Effect of Ambient Temperature on The Performance of Heat Recovery Steam Generator for Benghazi Combined Cycle Power Plant

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***Abstract*—*In view of the energy crisis, the heat recovery system at any stage is very important in the field of conservation of energy. The heat recovery steam generator is one of the important components in the combined cycle (gas turbine cycle and steam power cycle) and is the most efficient energy conservation system in recent trends. Its function is to recover the waste heat present in the exhaust gases of the gas turbine cycle and to generate the steam to run a steam power cycle. This project focused on the effect of ambient temperature on the performance of heat recovery steam generator in Benghazi combined cycle power plant at different ambient conditions. The results show that the increase of ambient temperature increases the exhaust outlet temperature from the gas turbine and thus increases the heat content present in the flue gases. So, it is possible to generate more amount of steam at high ambient temperatures. It is observed that the percentage of heat utilization increases because the inlet temperature of heat recovery steam generator increases with increase of ambient temperature.*

***Keywords*—(HRSG, Gas Turbine, Steam Turbine, Ambient temperature)**

1. INTRODUCTION

Nowadays, extending the energy supply, design optimization and increasing the efficiency are the main goals and targets of the industries and their future plans. Due to the increase of human population, a continuously increasing amount of electricity needs to be generated. There are various technologies for power generation in the world, such as wind energy, water energy, steam turbines (ST) and gas turbines (GT). In this regard, steam is used as the main source of energy for processes, heating, chemical reactions, power generation, etc[1], in most industries. On the other hand, the costs of the fuels are increasing continuously in the entire world. Consequently, development of new methods for electricity and power generation, increasing efficiency and also cost optimization of power plants are attractive subjects for engineers. Some part of the world's power is generated in thermal power plants by using fired boilers and steam turbines. But, combined cycle power plants (CCPPs) are more efficient in power generation, see Fig. 1.

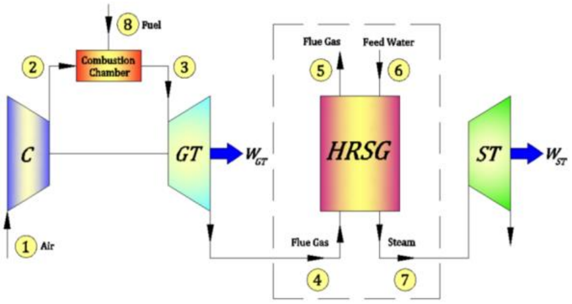

Fig.1. Schematic diagram of a combined cycle plant [2]

The thermal efficiency of a CCPP can exceed 60% depending on the ambient conditions and the design of its components. Gas turbines and steam turbines are two main components of a CCPP. In a CCPP, the exhaust gas from the gas turbine is used in a heat recovery steam generator (HRSG) to produce steam. Then, the produced steam is used in steam turbines for electricity production. The gas turbine and the steam turbine produce approximately 65% and 35% respectively of the total produced power in a CCPP[3]. In a combined cycle, the HRSG is a very important component and shall follow both the requirements of steam turbine and the constraints of the gas turbine.

Any change in the ambient temperature of the HRSG directly affects the CCPP efficiency, produced net power. In several gas turbine systems are available with different operating parameters, such as back pressure and exhaust gas temperature. The latter is very important in the performance of HRSG (in general, the exhaust gas temperature can range from 700 to 950K)[4]. For each selected gas turbine, a compatible design of the steam cycle (combination of HRSG and steam turbine) is required. The thermal efficiency of the steam cycle is strongly dependent on the HRSG thermal design. Similar to thermal power plants, combined cycle power plants produce thousands of Megawatts of power. In combined cycle power plants, steam pressure and temperature of the heat recovery steam generators have been increased to produce more electricity. Multi-pressure HRSGs are designed and developed to increase energy recovery.

The heat recovery steam generator is one of the critical components is the combined cycle (gas turbine cycle and steam power cycle) and is the most efficient energy conversion system in recent trends. Its function is to recover the waste heat present in the exhaust gases of the gas turbine cycle and to generate the steam to run a steam power cycle. Fig. 2.shows the general view of a HRSG including the inlet duct, heating surfaces, drum, stack, etc.

