**NTU Journal of Renewable Energy** **RESEARCH ARTICLE**
**ISSN: 2788-9912 (print); 2788-9920 (online) Vol. 3, No. 1** **open access**

**Available online at:** https://journals.ntu.edu.iq/index.php/NTU-JRE
**DOI: https://doi.org/10.56286/ntujre.v2i1.157**

# Theoretical and practical investigation of the CTPTC performance using FUZZY logic control

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**Received:** 03 March 2022, **Received in Revised form**:10 March 2022 **Accepted:** 27 March 2022, **Published online:** ***06 April 2022

**Abstract.** The purpose of this research is to determine the performance of a close type parabolic trough collector (CTPTC) by varying the design and operating parameters on a sunny day. It was carried out at Iraq's Renewable Energy Unit in Hawija. 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. The fuzzy technique was used to analyze the system's performance, where the theoretical analysis was carried out according to ASHRAE 93-1986 (RA-91). The findings demonstrated that theoretical efficiency reaches a maximum of 58 % when the mass flow is greatest, and the concentration ratio is minimum. Simultaneously, the practical efficiency increases to 38% under the same circumstances.

***Keywords*:** solar energy; mass flow; CTPTC; Fuzzy.

## 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 | $w/m^2℃$ |
| $h_{rad,r-Sky}$ | Radiation heat transfer coefficient | $w/m^2℃$ |
| $h_w$ | heat transfer coefficient | $w/m^2℃$ |
| $I_b$ | Vertical solar radiation intensity | $w/m^2$ |
| $k_f$ | Thermal conductivity of a fluid | w/m℃ |
| $k_r$ | Thermal conductivity of absorber | w/m℃ |
| L | Collector length | m |
| m. | A mass flow rate of fluid | kg/sec |
| S | Absorber solar radiation | $w/m^2$ |
| $T_a$ | Air temperature | ℃ |
| $T_{amb}$ | Ambient temperature | ℃ |
| $T_{f,i}$ | Inside tube temperature | ℃ |
| $T_{f,O}$ | Outside tube temperature | ℃ |
| $T_r$ | Absorber tube temperature | ℃ |
| $T_{Sky}$ | Sky temperature | ℃ |

| | | |
|---|---|---|
| $U_L$ | Overall heat transfer coefficient | w/m℃ |
| V | Wind speed | m/sec |
| w | Width of collector | m |
| $p_{r,f}$ | Prandtl number | - |
| $R_{ef}$ | Reynolds number | - |
| $\eta_O$ | Optical efficiency | - |
| $\eta_{th}$ | Theoretical efficiency | - |
| $\varepsilon_r$ | Tube absorbers | - |
| σ | Stephan Poltesman constant | $w/m^2 k^4$ |
| γ | Interception Factor | - |
| $p_a$ | Surface reflector | - |
| τ | Permeably | - |
| CTPTC | Close type Parabolic trough collector | - |
| PTC | Parabolic trough collector | - |
| WF | Working fluid | - |
| HWS | Hot Water Storage | - |

## Introduction:

Solar energy is the primary energy source in all sorts of non-conventional power sources. In addition, solar energy is a valuable source for various purposes, such as the generation of direct steam, power, and desalination of parabolic [1,2].

Because the parabolic trough collector is a well-known method in solar energy, any changes to the PTC's output are critical. Solar technology has been thriving for more than 70 years. The beginning of the oil crisis in the 1960s paved the way for a global alternative energy source, and various parabolic trough systems were developed. The temperature of the absorber tube in the typical trough collector system can reach 360-410 °C. The concentration ratio mostly determines the thermal efficiency of solar collectors. Trough collectors are now a thing of the past [3,4].

The PTC can be used for various purposes, including heat generation, power generation, and desalination. Desalination refers to the process of transforming saltwater water into drinkable water. Water desalination is now carried out via reverse osmosis technology, which raises energy consumption costs and depletes fossil fuels [5-7].

Thermo-hydraulic properties of porous rings were investigated using numerical SPTC analysis. The collector's thermal efficiency is calculated using distance comparisons and the inner diameters of the rings. The addition of porous rings to the solar tubular receiver boosts heat transfer and improves the receiver's characteristics. The porous medium should be employed throughout the receiver tube because it reduces thermal resistance and increases turbulent intensity, improving thermal properties [8-11].

