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Design, Fabrication, and study of Solar Parabolic Trough for solar thermal Applications in Tikrit, Iraq

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ABSTRACT

This study presents the design and manufacture of solar parabolic trough for a purpose of conducting a practical study of the performance of this collector, which was tested on the surface of building of Physics Department a college of Science at University of Tikrit at the longitude (43.67°) and latitude (34.59°) the collector has been manufactured with length (1.5 m) and width (1 m) from the materials available locally. Stainless steel tapes were used as a reflective surface and an absorbent iron tube with internal diameter (0.023 m) and outer diameter (0.027 m), has been painted in black color as a receiving surface, and a tank with capacity (40 L) for storage of hot water, and the water that was recycled from the main tank was used as a conveyor fluid for heat. All the variables have been calculated using a computer program designed for this purpose. It was found that the concentration ratio of the collector is (11.47676), and the useful thermal energy absorbed by the water which passes in the absorber tube (786W), and the maximum practical efficiency of the system is (59.5%) at Noon time in April 17/4/2018 with a flow rate of a fluid of (0.036111 kg/sec).

1- Introduction

Energy is the lifeline of its strategic and economic importance throughout the world. Current energy trends focus on renewable, sustainable, clean, and less polluting energy from conventional energy sources [1]. For modern application, used solar energy to producing solar thermal, by using many type of solar collectors such as solar dish, solar trough [2]. The Countries that high solar radiation has many opportunities in getting solar energy with high efficiency. Iraq is one of those countries [3]. The temperature fluctuation in the conditions of the irregular radiation related to thermal applications using solar energy and it is found that the size of the thermal tank must be greater than 14.51m^2 of collector area to produce stable transmission thermal operation during the heat transfer period [4]. Design and manufactured a solar trough collector with a total area of 3.75m^2 . It has been directed to the south where aluminum paper has been used as a reflective surface for solar radiation and copper pipe and aluminum metal has been used as an absorbent surface and oil has been used as the heat transfer medium. The results showed that the maximum

efficiency of the system is (43.3%) in August[5]. Study the performance and operation of a solar trough in Northern Cyprus. The aim of using this solar trough is to supply hot steam to the electricity station solar thermal[6]. Designed and studied solar collector of a simple parabolic trough that has been tested under local climatic conditions. The collector has been made of available local materials such as stainless steel tapes as a reflective surface, and a zinc-plated steel tube as a recipient. It is found that the efficiency of the collector is approximately 37 % [7]. Design, evaluation and forming of solar trough for water heating as an illustrative design model and considered the width of the parabola was 0.5 m and its length 0.95 m. Computer-aided design and manufacturing have been done. From the results of the assessment of the thermal performance of the solar trough showed that the maximum temperature of 47.3°C at direct solar radiation $783\text{W}/\text{m}^2$ at a flow rate of $0.200\text{L}/\text{min}$. [8]. Designed the solar collector for electricity generation, a solar trough with an area of 194m^2 and a width of 1.4 m, and a length of 1.4 m, a diameter of the internal absorbent pipe

(0.0315 m), and its outer diameter of 0.0325 m. The Liquid outlet temperature (dissolved salt) reached 763.4994 °C in April and 752.9932 °C in December. This output can be used to supply a village with electricity for a day and night[9]. Design and manufactures the solar parabolic trough with a length of 2.4 m and a width of 0.8 m and an area of 1.92 m², water was used as a transfer medium for heat and aluminum foil was used as a reflective surface for radiation, and has been used two types of absorbent tubes with a length (2.4 m) has been used. The absorbent tube made from copper, painted in black, envelope a discharged glass tube from the air and the absorbent tube made from copper which is painted with black color, and a tank with a capacity of (80 L) for storage of water and using four values of the mass flow rate for water (m^o = 0.02 Kg / sec, m^o = 0.04 Kg / sec, m^o = 0.06 Kg / sec, m^o = 0.08 Kg / sec)[10]. The design, construction and testing of two types of solar collector trough has been made of available local materials, which were tested empirically under local climatic conditions in city of Sabratha in Libya (latitude 32.8 °N, longitude 12.5°E), water was selected as a heat transfer medium, the test results showed that the maximum thermal efficiency reached 52.7% on 4 January, 2016. Moreover, the maximum temperature of a fluid outlet reached 88.1 °C on 30 March 2016 [11]. The Euro trough model of the parabola collector was selected, for different storage tanks from the capacity of 3 m³ to the capacity of 15 m³ and the performance of the collector was tested during which, and the tank was used with different sizes[12]. Various programs and methods of examination of solar parabolic trough since 1981, which can distinguish their particular mathematical models or techniques followed in particular, and that mathematical models are required for design, analysis and examination because it provides a dynamic behavior and physical properties of the system. The mathematical models allow for the calculation of the different elements of the solar parabolic trough system, the effective angle of the collector surface and the working forces on the system, different types of collector and recipient, and with different measurements were examined. The study showed that the Optical efficiency values are about 63 % and the maximum theoretical efficiency reached 75 % [13]. The aim of this research: 1. Study the solar collector, 2. Design and manufacture of the solar trough collector, 3. Study the heat transfer process at different times, 4. Study the effectiveness of the solar collector in the governorate of Salah al-Din Tikrit, 5. Use the system as a solar heater.

