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Influence of Pinch Point Temperature on the Performance of Integrated Solar Combined Cycle

Sohair F. Rezeka
Department of Mechanical Engineering
Arab Academy for Science and Technology
Alexandria, Egypt

Wael M. El-maghalany
Department of Mechanical Engineering
Alexandria University
Alexandria, Egypt

Adham M. Abdelhalim
Department of Mechanical Engineering
Arab Academy for Science and Technology
Alexandria, Egypt

***Abstract*— This paper studies the influence of the pinch point temperature (PPT) on the performance of integrated solar combined cycle. The pinch point temperature has put some constraints on the cycle where at a certain point the heat transfer process would be reversed and won't be effective. There are two modes of operation; power boosting and fuel saving. This paper concerns the fuel saving mode, where the output power of the power plant is constant all over the day and the solar heat absorbed is used to improve the percentage of the fuel saved. A PID controller is used to control two main parameters which are the water flow rate (m_7) and the gas flow rate (m_g). The results showed that the solar heat absorbed is inversely proportional to the PPT. Increasing the solar heat absorbed by the collector increases the water flow rate and decreases the gas flow rate, which lead to decrease the amount of fuel burnt in the combustion chamber.**

I. INTRODUCTION

Energy demands have been increased a lot in the last decades as a result of the continuous increase in the world population, and the enormous economic flourishing in developing countries, particularly China and India [1, 2]. This has led to the inflation of the world environmental problems such as global warming and climate change [3]. It was also found that the energy resources are shrinking and their prices are swelling irrationally, and it was also predicted that the non-renewable energy resources will exterminate soon. The recent estimates have confirmed that there are about 2670 billion barrels of conventional hydrocarbons including crude oil and natural gas [1], but this will not sustain the world need of energy by the year 2050.

Thus, and according to the changes in the world's energy plan, most of the researches in the energy field have dedicated their work to the renewable energy sources as it is the only way to accommodate with the need of energy in the next decades. Hybrid power plants are the most promising configuration for converting solar energy into electrical energy [4]. There are many types of renewable energy such as; solar energy, wind energy, biomass and hydro. The most widespread source is the solar energy because of the huge amount of solar energy available on the earth's surface.

A collector must be used to focus and concentrate the solar heat in on point. The heat transfer fluid (HTF) with high capacity is fed into the collector to absorb the concentrated heat irradiance in the collector to heat the water fed to the steam turbine. There are four types of concentrating solar collector; parabolic trough, linear Fresnal, dish collector and central receiver. Parabolic trough technology is currently one of the best thermoelectric technologies. There are a lot of plants in the world using parabolic trough in operation, ranging from 0.5 MW, like the Shiraz solar power plant in Iran, to 359 MW, like the solar energy generating systems (SEGS) in California, which also is the largest parabolic trough power plant in the world.

The objective of this paper is to study the influence of the PPT to obtain maximum fuel saving in the integrated solar combined cycle. The pinch point temperature is the difference between the temperature of the exhaust exiting the evaporator and the temperature of the saturated water evaporated. The lower pinch point, the more heat is recovered from the flue gas to the water-to-steam process. On the designing scale the lower pinch point means the higher cost for the heat exchanger [7]. The pinch point temperature is usually between 5ºC and 15ºC [7].

II. SYSTEM DESCRIPTION

The system in this study consists of three main components; combined cycle, parabolic trough collector and PID controller. A complete schematic diagram for the solar integrated combined cycle will be found in figure 1.

