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

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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	$w/m^2{}^\circ C$
$h_{rad,r-sky}$	Radiation heat transfer coefficient	$w/m^2{}^\circ C$
h_w	heat transfer coefficient	$w/m^2{}^\circ C$
I_b	Vertical solar radiation intensity	w/m^2
K_f	Thermal conductivity of a fluid	$w/m^\circ C$
K_r	Thermal conductivity of absorber	$w/m^\circ C$
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	$^\circ C$
T_{amb}	Ambient temperature	$^\circ C$
$T_{f,i}$	Inside tube temperature	$^\circ C$
$T_{f,o}$	Outside tube temperature	$^\circ C$
T_r	Absorber tube temperature	$^\circ C$
T_{sky}	Sky temperature	$^\circ C$

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	-
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.

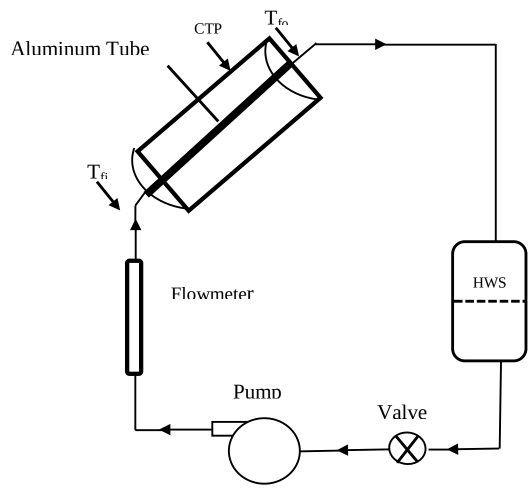

Fig (1): Solar collector with its main contents

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	$0.582 m^2$	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
(Dr,i)	0.008m	Perembltу* 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].

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

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 :

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

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] :

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

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] :

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

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.

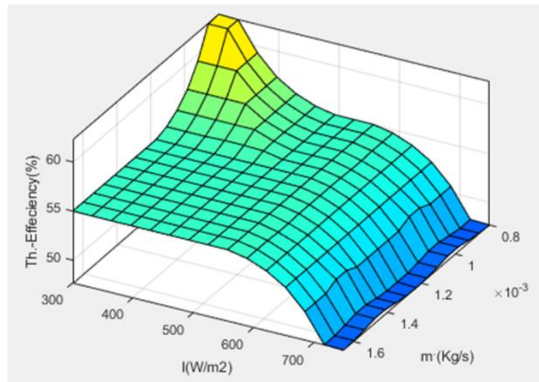

Fig (2): Effect of mass flow rate and solar radiation intensity on theoretical efficiency.

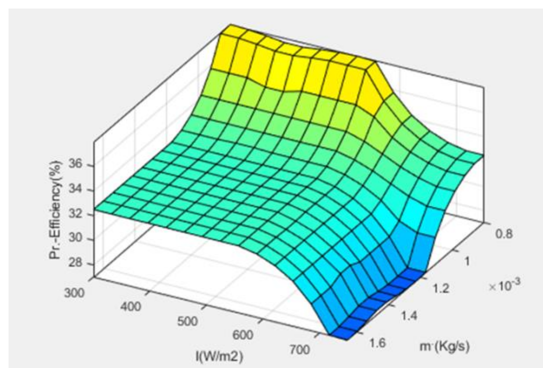

Fig (3): Effect of mass flow rate and solar radiation intensity on practical efficiency.

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.

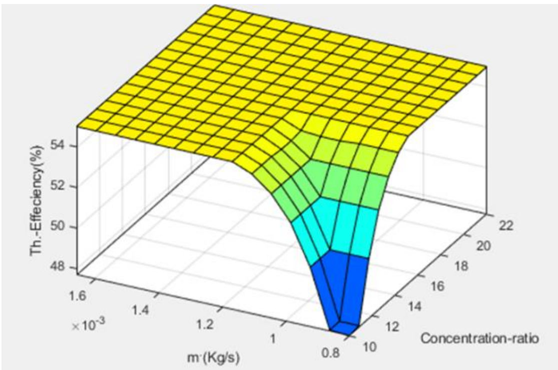

Fig (4): Effect of mass flow rate and concentration ratio on theoretical efficiency.

