Effective Parameters on Performance of Dual Pressure System Combined Cycle Power Plants

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Abstract

This study is concerned with studying the factors affecting the efficiency of the combined cycle with two pressure system (DPCC), such as extra heating, temperature of the surrounding, heat loss to the atmosphere and condenser pressure. Mathematical equations have shown that these factors are interrelated in their impact on the overall efficiency of the cycle. We then design a cycle by CyclePed software which is specialist in thermodynamics cycles, then review the impact of each factor separately from others, the results shown that the predetermination of pinch points in HRSG has played a key role, since it is responsible for determining the air flow rate in the gas cycle and then the total power produced, which became clear that its rising did not necessarily lead to raise the overall efficiency of the Dual Pressure Combined Cycle.

Keywords: Dual Pressure Combined cycle; Gas turbine; Steam turbine, Ambient temperature; Condenser pressure; Heat Recovery Steam Generator; Pinch Points.

1. Introduction

The literature has often suggest combining two or more thermal cycles within single power plant, the intention was to increase efficiency over that of single cycles, thermal processes can be combined in this way whether they operate with the same or with differing working media. However, a combination of cycles with different working media is more interesting because their advantage can complement one another. Up to the present time, only one combined cycle has found wide acceptance: the combination gas turbine/steam turbine power plant. Other combinations are also possible, e.g. mercury vapor process or replacing the water with organic fluids or ammonia. However, disadvantage of this combination i.e. development costs, environment impact, etc. appear great enough to prevent ever replacing the steam process in a combined cycle power plant [1]. This article deals mainly with the combination of gas turbine with water/steam cycle, there are some previous studies in this cycle with deferent configuration. Thamir, Ahmed [2] was studies the Optimum Gas Turbine Configuration for Improving the performance of Combined Cycle Power Plant, they found that The overall thermal efficiency of combined cycle decreases and total power output increases linearly with increase of ambient temperature, in their study the compressor of a gas turbine is designed to operate with a constant volume of air with no predetermined the pinch points in HRSG. Felipe, Silva[3] has studied the Influence of ambient temperature on combined cycle power plant

supplementary firing), they concluded that Supplementary firing causes, on average, a fall in efficiency of 1.5% for any of the ambient temperature values. A. Ganjehkaviri, S.E. Hosseini [4] in their article deals with the effect of steam turbine outlet quality on the output power of a combined cycle power plant, results show the system with 88% quality at steam turbine outlet is the most realistic in respect to the efficiency. Chuang, Deng [5] studies the Performance effects of combined cycle power plant with variable condenser pressure and loading, they concluded, the CCPP can produce more power output when operating at a lower ambient temperature (or lower condenser pressure). The difference in this study that its deals on Dual-Pressure System Combined Cycle (DPCC), with predetermine the maximum temperature difference in HRSG, at economizer side and super-heater as will, which is called Pinch Points

2. System Layout

The main problem in laying out a combined cycle plants is making optimum use of exhausts heat from the gas turbine in the waste heat boiler (Heat Recovery Stem Generator HRSG). This heat transfers between the topping and the bottoming cycle entails losses, therefore. heat utilization is not optimum, either energetically or exergetically [1]. In fact, there are several layouts used in an attempt to take advantage of this heat, some of them are listed as following:

- *Single Pressure System* (SPCC)

performance, in their article they carried out two variables (ambient temperature and gas temperature after

- *Single Pressure System with preheating loop*
- *System with Steam or Water Injection*
- *Dual Pressure System*(DPCC)
- *Triple pressure System (TPCC)*

3.Description of the Dual-Pressure System Combined Cycle (DPCC)

In generally in DPCC air enters the compressor at ambient conditions to come out when the pressure rise up to a design value, then heated to a max temperature in the combustion chamber works in general by natural gas as a fuel, exhaust gas enters to gas turbine which extract the power and leaving to the Heat Recovery Steam Generator (HRSG) to be used as a heat provider in a steam cycle. HRSG is a series of heat exchangers, for every pressure level as shown in fig (1). Every heat exchanger in the HRSG could be considered a cross flow heat exchanger, the type of circulation fluid in the evaporator is a forced circulation by circulated pump for each pressure level. The most important parameter of HRSG is Pinch Point, which is a difference between the gas and the saturation temperature corresponding to the steam pressure in that section. In the steam cycle the steam enters the turbine at high pressure and temperature then extended, in order to extract the power, the leaving steam mix with saturated steam coming from the evaporate at HRSG, the mixture enters to low pressure turbine, and extends to the condenser pressure, condensate water is pumped to the HRSG, the saturated liquid out of the economizer partitioning between low pressure unit where is returned to the evaporator and goes out saturated steam, and high pressure unit where is pumped to the super-heater and leaving to the high pressure turbine.