Fig.2. Heat recovery steam generator [5]

In combined cycle plants, natural gas is the main fuel burned. Therefore, clean flue gas is expected. In general, water tube boilers with extended surfaces are used for heat recovery and steam production. The range of inlet gas temperatures of HRSGs varies from 700 to 950 Kand flue gas pressure typically is a little higher than atmosphere pressure[2].

2. Thermal Process of HRSG sections

HRSGs are used to absorb the maximum thermal energy and produce an expected amount of steam for maximum recovery. HRSG design is a very exact work which cannot be revised or corrected by additional considerations in case of any probable error. The starting point in the thermal design of an HRSG is the evaluation of its steam generation and temperature profiles of the gas and steam. Due to the low inlet gas temperature (700 - 950 K in an unfired HRSG)and the large ratio of gas to steam flow, the thermal design of a HRSG would be different than that of fired boilers. In this regard, the flue gas exit temperature is an important factor for the HRSG. Due to the low temperature of the gas entering the HRSG, less steam will be generated than in conventional steam generators with the same gas flow. Therefore, the economizer duty in the HRSG will also be low. To generate as much steam as possible, the HRSG should be designed to absorb the maximum heat from flue gas[6].

The aim of this project is to study the effect of ambient temperature on the performance of heat recovery steam generator in Benghazi combined cycle power plant at different ambient conditions.

3. Benghazi Combined Cycle Power Plant

The Benghazi combined cycle power plant (BCCPP) is located in the north of Benghazi city. The north Benghazi power plant is the main power source in the eastern wing of the general electricity network of the Libyan state.

The first stage was established in 1971, which consisted of six steam units, four units of 40 MW and two units of 30 MW, and all of them were constructed by Siemens manufacturing company.In view of the increasing demand for electric power as a result of the urban and industrial expansion, the general electricity company (GECOL) contracted with ABB (Swiss-Swedish multinational company) to install gas turbines in 1992 and the installation of three gas units (kind of these units are GT13 E1) with a total capacity of 150 MW per unit and access to the public network for electricity in 1995, where these units operate by gas and liquid fuel in simple cycle system, see Fig. 3.

Fig.3.Benghazi combined cycle power plant

In 2001, Alstom company (multinational company), was contracted to set up an additional gas unit module GT13E2. It was installed in 2002 and entered on the general electricity grid with a capacity of 160 MW. In 2002, Daewoo Korean Company was contracted to set up the first combined cycle that consists of two steam turbines from the Japanese Fuji manufacturing company with a total capacity of 150 MW.In 2008, Daewoo Korean company was contracted the second combined cycle to set up the second companied cycle integrated unit consisting of two gas turbine generators (Siemens SGT5-PAC 4000F) with a production capacity of 250 MW and two HRSGs manufactured by BHI Korean company and one steam unit manufactured by Japanese Fuji company operated by steam produced from the recovery of the heat of the exhaust gas by the gas units through the steam generators (Heat Recovery Steam Generators) to generate about 250 MW the gas units were entered on the public grid of electricity in 2009, but the steam unit was terminated by the end of 2010 and delayed entry on the public electricity network as a result of the outbreak of the revolution of the seventeenth of February and was entered in 2012 on the public grid of electricity.Fig. 4.showsthe second Benghazi combined cycle power plant.

Fig.4.The second Benghazi combined cycle power plant

From the historical profile of the north Benghazi power plant, it is noted that the direction and concentration of the general electricity company (GECOL) to benefit from the companied cycle system which focuses on upgrading the efficiency of the plant by taking advantage of the thermal energy of the gases generated by the gas units in generating steam from (HRSGs).

4. Literature Review

Ameri andAhmadi[7], they investigated the effects of ambient temperature variation on the exergy loss of the heat recovery steam generator (HRSG). The HRSGs of this CCPP are equipped with the supplementary firing. The estimations are done for the yearly minimum average, yearly average and yearly maximum temperatures. The results have been used to evaluate the exergy losses for each element of HRSG. The results show that for the fired and unfired modes, the exergy loss in 1st HP-EVP is more than other parts. The results also show that the exergy losses have a minimum point at 19°C which is the design temperature. Moreover, the results reveal that the supplementary firing increases the exergy loss of HRSG as well.

