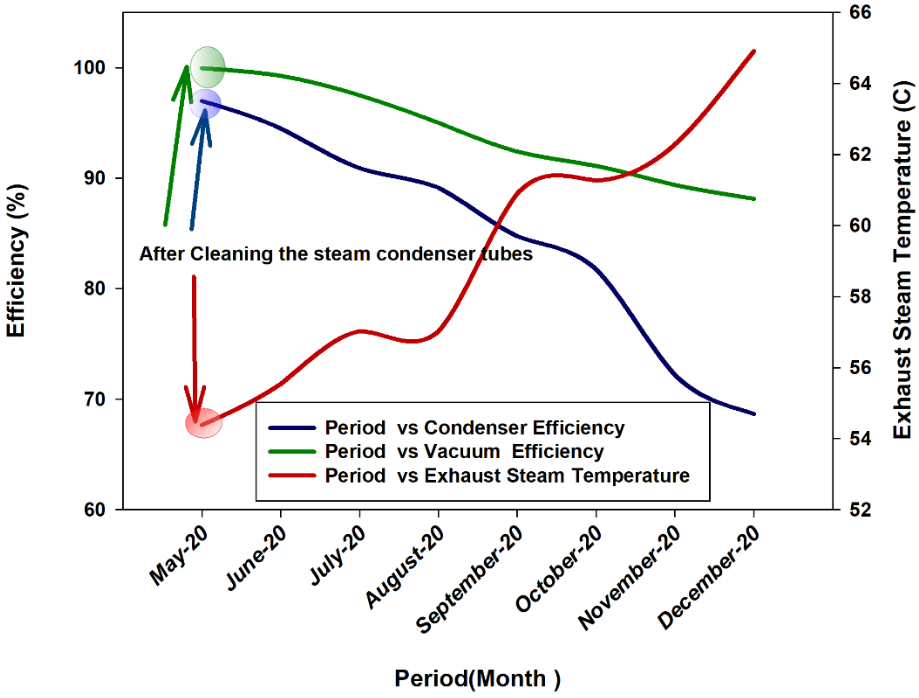

Figure 8-The relationship between efficiency and period

The relationship between the efficiency of the steam condenser and the rate of flow of cooling water for the load flowing to the steam condenser is shown in Figure No. (9). The results showed that in May, after cleaning the condenser tubes and the cooling tower, the maximum efficiency of the steam condenser was 96.99 % and the cooling water rate was 9742.96 kg / s. The results also showed that in the months of September and October, the rate of impact of cooling water was 9365 and 8752 kg / s, respectively, the highest rate of mud and marine sediment formation. The most prominent explanation is that in December, the lowest decrease in the density of the steam condenser was 68.88 % and the exhaust density was pushed by it.