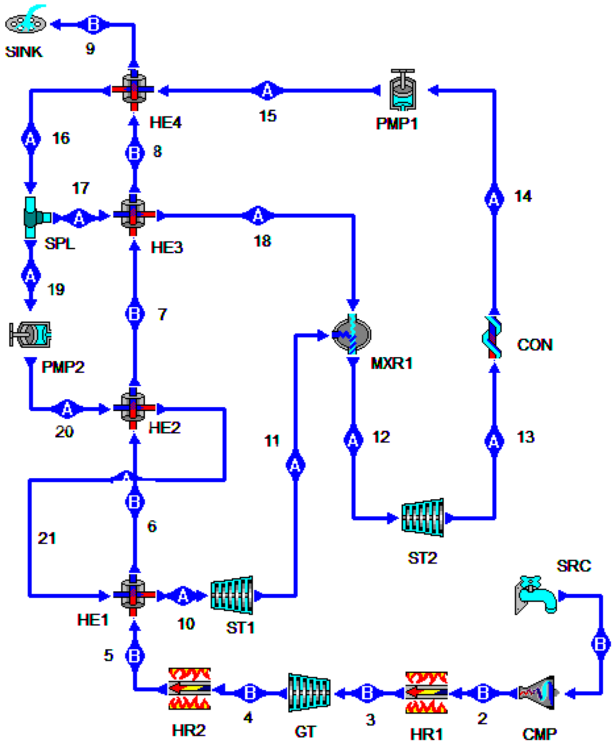

Fig (1) A schematic diagram of the Dual Pressure System Combined Cycle power plant

The previous cycle called Open Cycle, there is another type called the closed cycle, in which the exhaust gas return back to heat exchanger pulls the residual heat and used it to heat the air coming into the compressor as shown in fig (2). This study will include testing of two types.

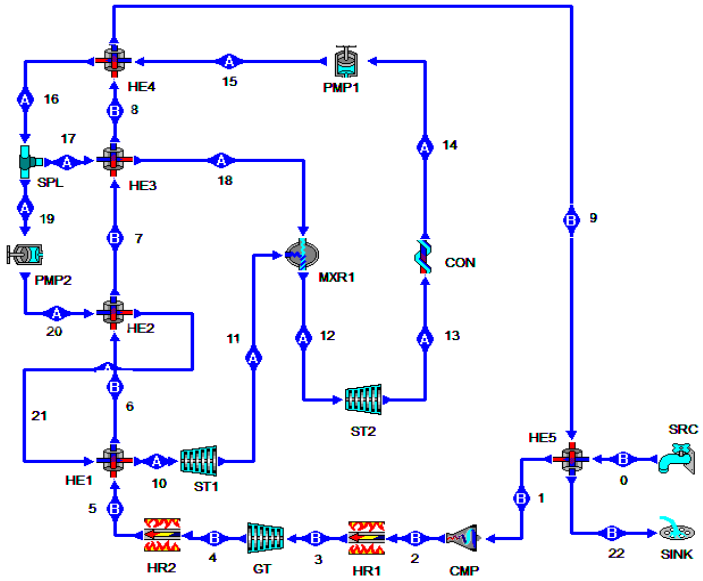

Fig (2) A schematic diagram of closed cycle DPCC

4. Thermodynamic Model and Analysis

4.1 Model Assumptions

During the analysis of this study, the following assumptions have been made:

- Atmospheric conditions are taken as temperature 298 K, pressure 1.01 bar
- Isentropic efficiencies of both the compressor and the gas turbine 85%, 85% respectively
- Isentropic efficiency of HP and LP steam turbines are taken as 80%.
- Isentropic efficiency of HP and LP pumps are taken as 85%.
- Heat added in the combustion chamber assumed 850 kJ/kg as a first assumption.
- Steam pressure inlet to the (HP) steam turbine is 50 bar, and temperature equate to temperature of exhaust gas entering to HRSG.
- The condenser pressure 0.05 bar.
- The pinch points in economizer, and super-heater at HRSG are taken as zero.
- Pressure drops in the combustion chamber, HRSG and condenser are neglected.
- Heat losses in the combustion chamber, HRSG, turbines, and condenser are neglected.
- All the processes are steady state and steady flow.
- Atmospheric conditions, Heat added and condenser pressure will increase and decrease in order to study their effects in overall performance.