The hand layout technique for producing hot water with fibre reinforced PTC, with a parabolic trough thickness of 70 cm and a rim angle of 90o, respectively [12]. The reflector affixed to the concave surface of PTC is given a high level of surface quality during production. A wind tunnel with a speed of 34 m/s is used to test the fibre-reinforced parabolic trough concentrator. The results demonstrate that the fibreglass-reinforced PTC has a thermal power of 70%[13, 14]. Using Therminol VP-1 synthetic oil and liquid water as the HTF, PTC's performance was evaluated. At temperatures above 400 °C, synthetic oil is thermally stable. As a result, synthetic oil is often utilized in PTC as a traditional heat transfer fluid. When liquid water is utilized as an HTF, thermal performance improves by 2% in the summer, with a mean of 72.3 percent in all seasons. When synthetic oils are employed as an HTF [15]. The absorber tube, the glass envelope, and the output fluid temperatures all rise faster than in liquid water scenarios. According to the research, synthetic oil is only acceptable at high temperatures [16].

As a heat transfer fluid and a solidified medium sensitive retention method, PTC with Synthetic Oil effectively lowers supply and maintenance costs. Two holding systems with a maximum temperature of 390°C and a capacity of 350 kWh are being constructed.

High-temperature ceramics made of rubber and concrete have been chosen as ideal heat storage sensitive systems for solid media [17, 18]. A theoretical and practical study to know the efficiency of PTC, once using water and oil as a working fluid to compare them studying. The results showed that the solar collector efficiency using water like fluid is better than the efficiency at some solar collectors when using converter oil as a fluid in the same climate condition and at the same rate of the mass flow rate [19].

A theoretical and practical study was conducted to analyze the performance of a solar collector using the Fuzzy logic technique. This study aims at the joint effect of the design variables represented by the concentration ratio and the operational variables defined by the mass flow rate. Moreover, the possibility of adopting the optimal design corresponds to the amount of flow that gives the maximum efficiency of the solar collector. Comparison of practical and theoretical efficiency using ASHRAE 93-1986 (RA-91).

**Characteristics of the solar collector**

The CTPTC 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 [10-14].

Figure (1) shows a detailed plan of the CTPTC used in research and its features explained in table (1), consisting of two parts, the base and the movable part. The solar collector used is a galvanized metal plate covered by mirrors with high reflection. The chosen suction pipe is made of aluminium rust resistance; the tube is shaped as a coil around a supporting pipe made of iron for a length of (0.6 m) to control the concentration ratio. Three supporting pipes are used with dimensions (0.0254, 0.0508, 0.0762 m) to control the demanded concentration ratio. The pipe is painted black to increase its absorption and reduce reflection, using water as a working fluid.

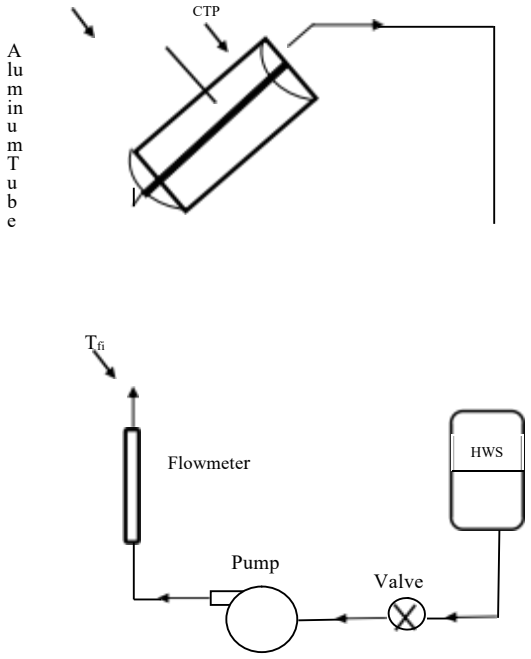



**Fig (1):** Solar collector with its main contents

**Table 1:** Characteristic of the CTPTC.

| 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 | 0.582m$^2$ | Tracking pattern | 2-Dim |
| Length of absorber | 0.6m | Concentrating Ratio | 10,14,22 |
| Rim Angle | 90 ◦ | (γ) | 0.995 |
| Focal length | 0.24m | (p) | 0.95 |
| (Dr,i) | 0.008m | Peremblty* reflectivity | 0.99 |
| (Dr,o) | 0.0095 m | Specific heat of material | 900J /kg. k |
| Length of coil (m) | 7.66,12.05,16.43 | Specific heat of fluid | 4.18J /kg. k |

## Methodology

Calculating the theoretical and practical efficiency that study carried out according to Ashrea standard ASHRAE 93-1986 (RA-91). While stabilization condition is to be a supposed 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 equation [15].

$$\eta_o = \frac{s}{I_b} \quad (1)$$

The absorber solar radiation by the suction pipe can be calculated from the following equation [16, 17].