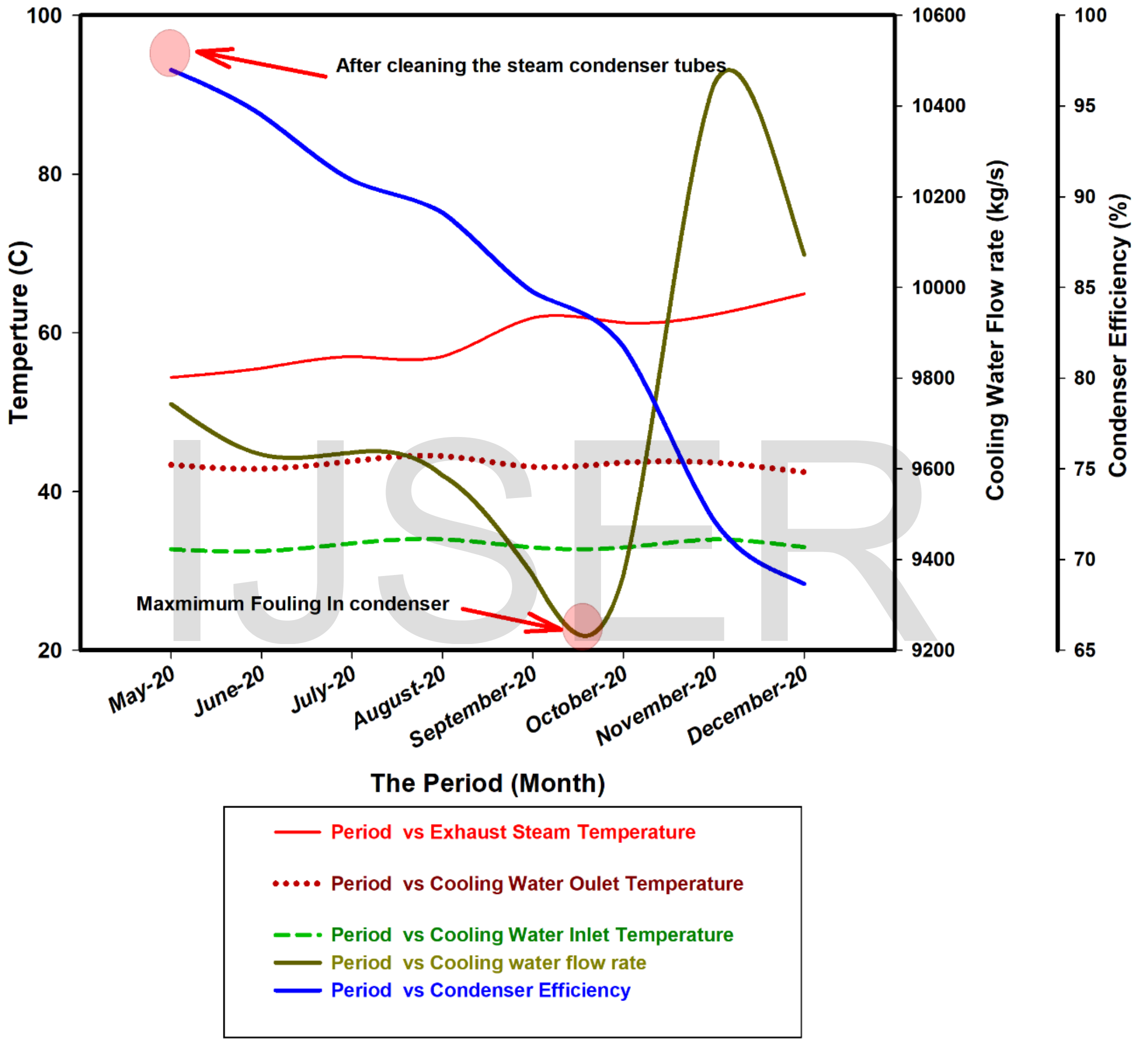

Figure 9-The relationship between the cooling water and period

Figure 10 illustrates the relationship between the rate of heat load absorption in the condenser and the deposition of mud deposits and marine organisms during time. The study indicate that an increase in mud deposits and marine organisms causes the highest rate of heat loss in the steam condenser, with the highest rate of heat loss in the steam condenser. After 8 months of cleaning the steam condenser tubes as part of the annual thorough maintenance, the rate of heat loss increased to 546.55 megawatts, a 20.5 %.