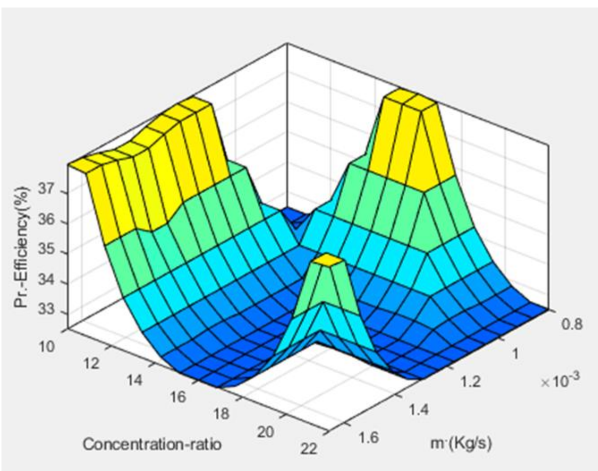

Fig (5): Effect of mass flow rate and concentration ratio on practical efficiency.

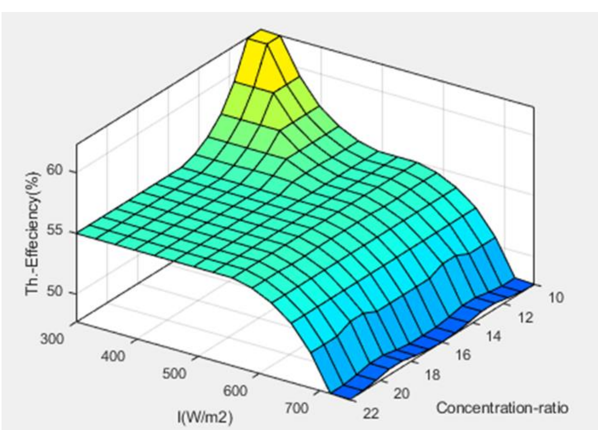

Fig (6): Effect of concentration ratio and solar radiation intensity on theoretical efficiency.

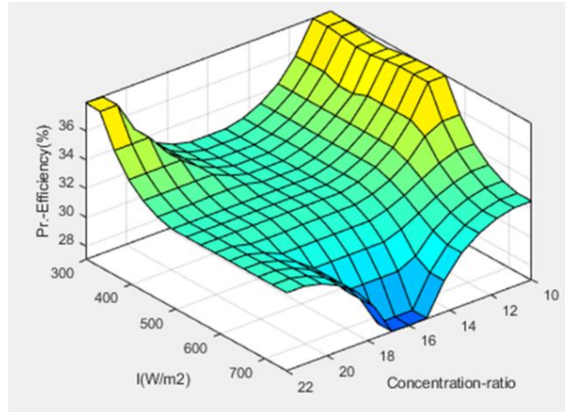

Fig (7): Effect of concentration ratio and solar radiation intensity on practical efficiency.

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.

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References:

[1] O. K. Ahmed and A. Ahmed Hassen, Principle of Renewable energies, First edit. Baghdad: Foundation of technical education, 2011.
[2] Alwan, N. T., Majeed, M. H., Shcheklein, S. E., Ali, O. M., & PraveenKumar, S. (2021). Experimental Study of a Tilt Single Slope Solar Still Integrated with Aluminum Condensate Plate. Inventions, 6(4), 77..
[3] Alwan, N. T., Shcheklein, S. E., & Ali, O. M. (2019). A practical study of a rectangular basin solar distillation with single slope using paraffin wax (PCM) cells. International Journal on Energy Conversion, 7(4), 162–170.
[4] G. Harper, Solar Energy Projects for the Evil Genius. 2007.

[5] Alwan, N. T., Shcheklein, S. E., & Ali, O. M. (2020). Effect of Hollow Drum Rotational Speed Variation on the Productivity of Modified Solar Still According to Yekaterinburg City, Russia. Applied Solar Energy, 56(4), 276–283.

[6] Database for applications of solar heat integration in industrial processes [internet]. [cited 2017 July 20]. Available from: http://ship-plants.info/?collector_type 5.

