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RESEARCH ARTICLE
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Theoretical Investigation of the Effect of Mass Flowrate on PTC Performance.

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Abstract: The objective of this paper is to study the performance of TPC. A theoretical study was conducted to examine the Effect of mass flow on PTC performance Using MATHLAP program. It was done at the Renewable Energy Unit in Hawija, Iraq. Use water as working fluid WF at a mass flow rate of 0.00083.0.0011 0.00138, and 0.00166 Kg/s. The concentration ratio of 10, 14, 18 and 22 are used. This theoretical investigation was carried out by ASHRAE 93-1986 (RA-91). The results indicate that the theoretical efficiency starts at 40% in summer and increases relatively as mass flow increases to a maximum value of 6% in Winter. Moreover, the results demonstrated that efficiency is inversely related to concentration ratio and temperature. The performances of TPC in spring and autumn are convergent.

Keywords: solar energy, mass flow, PTC.

Nomenclature

Symbol	Description	Unit
I_T	Total solar radiation	w/m^2
A_a	Area collector	m^2
$A_{r,i}$	Inside tube area	m^2
C	Concentration ratio	-
cp_f	Specific heat of the fluid	$J/kg.k$
cp_r	Specific heat of absorber	$J/kg.k$
$D_{r,o}$	The outside diameter of the absorber	m
$D_{r,i}$	Inside diameter of the absorber	m
F'	Collector efficiency factor	-
F_R	Heat removal factor	-
$h_{c,i}$	Inside convection heat transfer coefficient	w/m^2°C
$h_{rad,r-sky}$	Radiation heat transfer coefficient	w/m^2°C
h_w	heat transfer coefficient	w/m^2°C
I_b	Vertical solar radiation intensity	w/m^2
K_f	Thermal conductivity of a fluid	w/m°C
K_r	Thermal conductivity of absorber	w/m°C
L	Collector length	m
$\dot{m}$	A mass flow rate of fluid	kg/sec
S	Absorber solar radiation	w/m^2
T_a	Air temperature	°C
T_{amb}	Ambient temperature	°C
$T_{f,i}$	Inside tube temperature	°C
$T_{f,o}$	Outside tube temperature	°C
T_r	Absorber tube temperature	°C
T_{sky}	Sky temperature	°C
U_L	Overall heat transfer coefficient	w/m°C
V	Wind speed	m/sec
W	Width of collector	m
$P_{r,f}$	Prandtl number	-
R_{ef}	Reynolds number	-
η_o	Optical efficiency	-
η_{th}	Theoretical efficiency	-
ε_r	Tube absorbers	-
σ	Stephan Poltesman constant	w/m^2K^4
γ	Interception Factor	-
ρ_a	Surface reflector	-
τ	Permeably	-
PTC	Parapulic trough collector	-
WF	Working fluid	

Introduction

Energy is the backbone of life because of its economic importance, especially in countries lacking fossil fuel sources. Over the past few decades, industrial and commercial energy demand has increased dramatically [1-3]. Unfortunately, most of the energy was produced using growing fossil fuel technologies, the release of pollutants into the atmosphere contributing to global warming and the deterioration of human health. Solar energy is one of the green energy resources that can reduce the consumption of fossil fuels to meet the demands of the industrial and commercial sectors. Moreover, the cost of solar PV and solar thermal energy has tended to decrease as their energy efficiency increased towards the end of the years [4-6]. The solar collector principle is based on focusing solar radiation on a small area, which is the receiver area. The receiving tube contains a working fluid in the interior. This fluid is water or oil for transferring heat across a heat exchanger. Concentrated solar collectors may be used for water heating, absorption cooling, electricity generation and furnaces [7-9]. The application of solar energy in industrial heating application is widely studied literature, and PTC is used in various industries. The collector transfers heat to the WF, which is used as an energy source for a given process, with the heating fluid being the primary purpose of the PTC system. Heating applications can be divided into two groups based on the temperature achieved by the WF. Low-temperature applications are for a maximum temperature of 100°C, and medium-temperature applications usually reach temperatures up to 400°C. Low-temperature PTC systems are commonly used in preheating and drying commercial, residential, and industrial sectors. Steam generation are the principal applications for medium-temperature PTC systems [10-12]. Several studies have been conducted to estimate the performance of PTC using water as a WF. The results proved that the performance of the PTC is a function of the mass flowrate, temperature and concentration ratio [13-16]. The use of oil as a heat transfer medium in solar collectors has been accepted in engineering applications, despite the decrease in the specific heat for reasons including low temperatures and corrosion problems. Studies in this field have shown that the efficiency improves with the increase in mass flowrate to reach 43% [17-19]. The freezing of pure water in solar collectors is one of the problems that conflict with use. Brine solutions were used as heat transfer fluids to bypass the problem of freezing. The results showed that the efficiency improved by 6% [20]. The use of alcohol as a working fluid has also been accepted in engineering applications. It has low evaporation temperatures at normal pressures. Therefore, these applications are suitable for evaporators, but at the expense of heat transfer and thus low efficiency [21]. The primary objective is to study the Effect of mass flow on the performance of a PTC for different values of concentration ratio. Results will be used in an ongoing Renewable Energy Research Unit. Secondly, the study was intended to demonstrate capacity in the field of collector testing through the use of the rigorous ASHRAE 93-1986 (RA 91).