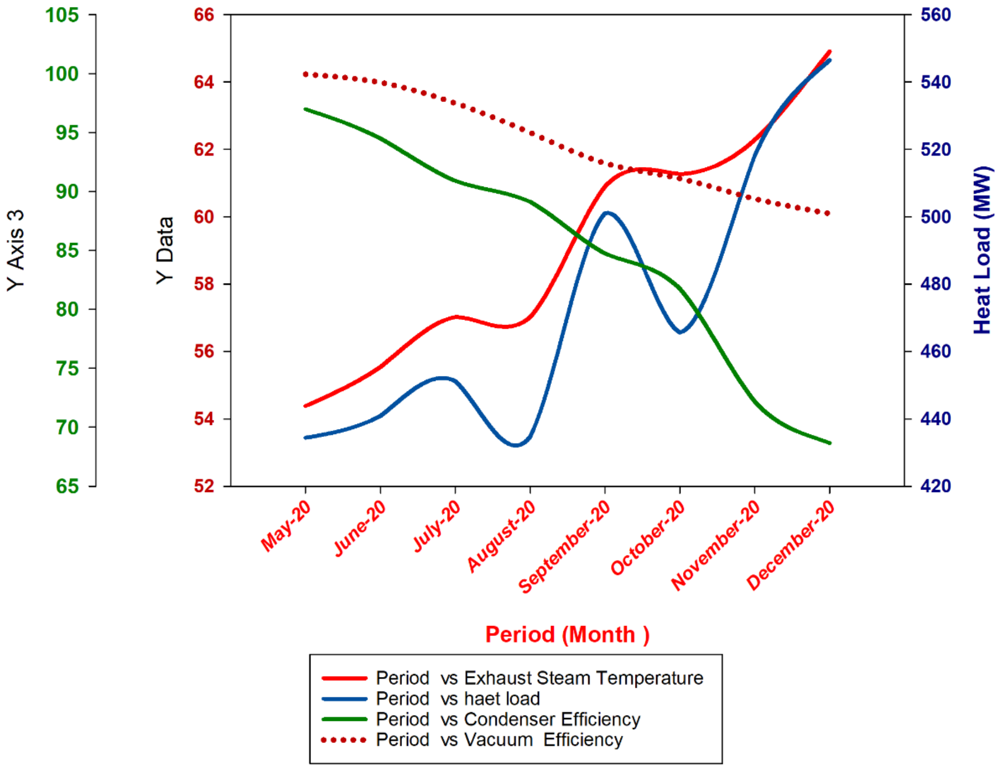

Figure 10 - the relationship between heat load and period

Table 3- Operation data during period

			Operation Data			
	Exhaust Steam Temperature	Saturation pressure[6]	Condenser pressure	Barometer pressure	Condenser Efficiency	Vacuum Efficiency
Period	T_s	p_s	p_c	p_b		
Month	°C	m bara	m bara	m bara	%	%
May-20	**54.38**	**160.7**	**161.10**	**978.15**	**96.99**	**99.95**
June-20	**55.54**	**161.7**	**167.72**	**971.79**	**94.50**	**99.26**
July-20	**57.02**	**173.5**	**193.45**	**971.43**	**90.91**	**97.50**
August-20	**57.02**	**173.5**	**213.47**	**974.19**	**89.13**	**95.01**
September-20	**60.90**	**207.9**	**266.83**	**984.45**	**84.75**	**92.41**
October-20	**61.27**	**211.5**	**280.17**	**984.45**	**81.75**	**91.11**
November-20	**62.29**	**211.5**	**293.52**	**984.45**	**72.18**	**89.39**
December-20	**64.91**	**245.97**	**333.54**	**984.45**	**68.66**	**88.14**

Conclusion

The present study deals with evaluation of steam condenser efficiency and condenser vacuum efficiency of combined cycle gas turbine and impact of fouling in condenser and cooling tower on total thermal efficiency . It can be stated that consideration in during the performance of steam condenser and cooling tower were evaluated parametric , study showed that fouling deposits played a very vital role on the performance of steam condenser and cooling water , it can by summarized into the following :

- Increasing the rate of mud and marine sediments in the steam condenser and cooling tower leads to reducing the condenser efficiency to 68% within eight months.
- The vacuum efficiency inside the steam condenser decreased to 88% after eight months due to the increase in the rate of mud deposits and marine sediments inside the steam condenser and cooling tower.

Recommendation

The current study is a study to evaluate the performance of the steam condenser and cooling tower in the common gas turbine units and the effect of the formation of mud and marine sediments during a period of 8 months on the efficiency of the condenser and the efficiency of the vacuum. Among the suggested recommendations are summarized as follows:

- Increase the cleaning times of the steam condenser and cooling tower of the unit.
- Use the steam condensed washing system during operation .
- Clean the hot well of the steam condenser at least every 8 months.
- Cleaning the water pipes and basins in the cooling tower.
- Check the condenser incoming water and steam piping connections for any air leaks that reduce the vacuum efficiency of the steam condenser.

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