$$s = I_b(p_a \tau \alpha_r \gamma) \quad (2)$$

The calculation of the overall heat transfer coefficient is according to the following equation [1]:

$$U_L = h_w + h_{rad,r-Sky} \quad (3)$$

hw is calculated as the following equation [1]:

$$h_w = 5.7 + 3.8v \quad (4)$$

The radiation heat transfer coefficient from the suction pipe to the external surrounding is calculated as [1]:

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

Tsky calculated as the following equation :

$$T_{sky} = 0.055T_a^{1.5} \quad (6)$$

The temperature of the absorber is calculated as:

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

The average temperature is calculated as :

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

The valuable energy is calculated from the following equation :

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

The temperature of the exit flued is calculated as[1] :

$$T_{f,o} = T_{f,i} + \frac{Q_u}{\dot{m}^{\circ} cp} \quad (10)$$

The convection Heat transforming coefficient in the suction pipe is calculated from the following equation[1,18] :

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

Renolds number is calculated as [19,20,21]:

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

The solar collector factor is calculated as the following equation [18]:

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

The heat removal factor is calculated as[1] :

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

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

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

The practical efficiency is calculated as the following equation[1]:

$$\eta_{Exp} = \frac{\dot{m}C_p(T_{f,O}-T_{f,i})}{A_a \cdot I_b} \quad (16)$$

## Fuzzy logic control design

The model for the fuzzy controller was designed based on the Mamedani structure, with three inputs and two outputs. One of the important issues in the fuzzy controller is the mechanism of choosing the type and number of the input with its activation function. In this work, the Sikwind function has been relied on as an activation function for the inputs as non-linear variables directly proportional to time. On the other hand, the decision-making rules for fuzzy logic are based on the conditional if function, where when the first input is with the second input with X of the inputs at a particular case, there will be a certain decision, this decision varies with the different inputs or one of them[20-23].

## Fuzzy logic control design

A practical and theoretical study was conducted to analyze the performance of a closed-type solar collector using the fuzzy technique to analyze the results. Using such a technique in the analysis is useful to display the performance of two variables and their effect on the third variable, which is efficiency. Figures 2 and 3 represent the combined effect of mass flow rate and solar radiation intensity on theoretical and practical efficiency. The results proved that the theoretical and practical efficiencies are directly proportional to the mass flow and inversely proportional to the intensity of solar radiation, where the highest value for theoretical and practical efficiency reached 60% and 37%, respectively. This behaviour can be explained by the fact that the thermal losses are a function of temperature, as the higher the temperature of the device, the greater the losses. Therefore, we note this discrepancy in the results. As for the effects of mass flow seem clear proportionality because the turbulence leads to the withdrawal of the most significant amount of heat and thus improves efficiency.

Figures 4 and 5 represent the effect of the mass flow rate and the concentration ratio on the performance of the solar collector. It seems clear that the effect of mass flow rate on efficiency is positive for the same reason mentioned when discussing Figures 2 and 3. However, as for the effect of the concentration ratio, it is often negative within certain limits, and this depends on the shape of the aggregate. For example, the concentration ratio may be multiplied dozens of times for spherical shapes than for cylindrical shapes. Furthermore, the losses increase due to the scattering of the largest amount of radiation in addition to the type of reflective surface.

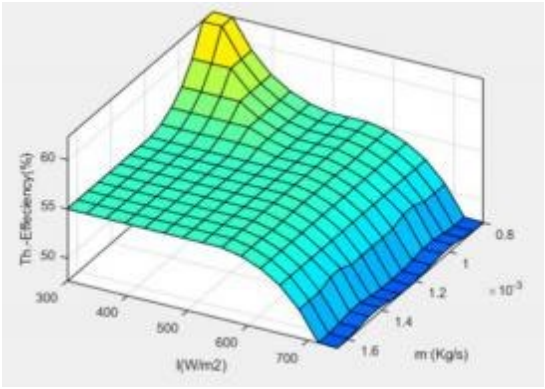



**Fig (2)**: Effect of mass flow rate and solar radiation intensity on theoretical efficiency.

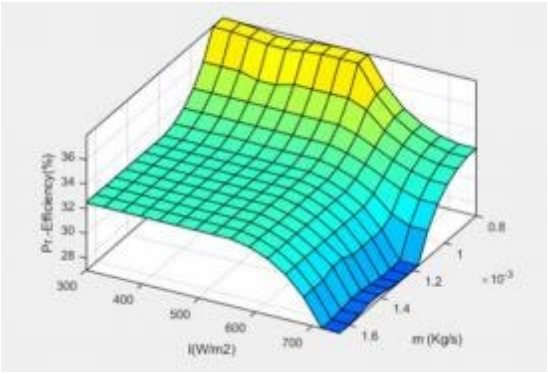



**Fig (3)**: Effect of mass flow rate and solar radiation intensity on practical efficiency.

Figures 6 and 7 represent the effect of the intensity of solar radiation and the concentration ratio on the system's performance. Following up on the previous results, the negative impact of the two variables on efficiency is observed. The average theoretical efficiency was 50%, while the practical efficiency was 32%. The explanation may be traced back to the fact that the assumptions chosen in the mathematical model for perfect circumstances were disregarded, just as the losses were overlooked in the mathematical model. Consequently, we discover

a significant disparity between theoretical and real outcomes.