Characteristics of Solar Collector

The PTC comprises five main components: mirrors, a supporting structure, a receiver, working fluid, and a tracking system. Each component is designed to fulfil a specific purpose and is fabricated using materials based on its functions and desired properties [22-23]. Figure (1) shows a detailed plan of the PTC model and its features explained in a table (1). Four supporting pipes are used with dimensions (0.0254, 0.0508, 0.0762, and 0.1016 m) to control the demanded concentration ratio. In addition, the pipe is painted black to increase its absorption and reducing reflection, using water as a working fluid.

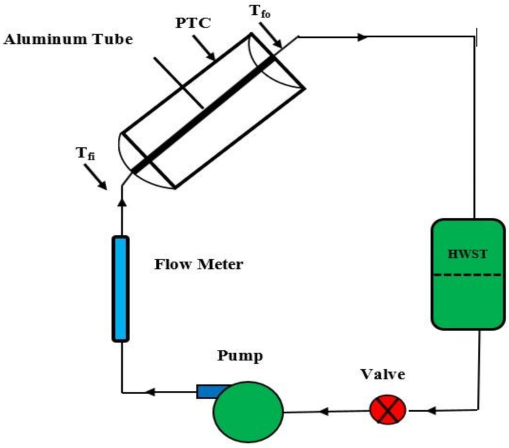

Figure 1. Solar collector model with its main contents.

Methodology

the theoretical efficiency that study carried out according to Ashrea standard(ASHRAE 93 -1986) (RA-91). While stabilization is supposed to be a daring test, the fluid state in the suction pipe is unchanged. Still, it remains as one state, neglecting the change in the external surface heat of the suction pipe, stabilizing the fluid pressure in the suction pipe, neglecting the heat loss by conduction along the suction pipe. The temperature of the liquid, wind velocity, solar radiation, and the temperature has been taken instantly.

The optical efficiency of the collector is calculated from the following equations [2].

Table 1: Characteristic of the PTC model

Symbol	value	symbol	value
Aperture Length	0.6m	supporting pipe diameter	**(0.0254, 0.0508, 0.0762 m)**
Aperture Width	0.97m	pump	**40W**
Aperture Area	$0.582\,m^2$	Tracking pattern	**2-Dim**
Length of absorber	$0.6m$	Concentrating Ratio	**10, 14, 22**
Rim Angle	90°	(γ)	**0.995**
Focal length	0.24m	(ρ)	**0.95**
$(D_{r,i})$	0.008m	Perembly*reflectivity	**0.99**
($D_{r,o}$)	0.0095m	Specific heat of material	$\boldsymbol{900J/kg.k}$
Length of coil (m)	7.66,12.05,16.43	Specific heat of fluid	$\boldsymbol{4.18J/kg.k}$

$$\eta_o = \frac{s}{I_h} \tag{1}$$

The absorption of solar radiation through the suction pipe can be calculated according to the following equation.