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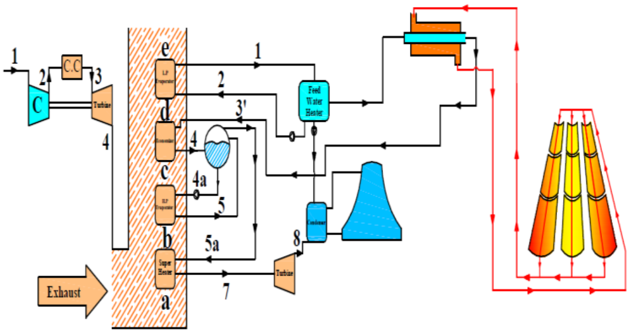

Figure 1: Schematic of solar integrated combined cycle

A case study was made for Egypt where sunshine direct solar radiation is varying, through the year, from 2000 kWh/m^2 to 3200 kWh/m^2. The collector is of LS-2 type and of 5m width and 50m long for a single collector. The HTF fluid used is Therminol Vp-1 where it has good thermal properties and it has a good temperature range [5]. This HTF is used in many different power plants driven by parabolic trough solar collector (PTSC) [6]. The solar heat is absorbed by the PTSC where the HTF is heated, and then the heated oil will be used in a heat exchanger to heat up the water flowing into the economizer at point $T_{3'}$. The inlet temperature of the oil is kept at 135.5^{o}C.

The ambient temperature is 24^{o}C and the ambient pressure is 1 bar. The compression ratio is 15.7. There are two cycles in the steam plant, the low pressure cycle (2.4bar) and the high pressure cycle (43bar). The total power of the plant is 84 MW, where 55 Mw is the output of the gas turbine cycle and 29 MW is the output of the steam turbine cycle.

III. HEAT BALANCE MODEL

Heat balance model is presented in this section. The energy equation analysis for the PTSC in this section is based on the equations presented in [8]. The heat balance for the heat recovery steam generator (HRSG):

a) Super heater

$$m_g C_p (T_a - T_b) = m_7 (h_7 - h_{5a}) \qquad (1)$$

b) High pressure evaporator

$$m_g C_p (T_b - T_c) = m_7 (h_5 - h_{4a}) \qquad (2)$$

c) Economizer

$$m_g C_p (T_c - T_d) = m_7 (h_4 - h_3) \qquad (3)$$

d) Low pressure evaporator

$$m_g C_p (T_d - T_e) = m_1 (h_1 - h_2) \qquad (4)$$

The pinch point temperature

$$PPT = T_c - T_{Sat} \qquad (5)$$

Where the (T_{Sat}) is the saturation temperature of water at 43 bar.

The power produced by the steam turbine is defined as

$$P_{ST} = m_7 * (h_7 - h_8) \qquad (6)$$

Where (h) is the enthalpy and the subscript (ST) indicates steam.

The power produced by the gas turbine is defined as

$$P_{net} = P_T - W_C \qquad (7)$$

Where (P_T) is the power of the turbine, (W_C) is the work of the compressor.

And the total power for the combined cycle is

$$P_{Total} = P_{net} + P_{ST} \qquad (8)$$

IV. CONTROL SYSTEM

The main goal of the control system is keeping the output power of the power plant constant. This mode is called "Fuel saving" where the net output power is kept constant for every time step. Two PID controllers were used: the first PID controller should maintain the output temperature of the super heater (T_7) constant at 441^{o}C, while the second PID controller should keep the output power constant at 84 MW. The controlled parameters are the water flow rate (m_7) and the gas flow rate (m_g). Figure 3 shows a diagram of the control system.

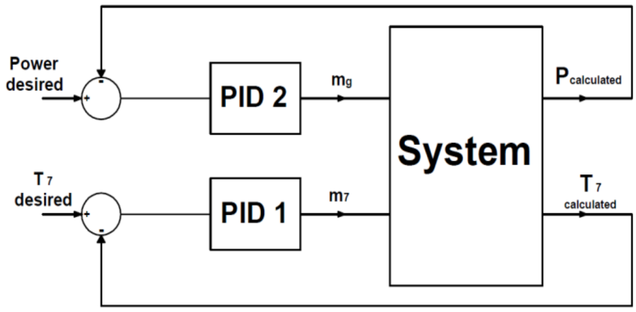

Figure 3: Control system diagram

The PID control equation is given by

$$u = \underbrace{K_p e}_{\text{Proportional Term}} + \underbrace{K_i \int_0^t e\, dt}_{\text{Integral Term}} + \underbrace{K_d \frac{d}{dt} e}_{\text{Differential Term}}$$

The control coefficients are tuned for minimum overshoots, and fast response.