Kolluru, Dhanasekhar and Kumar [8]they studied the performance and analysis of a triple pressure heat recovery steam generator in combined cycle power plant at different ambient conditions. The results show that the increase of ambient temperature increases the exhaust outlet temperature from the gas turbine and thus increases the heat content present in the flue gases. so, it is possible to generate more amount of steam at high ambient temperatures. It is observed that the percentage of heat utilization increases because the inlet temperature of heat recovery steam generator increases with increase of ambient temperature. It is noticed that the percentage of heat utilization increases as 58.2%, 61%, 62.9% for the ambient temperatures of 150C, 300C, 450C, respectively.

5. Design Pressure and Hydrostatic Test Pressure of the Units

To improve the efficiency that resulted from heat recovery steam generator and operate it in safe condition,it is important to take into account the design pressure, therefore, the cycle is assumed to operate HRSG under these values showed in TABLE I.

TABLE IDesign Pressure and Hydrostatic Test Pressure of The Units

Section	Design Pressure (bara)	Hydro. test Pressure (bara)
HP superheater & evaporator	136	204
HP economizer	220	330
LP superheater & evaporator	13	19.5
LP economizer	30	45
Condensate Preheater	30	45

Thesevaluesof design pressure and hydrostatic test pressure of the units, that are mentioned in TABLE I, are real values and collected from the control room of the north Benghazi combined cycle power plant during a normal operating day, see Fig. 5.

6. Results and Discussion

The performance of heat recovery steam generator in Benghazi combined cycle power plant depends on a different parameter. In this project, the effect of ambient temperatureon the performance of the cycle is focused. Therefore, the data for different operating ambient temperature conditionsare collected.

The exhaust gas from the gas turbine that enters the HRSG will pass by the heat transfer sections of the HRSG, heating the steam or water inside the tubes. The exhaust gas will pass across the pressure sections in the following order:

HP Superheater3 -> HP Superheater2 -> HP Superheater1 -> HP Evaporator -> HP Economizer 4 -> HP Economizer3 -> HP Economizer2 -> LP Superheater -> LP Evaporator -> HP Economizer 1 -> LP Economizer -> Condensate Preheater (CPH).

The differentevaporators in the cycle and their areas are shown in TABLE II.

TABLE II AREA DETAILS OF EACH SECTION IN HRSG

No	Item description (HRSG)	Area (m2)
1	HP super heater	4,190
2	LP super heater	593
3	HP Evaporator	39,990
4	LP Evaporator	20,903
5	HP Economizer	13,352
6	LP Economizer	2,986
7	CPH	14,398

Fig.5. Heat transfer sections of HRSG [9]

Formulae used in calculation for all ambient temperatures

Heat content passed within the HRSG:

$$Q = \dot{m}c_p\,(T_{out} - T_{in}) \quad (1)$$

Heat developed within HP-Super heater:

$$Q_{HPs} = \dot{m}c_p\,(T_{out} - T_{in}) \quad (2)$$

Heat developed within LP-Super heater:

$$Q_{LPs} = \dot{m}c_p\,(T_{out} - T_{in}) \quad (3)$$

Heat developed within the HP-Evaporator:

$$Q_{HPEV} = \dot{m}\,c_p\,(T_{out} - T_{in}) \quad (4)$$

Heat developed within the LP-Evaporator:

$$Q_{LPEV} = \dot{m}c_p\,(T_{out} - T_{in}) \quad (5)$$

Heat developed within the HP-Economizer:

$$Q_{HPEC} = \dot{m}c_p\,(T_{out} - T_{in}) \quad (6)$$

Heat developed within LP-Economizer:

$$Q_{LPEC} = \dot{m}c_p\,(T_{out} - T_{in}) \qquad (7)$$

By using the previous set of equations (1 to 7), the nextresults, which are showed in TABLE III, can be obtained:

Table III RESULTS AT DIFFERENT AMBIENT TEMPERATURE

Item description	At 15˚C (KW)	At 20 ˚C (KW)	At 25˚C (KW)	At 30 ˚C (KW)	At 35˚C (KW)
HP super heater	76457.7	77613.8	81595.2	82551.7	86259.4
LP super heater	2111.90	2031.64	1661.26	1527.29	1805.75
HP Evaporator	42942.8	45966.1	43945.6	45974.4	47311.9
LP Evaporator	508.77	536.28	940.14	969.71	1364.76
HP Economizer	77579.3	82932.9	85178.7	78906.4	75055.83
LP Economizer	1703.98	2310.97	1912.64	2095.06	1777.61

Fig.6.shows that when the ambient temperature increases, the gas turbine exhaust temperature also increases, thus the efficiency of HRSG increases. And it is important to notice that the ambient temperature has the influence on the HRSG operation. Thereby, increasing of ambient temperature will increase the gas turbine inlet temperature.