$$s = I_b(\rho_a \tau \alpha_r \gamma) \tag{2}$$

The calculation of the overall heat transfer coefficient is according to the following equation [2]:

$$U_L = h_w + h_{rad,r-sky} \tag{3}$$

h_w is calculated as the following equation [2]:

$$h_w = 5.7 + 3.8V \tag{4}$$

The radiation heat transfer coefficient from the suction pipe to the external surrounding is calculated as follows [2]:

$$h_{rad,r-sky} = \varepsilon_r.\sigma(T_r + T_{sky})(T_r^2 + T_{sky}^2) \tag{5}$$

T_{sky} calculated as the following equation :

$$T_{sky} = 0.055T_a^{1.5} \tag{6}$$

The absorbent temperature is calculated as follows:

$$T_r = T_{m,f} + \frac{\dot{m}cp_r(T_{f,o} - T_{f,i})}{h_{c,i}.A_{r,i}} \tag{7}$$

The average temperature is determined as follows:

$$T_{f,m} = T_{f,i} + \frac{Q_u}{A_{r,i}.U_L.f_r}\left(1 - \frac{f_r}{f'}\right) \tag{8}$$

The useful energy is computed according to the following equation:

$$Q_u = A_a.f_r\left[s - \frac{A_r}{A_a}U_L(T_{f,i} - T_{amb})\right] \tag{9}$$

The output pipe temperature shall be calculated as [2]:

$$T_{f,o} = T_{f,i} + \frac{Q_u}{m^\circ cp} \tag{10}$$

The convection Heat transforming coefficient in the suction pipe is calculated from the following equation:

$$h_{c,i} = \frac{K_f}{D_{r,i}}\left[3.6 + \frac{0.668\left(\frac{D_{r,i}}{L}\right)R_{e,f}.P_{r,f}}{1 + 0.04\left[\left(\frac{D_{r,i}}{L}\right)R_{e,f}.P_{r,f}\right]^{2/3}}\right] \tag{11}$$

Renolds number is calculated as belw [24,25]:

$$R_{e,f} = \frac{4\dot{m}}{\pi\rho_f.v_f.D_{r,i}} \tag{12}$$

The solar collector factor is calculated according to the following equation [2]:

$$F' = \frac{1/U_L}{\frac{1}{U_L} + \frac{D_{r,o}}{h_{c,i}.D_{r,i}} + \frac{D_{r,o}\ln(D_{r,o}/D_{r,i})}{2K_r}} \tag{13}$$

The heat removal factor is determined as follows [1] :

$$F_R = \frac{\dot{m}_f cp_f}{A_r.U_L}\left[1 - \exp\left(\frac{-A_{r,i}.U_L F'}{\dot{m}_f.cp_f}\right)\right] \tag{14}$$

The thermal efficiency of the solar collector is calculated by the following equation [14]:

$$\eta_{th} = F_R\left[\eta_o - \frac{U_L(T_{f,i} - T_{amb})}{I_b.C}\right] \tag{15}$$

Results and discussion

Theoretical studies have been carried out to identify the efficiency of the PTC in the climate of the Renewable Energy Unit in Hawija at four seasons. The test started in the early morning and ends at dusk, the working fluid used is water. The study is carried out to show the effect of the mass

flow rate on the performance of the PTC. Four quantities of mass flow rate are chosen (0.00083, 0.0011, 0.00138 , and 0.00166 kg /sec) respectively. Four values of concentration ratio are chosen (10,14, 18 and 22). By observing solar energy data for previous years, the results indicate the possibility of exploiting solar radiation in solar collectors applications.
Figures (2, 3, 4, 5) represent the change in the theoretical efficiency during a time. The mass flowrate beings with the lowest value of 0.00083kg /sec and ends with the highest value of 0.00166 kg/s, and the concentration ratio beings with the lowest value of 10 in figure 2 and ends with the highest value 22 in figure 5. The results show that the efficiency in Winter is increased gradually from (50-67%) concerning mass flowrate. Also, it is decreasing gradually from (63-54%) regarding reversible to concentration ratio. The difference between the theoretical efficiencies in Winter for the same concentration and varying mass flow rate not exceeding 11%. These results correspond to references [14, 22].