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V. RESULTS

The system was examined under a solar radiation from 0 to 1081 W/m^2. Figure 4 shows the relation between the PPT and the absorbed solar heat. The relation tends to be inversely proportional, when increasing the amount of solar heat absorbed the pinch point decreases. The PPT reaches its minimum value of 14^{o}C at a maximum $Q_{Absorbed}$ of 496 W/m.

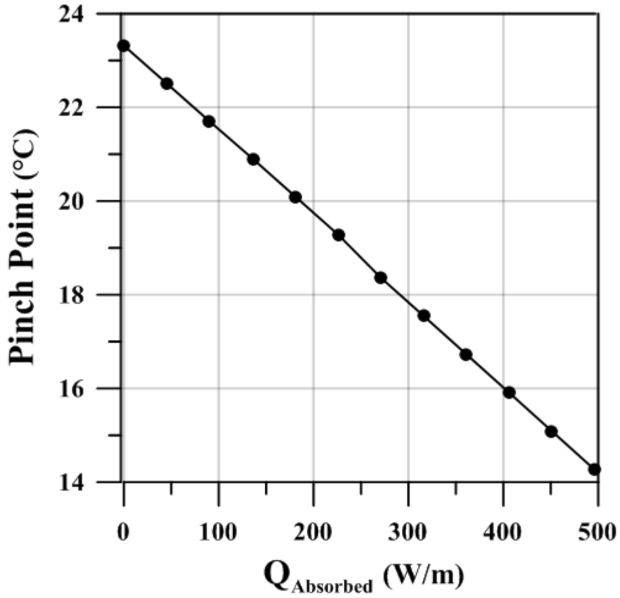

Figure 4: Solar heat absorbed vs. pinch point

From the previous curve, it is figured out that the absorbed solar heat cannot be increased over the value of 496 W/m. This is because the PPT will start to decrease below the permissible range. Temperature of water at point $T_{3'}$ increases gradually from 127^{o}C at zero solar intensity reaching its maximum (149^{o}C) at solar heat absorbed of 496 W/m as shown in figure 5.

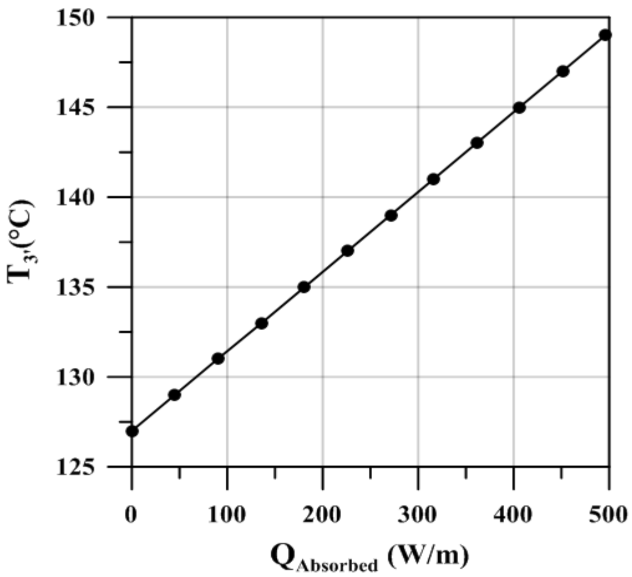

Figure 5: Solar heat absorbed vs. T3'