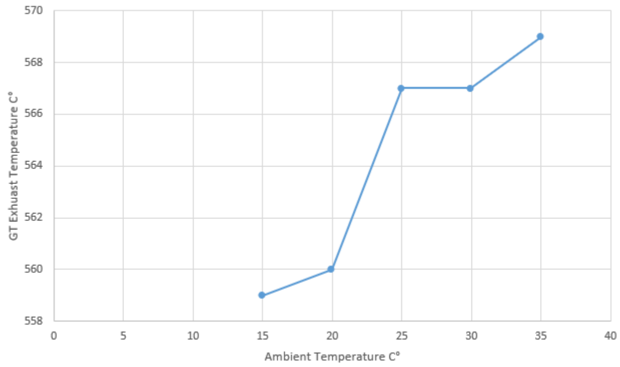

Fig.6. Relationship between ambient temperature &GT exhaust temperature

The increase of GT exhaust temperature consequent increase on heat content required to generate steam in HRSG. Fig. 7.shows that the heat content at HP superheater increases when ambient temperature increases.

Also, the mass flow rate increaseswith the increase in the ambient temperature as Fig.8.illustrates. It should be noticed that variations of the flow rate and exhaust gas temperature of the gas turbine fully depend on the control of gas turbine.

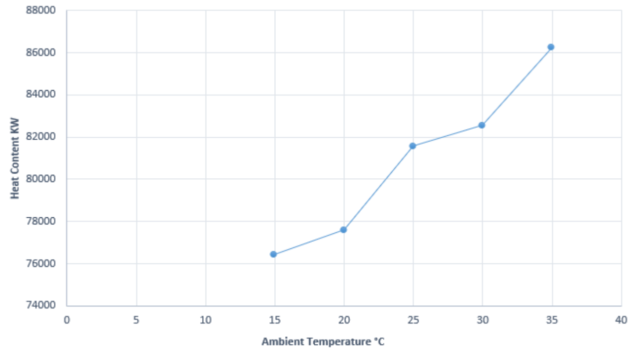

Fig.7. Relationship between ambient temperature & heat content

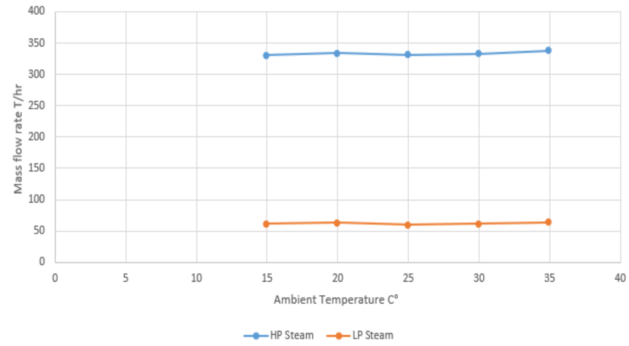

Fig.8. Relationship between ambient temperature & HP&LP steam mass flow rate.

7. CONCLUSIONS

The ambient temperature showed more importance on the performance of HRSG equipment, as the ambient temperature increases the gas outlet temperature from gas turbine increases this helps to increase the heat content present in the flue gases.

The exhaust flue gas temperature is 559°C at 15°C ambient temperature.While the ambient temperature increases to be 35°C, the exhaust flue gas temperature is 569°C which shows the importance of the ambient temperature on the performance of a companied cycle power plant operation.In addition, the effect of the ambient temperature on each stage of turbine individually which may lead to increase steam production rate.

The ambient temperature has an important influence on the energy production, as the increase in the inlet temperature of the HRSG flue gas increases the percentage of heat energy utilization.

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