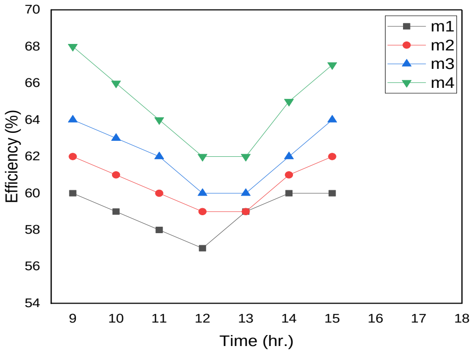

Figure 2: The variation of efficiency concerning time for concentration ratio 10

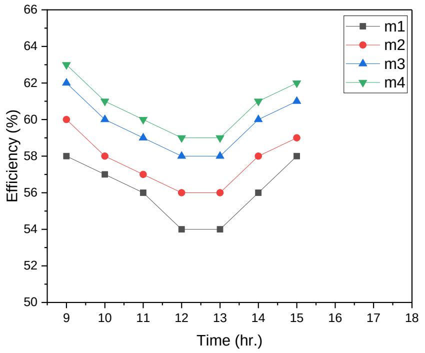

Figure 3: The variation of efficiency concerning time for concentration ratio 14

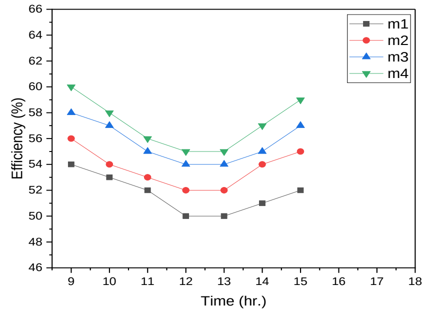

Figure 4: The variation of efficiency concerning time for concentration ratio 18

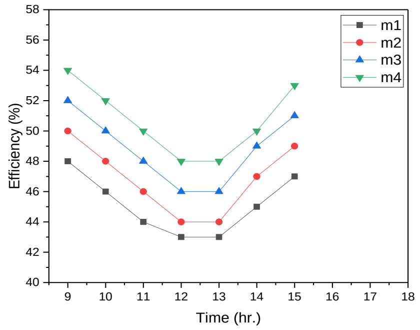

Figure 5: July 7th variation of efficiency concerning time for concentration ratio 22

Figures (7, 8,9, 10)show the change in the practical efficiency over time compared to the theoretical efficiency in Spring at varying concentration values. A mass flowrate begins at the lowest value 0.00083 kg /sec and ends with the highest value 0.00166 kg/sec. That is reaching its highest value, 58%. On the other hand, the theoretical efficiency is decreased to 54%at the lowest flow rate for the maximum concentration ratio. Thus, the difference between the hypothetical value of the efficiencies in Spring not exceeds 4%. The thermal performance of the collector is consistent with [13, 23, 24].