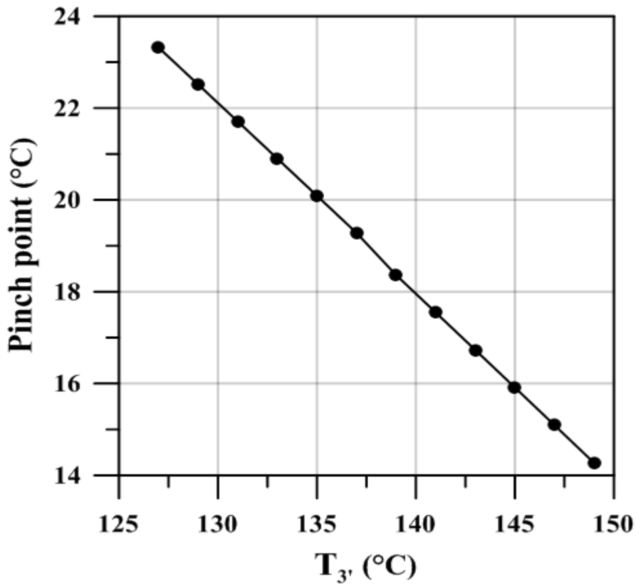

Figure 6: $T_{3'}$ vs. Pinch point

Figure 7 shows the relation between the water flow rate and the time at different solar heat absorbed with a range from 0 W/m to 496 W/m. The values of the m_7 are increasing from 25 kg/s to 25.79 kg/s.

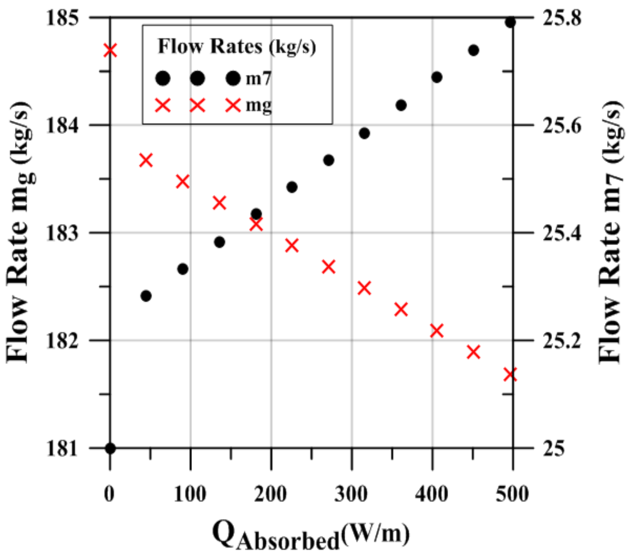

Figure 7: Flow rates vs. time

The gas flow is decreasing by increasing the absorbed solar heat. The m_g was initially at 184.7 kg/s at zero solar heat, and then it starts to decrease to reach a value of 181.56 kg/s at maximum solar heat absorbed of 496 W/m.

VI. CONCLUSION

In this paper, the influence of the pinch point temperature on an integrated solar combined cycle was clearly illustrated. While working on this type of power plants an important parameter must be always checked which is the pinch point because if it isn't kept within the permissible range the heat transfer process would be disturbed; the process would be reversed and the water starts to heat up the gases. The use of a control system helped in keeping the output power constant all the time, whereas without the PID controller it would be impossible to do such a mission. Finally it is proved that the integrating of parabolic solar trough with a combined cycle will results in decreasing the gases flow rate, thus fuel saving is achieved.

VII. NOMENCLATURE

Symbol	Subject	Unit
C_p	Specific heat	kJ/kg.^{0}C
H	Enthalpy	kj/kg
m_g	Gas flow rate	kg/s
m_7	Water flow rate	kg/s
P_{net}	Gas turbine power	MW
P_{ST}	Steam turbine power	MW
P_{Total}	Total power of the combined cycle	MW
W_c	Work of the compressor	MW

VIII. ABBREVIATIONS

HTF	Heat transfer fluid
HRSG	Heat recovery steam generator
PID	Proportional-Integral-Derivative
PPT	Pinch point temperature
PTSC	Parabolic trough solar collector

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