4.2 Thermodynamics Analysis

- *For the compression process of air*

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{(\gamma-1)/(\gamma\eta_c)} \qquad (1)$$

- *For the combustion process in the combustion chamber*

$$(1-f)c_{p_a}(T_2-T_0)+f\times CV = c_{p_g}(T_3-T_0) \qquad (2)$$

Where: f : fuel flow to the gas flow

CV: fuel calorific value

- *For the expansion of combustion gases in the gas turbine*

$$\frac{T_4}{T_3} = \left(\frac{p_4}{p_3}\right)^{(\gamma-1)\eta_T/\gamma} \quad (3)$$

- *Energy balance in HRSG*

-Super-heater

$$\dot{m}_{g/s} c_{p_g} (T_5 - T_6) = (1 - \dot{m}_{c/s})(h_{21} - h_{10}) \quad (4)$$

Where: $m_{g/s}$ gas flow to the steam flow
$m_{c/s}$ steam flow in low pressure unit to total steam flow

- Evaporator

$$\dot{m}_{g/s} c_{p_g} (T_7 - T_8) = \dot{m}_{c/s} (h_{17} - h_{18}) \quad (5)$$

-For the temperature of exhaust gas, energy balance must be applied in economizer

$$\dot{m}_{g/s} c_{p_g} (T_8 - T_9) = \dot{m}_s (h_{15} - h_{16}) \quad (6)$$

- *The total work produced from the steam turbines*

$$\dot{W}_{ST} = \dot{m}_s \left[(1 - m_{c/s})(h_{10} - h_{11}) + (h_{12} - h_{13})\right] \quad (7)$$

- *The total work consumed at the pumps*

$$\dot{W}_P = \dot{m}_s \left[(h_{15} - h_{14}) + (1 - \dot{m}_{c/s})(h_{20} - h_{19})\right] \quad (8)$$

- *Total power produced from steam cycle:*

$$\dot{W}_{SC} = \dot{W}_{ST} - \dot{W}_P \quad (9)$$

- *For the total power produced from the gas turbine cycle*

$$\dot{W}_{GC} = \dot{m}_g c_{p_g} (T_3 - T_4) - \dot{m}_a c_{p_a} (T_2 - T_1) \quad (10)$$

Where: $\dot{m}_a = (1 - f) \times \dot{m}_g$

- *Total energy supplied to the cycle*

$$Q_T = \dot{m}_f \times CV \quad (11)$$

Where: $\dot{m}_f = f \times \dot{m}_g$

- *Net Power Produced*

$$\dot{W}_T = W_{GC} + W_{SC} \quad (12)$$

- *Overall efficiency*

$$\eta_O = \frac{W_{GC} + W_{SC}}{Q_T} \quad (13)$$

5. Results and Discussion

The effect of the several parameters on the overall efficiency are listed as following.

5.1 Ambient air temperature effects

It is known that the rise in air temperature interring to the compressor in the gas cycle leads to lower in the inlet air density which leads to high power required for the operation of the compressor, which is decrease in the productive capacity of the gas cycle and thus decrease its efficiency. But in the combined cycle under this study, we find the total efficiency increases as the temperature of the air rises up as shown in fig (3).

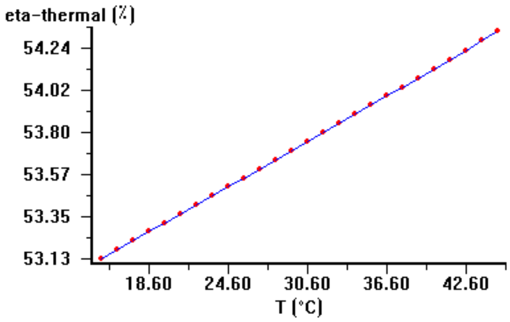

Fig (3) Thermal efficiency vs ambient temperature

This improvement in the efficiency is not necessarily results from the improvement in productive capacity. but in the conversely manner, the net capacity will decrease as shown in fig (4).