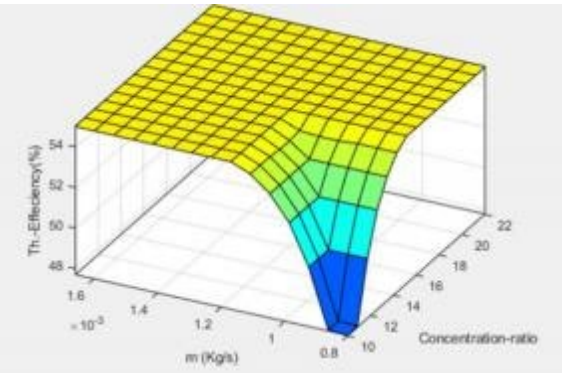



**Fig (4)**: Effect of mass flow rate and concentration ratio on theoretical efficiency.

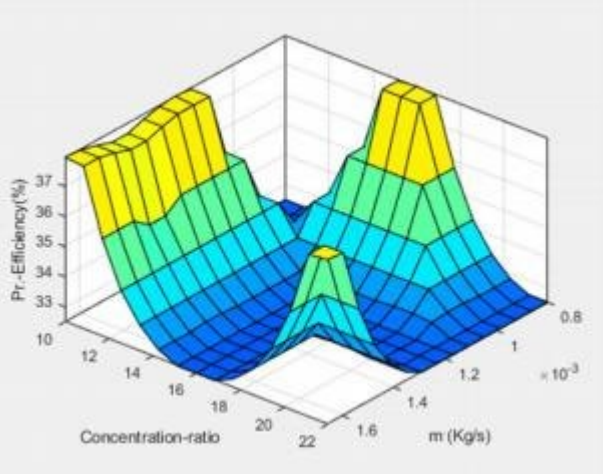



**Fig (5)**: Effect of mass flow rate and concentration ratio on practical efficiency.

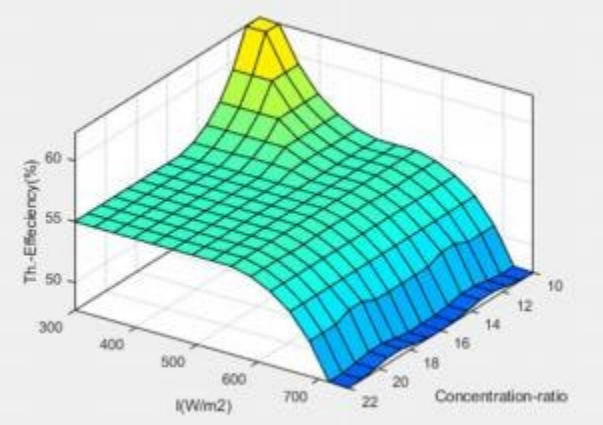



**Fig (6)**: Effect of concentration ratio and solar radiation intensity on theoretical efficiency.

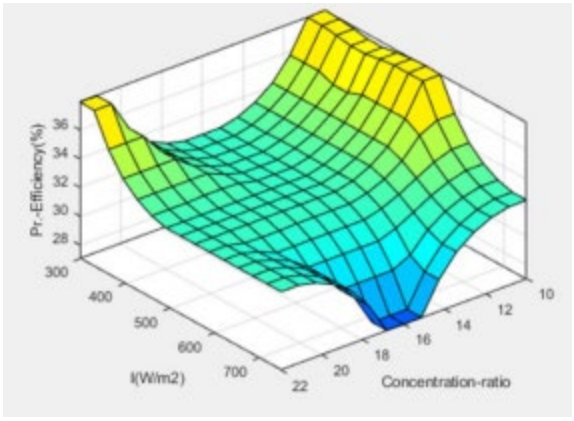



**Fig (7)**: Effect of concentration ratio and solar radiation intensity on practical efficiency.

## Conclusion:

Based on the findings, it was determined that the effectiveness of the CTPTC is dependent on several factors such as temperature, solar radiation intensity, mass flow rate, and the ratio of concentrations. A direct relationship exists between the quantity of mass flow rate and the efficiency; the relationship exists between the other factors.

## Acknowledgement

I would like to extend my thanks and gratitude to the Renewable Energy Research Unit staff, Hawija Technical Institute.

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