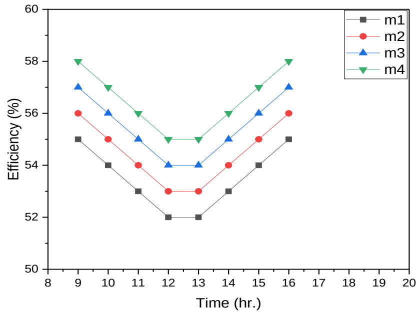

Figure 6: The variation of efficiency concerning time for concentration ratio 10

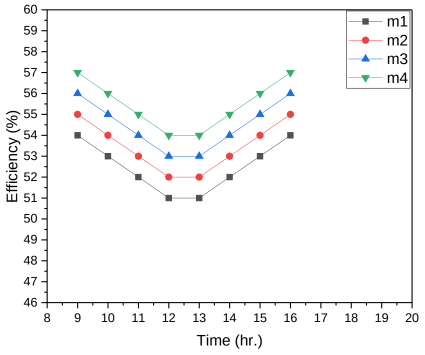

Figure 7: The variation of efficiency concerning time for concentration ratio 14

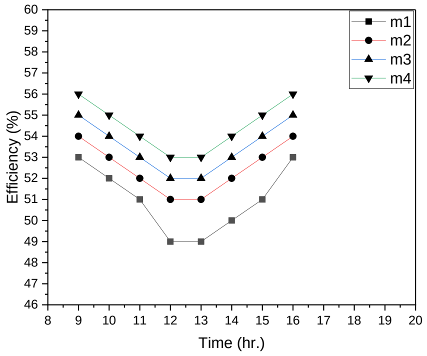

Figure 8: The variation of efficiency concerning time for concentration ratio 18

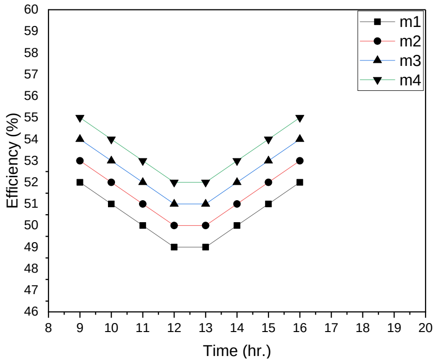

Figure 9: The variation of efficiency concerning time for concentration ratio 22

Figures (11, 12, 13, 14) represent the change in efficiency over time at mass flow rate starts at the lowest value to reach the maximum value. The highest value of the theoretical efficiency is about 50% at the lowest mass flowrate and increase relatedly to 56% at the highest flow rate and lowest concentration ratio where's the difference between the theoretical efficiency in Spring and Summer for the same concentration ratio of the total mass flow not exceeding 5%. Those results are consistent with references [25, 26].

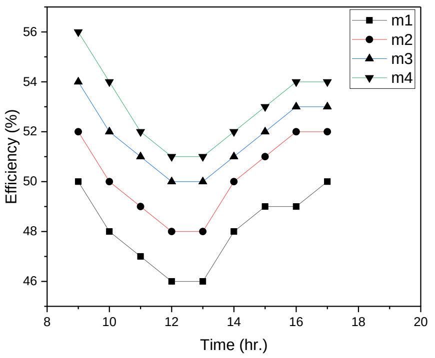

Figure 10: The variation of efficiency concerning time for concentration ratio 10

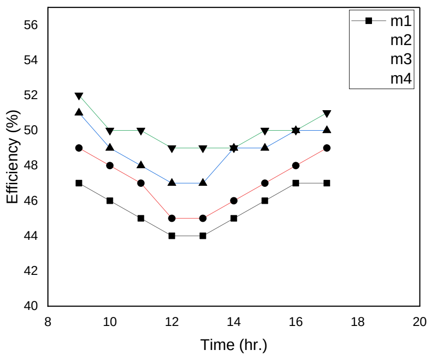

Figure 11: The variation of efficiency concerning time for concentration ratio 14

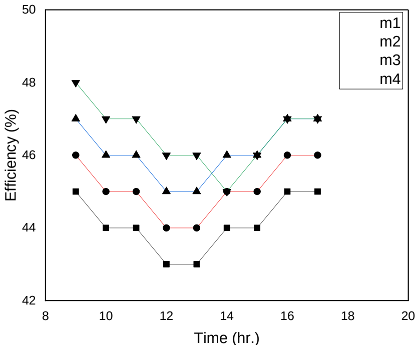

Figure 12: The variation of efficiency concerning time for concentration ratio 18

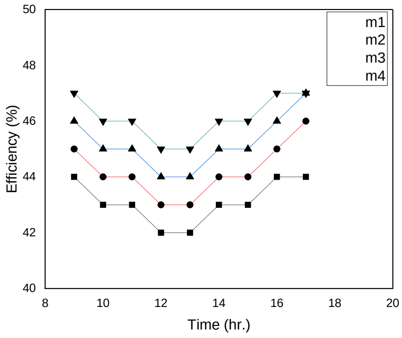

Figure 13: The variation of efficiency concerning time for concentration ratio 22

Figures (15,16,17,18) represent the change in efficiency with time for the autumn season, as it starts at the lowest mass flow and different concentration ratios. The performance of PTC is similar to an atom. This is due to the similarity in temperature.