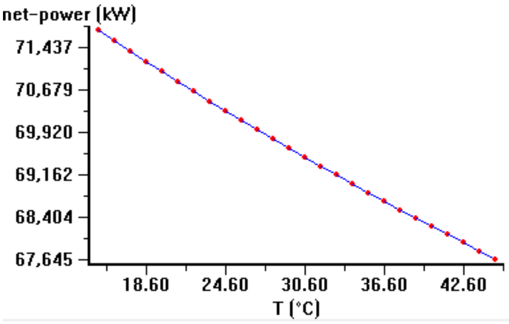

Fig (4) Net Power vs ambient temperature

The rising of the temperature of the air interring to the gas cycle will lead to a rise in temperature of the gas interring to HRSG, and hence the pinch point at HRSG is fixed, it would lead to reduce the gas flow required for the operation of the steam cycle, as shown in fig (5).

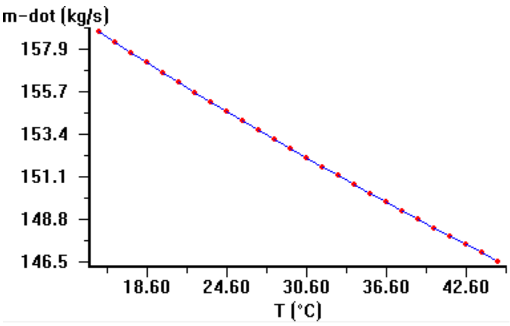

Fig (5) Gas flow rate vs ambient temperature

which leads to decrease the exhaust gas temperature. thrown to the atmosphere as shown in fig (6), this leads to improve the overall efficiency.

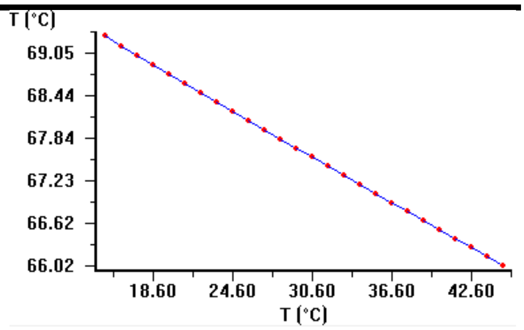

Fig (6) Exhaust temperature vs ambient temperature

5.2 Additional heating of gas turbine exhaust by fuel separation

Extra heating of the exhaust gas of gas turbine, or what is known as the separation of the fuel, is of paramount importance in the case of low temperature degree of outgoing gas from the gas turbine, but that it has an impact on the overall efficiency, the results of this study showed that when the outgoing gaseous form the turbine are heating, it will lead to lower in the overall cycle efficiency, as in fig (7)

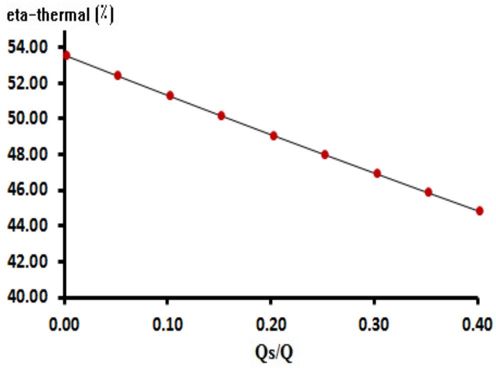

Fig (7) Overall efficiency vs fraction of fuel separation for extra heating of GT exhaust.

5.3 Benefit from the exhaust gas as closed cycle

In order to study the impact of the benefit from the exhaust gas in the overall efficiency, the cycle under this study has been updated and becomes a closed cycle, as it shown in fig (2), the results showed that it is possible to absorb the heat from the exhaust gas in whole or in part and may use it to raise up the temperature of the air entering to the compressor, thereby decreasing external heat loss to the atmosphere. As shown in fig (8)

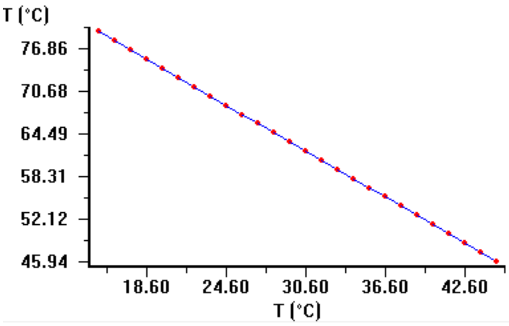

Fig (8) Temperature of entering air to the compressor vs temperature of exhaust gas