[7] EA. Solar process heat for production and advanced applications: Integration guideline [pdf on internet]. 2014 [cited 2017 July 20]. Available from: http://task49.iea-shc.org/ Data/Sites/7/150218_iea-task-49_d_b2_integration_ guideline-final.pdf

[8] Alwan, N. T., Shcheklein, S. E., & Ali, O. M. (2020). Evaluation of the productivity for new design single slope solar still at different saltwater depth. Journal of Physics: Conference Series, 1706(1), 12002.

[9] Krishna Y, FaizalM, Saidur R, Ng KC, Aslfattahi N (2020) State-of-theart heat transfer fluids for parabolic trough collector. Int J HeatMass Transf 152:119541. https://doi.org/10.1016/j.ijheatmasstransfer.2020.119541

[10] Alwan, N. T., Shcheklein, S. E., & Ali, O. M. (2020). Experimental investigation of modified solar still integrated with solar collector. Case Studies in Thermal Engineering, 100614.

[11] Kumaresan G, Sudhakar P, Santosh R, Velraj R (2017) Experimental and numerical studies of thermal performance enhancement in the receiver part of solar parabolic trough collectors. Renew Sust Energ Rev 77(March):1363–1374. https://doi.org/10.1016/j.rser.2017.01.171

[12] Alwan, N. T., Shcheklein, S. E., & Ali, O. M. (2020). Experimental investigation of solar distillation system integrated with photoelectric diffusion-absorption refrigerator (DAR). AIP Conference Proceedings, 2290(1), 50023.

[13] Reddy KS, Ravi Kumar K, Ajay CS (2015) Experimental investigation of porous disc enhanced receiver for solar parabolic trough collector. Renew Energy 77:308–319.

[14] Alwan, N. T., Shcheklein, S. E., & Ali, O. M. (2020). Experimental investigations of single-slope solar still integrated with a hollow rotating cylinder. Materials Science and Engineering, 745(1), 12063.

[15] Marif Y, Benmoussa H, Bouguettaia H, BelhadjMM, ZerroukiM (2014) Numerical simulation of solar parabolic trough collector performance in the Algeria Saharan region. Energy Convers Manag 85: 521–529. https://doi.org/10.1016/j.enconman.2014.06.002

[16] Alwan, N. T., Shcheklein, S. E., & Ali, O. M. (2021). Evaluation of distilled water quality and production costs from a modified solar still integrated with an outdoor solar water heater. Case Studies in Thermal Engineering, 27, 101216.

[17] Dhanalakshmi CS, Madhu P, Karthick A,Mathew M, Vignesh Kumar R (2020) A comprehensive MCDM-based approach using TOPSIS and EDAS as an auxiliary tool for pyrolysis material selection and its application. Biomass Conv Biorefinery. https://doi.org/10.1007/ s13399-020-01009-0

[18] Alwan, N. T., Shcheklein, S. E., Ali, O. M., Majeed, M. H., & Agyekum, E. B. (2021). Experimental and Theoretical Investigations of a Modified Single-Slope Solar Still with an External Solar Water Heater. Sustainability, 13(22), 12414.

[19] Ahmed T. Ahmed, A theoretical and practical study of a horizontal parabola trough collector using a tracking system, M.Sc, University of Tikrit College of Engineering, 2014

[20] Ahmed, O.K., Daoud, R.W., Bawa, S.M., Ahmed, A.H., "Optimization of PV/T solar water collector based on fuzzy logic control", International Journal of Renewable Energy Developmentthis link is disabled, 2020, 9(2), pp. 303–310.

[21] Ahmed, A.M., Ahmed, A.H., Daoud, R.W., Ahmed, O.K., "Optimization of Simple Solar Still Performance Using Fuzzy Logic Control" Proceedings of the 6th International Engineering Conference ''Sustainable Technology and Development'', IEC 2020this link is disabled, 2020, pp. 205–210, 9122819.

[22] Aldoori, W.H., Ahmed, A.H., Ahmed, A.M., "Performance investigation of a solar water distiller integrated with a parabolic collector using fuzzy technique" Heat Transfer - Asian Researchthis link is disabled, 2020, 49(1), pp. 120–134

[23] Omer Kh. Ahmed, Raid W. Daoud, "Determining the Coefficients of the Wedge Storage Solar Collector Based on Fuzzy Logic", 2018 International Conference on Engineering Technologies and their Applications (ICETA), Islamic University – ALNajaf – IRAQ, pp. 42-47.