It is mentioned for different daytime in Winter, Spring, Summer, and autumn. According to (ASHRAE 93 -1986) (RA-91) model, the theoretical study proves that the efficiency directly correlates with the mass flowrate quantity for the all concentration ratio. This belongs to the increase in the amount of water flow in the collector, which helps draw the highest amount of heat from the solar collector. Therefore, it witnesses an improvement in efficiency. This contradicts the basic principle of heat transfer, like heat transfer from the surface of the absorption to the fluid by convection. Indeed, the increase in flow mass and the increase in velocity, increasing in Renolds number, as the other variables are fixed, leads to an increase in the convection heat transfer coefficient, so this explains everything. The effect of the concentration ratio on the theoretical efficiency is negative. The efficiency decreases when the concentration ratio increases, whereas the negative relation despite the temperature and radiation intensity. Therefore, there is efficiency at noon; its lowest value is recorded for the whole season. This is not contradictory with the principle of solar collector operation, whereas the losses of the apparatus increase when the temperature of the collector increased. This behaviour is similar to [9,27,28].

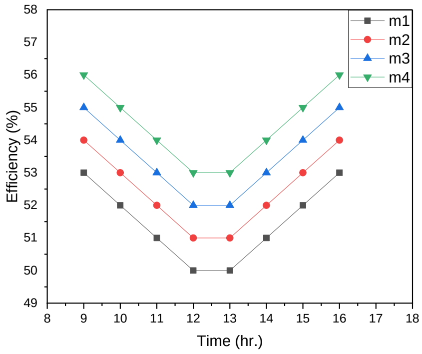

Figure 14: The variation of efficiency concerning time for concentration ratio 10

Conclusions

The losses of the solar collector increase with the increase in temperature. Increasing the mass flow leads to an improvement in the efficiency of the device.

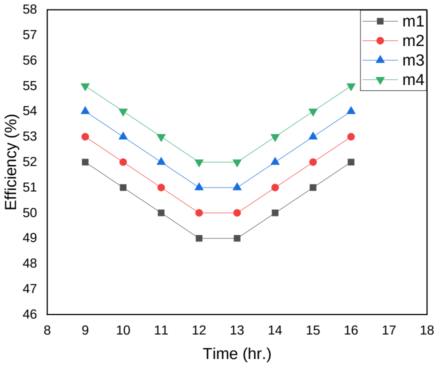

Figure 15: The variation of efficiency concerning time for concentration ratio 14

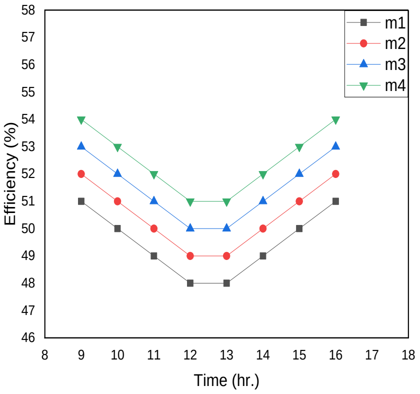

Figure 16: The variation of efficiency concerning time for concentration ratio 18

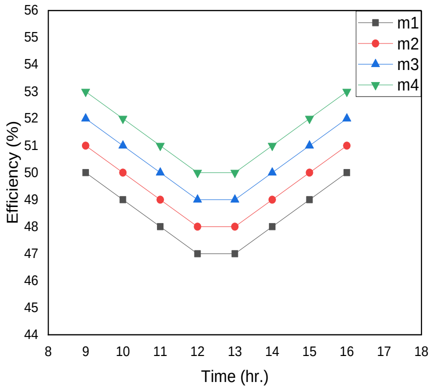

Figure 17: The variation of efficiency concerning time for concentration ratio 22

Recommendation

The results proved that an increase in the concentration ratio leads to an increase in the temperature of the PTC, and consequently, an increase in losses. Therefore, I recommend avoiding high concentrations, especially in regular PTC. And increase the amount of mass flow to withdraw the largest amount of heat.

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