This procedure has led to the rising up the overall efficient as shown in fig (9)

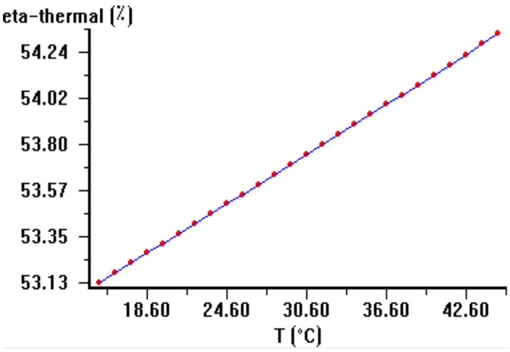

Fig (9) Overall efficiency vs Temperature of entering air to the compressor

This improvement in efficiency was not due to the improvement in the net power produced, the productive capacity will be reduced due to the increase in the power required for the operation of the compressor as well as lower gas flow rate to maintain the Pinch Point in the design limit, as was the case when the ambient temperature raised up.

5.4 The impact of lower condenser pressure

The study result shows great importance to the pressure of condensation, the more the low-pressure increased efficiency dramatically as shown fig (11),

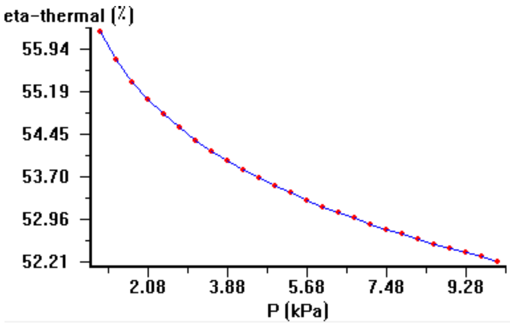

Fig (11) Overall efficiency vs condenser pressure

High efficiency at low pressures may have resulted from two factors: first, the improvement of the total net power as it illustrated in the fig (12),

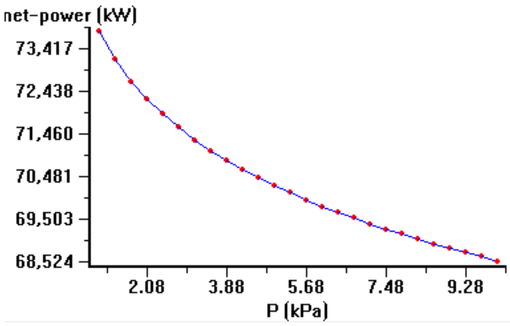

Fig (12) Net power vs condenser pressure

The second is decreases in the temperature of the exhaust gas as shown in fig (13), which is reduce the heat loss.

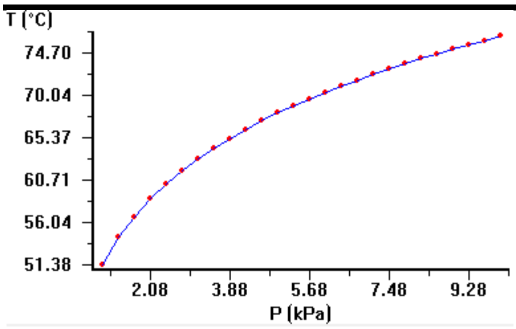

Fig (13) Exhaust gas temperature vs condenser pressure

7. Conclusion

The dual-pressure reheat combined-cycle was modeled and optimized at different values of ambient temperature, variable condenser pressure and different value of supplementary firing at predefinition of pinch point in HRSG. A comparison study leads to the following conclusions:

1. Determining the Pinch Points in HRSG plays a key role in the performance of DPCC, because it controls directly into the flow of gas in the gas cycle and the exhaust gas temperature, which has a great effect in net power producing.

2. The efficiency of DPCC with predetermine the Pinch Points can be improved when operating at a high ambient temperature, the reason for that returns to the reduction of exhaust temperature, but at the same time the total power output will decrease returns to the air flow decrease.

3. The supplementary firing goes to reduce the overall efficiency, which means it is better to burn all the fuel in a modern gas turbine that has the ability to withstand high temperature.

4. The use of exhaust gas to heat the air entering to the compressor would improve the efficiency, due to lower air flow rate regarded to maintain the pinch point as its predetermined, this leads to reduce the losses of heat and thus improve the efficiency

5. There is great effect of the condensation pressure on the cycle efficiency, as the pressure decrease the power output and efficiency will increase.

8- References

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