2- Design of the solar collector

A parabolic solar trough collector has been designed of stainless steel plates as a reflective surface with a length of 1.5 m and a width of 1 m and an area of 1.5 m². It has been fixed horizontally on an iron structure towards the south direction. The collector was

designed as shown in figure (1) by using a simple parabolic equation given by [7,14]:

$$X^2 = 4fy \quad \dots\dots\dots (1)$$

$$\left(\frac{d}{2}\right)^2 = 4fh \quad \dots\dots\dots (2)$$

$$h = \frac{d^2}{16f} \quad \dots\dots\dots (3)$$

where *f*, is the focal length. The focal length is one of the important dimensions which effects on the work and performance of parabolic trough solar and is defined as the distance from the vertex of the parabola to the focus. In the event of any error in the measurement of focal length leads to putting the absorber tube outside the center of the arc for collector, which leads to losses in the reflected radiations from the concentrator because of the passage of part of the reflected radiation from reflector surface outside the absorbent tube.

h, is the height of the parabola and is defined as the distance from the top of the parabola to the highest two points in the solar collector.

d, is the width of the aperture is the distance between the two highest points in the solar collector.

ψ_{rim}, is the rim angle is defined as the angle specified between the piece of rectum extending from the highest point in the solar collector to the focus and rectum that connects between the focus of the parabola and its bottom and given in the following equation [7].

$$\tan \frac{\psi_{rim}}{2} = \frac{d}{4f} \quad \dots\dots\dots (4)$$

$$\frac{\psi_{rim}}{2} = \tan^{-1} \frac{d}{4f} \quad \dots\dots\dots (5)$$

$$\psi_{rim} = 2 \tan^{-1} \frac{d}{4f} \quad \dots\dots\dots (6)$$

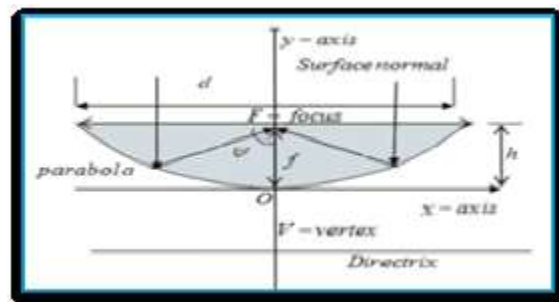


Fig.(1): The schematic of collector [14].

Geometric concentration ratio (*C*) is the ratio between the effective aperture area and the receiving tube area. The geometric concentration ratio (*C*) can be found from the following equation [15]:

$$C = \frac{\text{Effective aperture area}}{\text{Receiver tube area}} = \frac{d \cdot D_{r,ext}}{\pi D_{r,ext}} \quad \dots\dots\dots (7)$$

d = The collector width (m).

D_{r,ext} = External diameter of receiver (m)

It can also be calculated from the rim angle and the angle of acceptance [10]

$$C = \frac{\sin \psi_{rim}}{\pi \sin \theta_a} \quad \dots\dots\dots (8)$$

Where *ψ_{rim}* has represented the rim angle, and *θ_a* represents the angle of acceptance.

Figure (2) shows the basic dimensions of a parabolic solar collector, and table (1) shows the general

specifications of a solar trough collector used in this research.

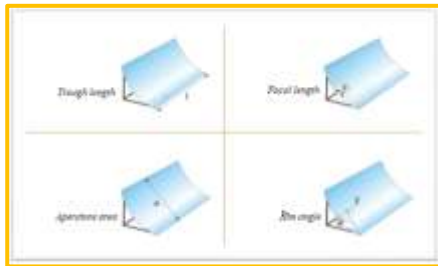


Fig. (2): The geometric dimensions of a parabolic trough solar collector [15] .

Table (1) Characteristics and specifications of the parabolic solar collector system.

Items	The Symbols	Values
Collector length	L	1.5m
Collector width	d	1m
Collector height	h	0.34m
Collector area	A_c	$1.5m^2$
Aperture area	A_a	$1.4595m^2$
Focal length	f	0.183824m
Rim angle	ϕ_{rim}	107.3463
Inner diameter of the absorber tube	$D_{i,abs}$	0.023m
Outer diameter of the absorber tube	$D_{o,abs}$	0.027m
Geometric concentration ratio	C_g	11.4/676

3- The solar collector consists of the following parts:

1-The structure: which has been manufactured as shown in figure (3) of iron. It was shaped as a parabola with a length of 1.5 m and a width of 1 m. Sheets of stainless steel thickness 0.1 mm was used as a reflective surface, due to the high reflectivity of sheets of stainless steel. For the purpose of reversing sunlight along the focal line which contains the absorbent tube. Holder of iron has been done with a thickness of (0.2 mm) and height (86 cm) for the purpose of carrying the structure of the concentrates, and it was installed in the ground to ensure that no movement occurred during winds. Fig. (4 A) and the Fig. (4 B) show the trough solar collector parts.

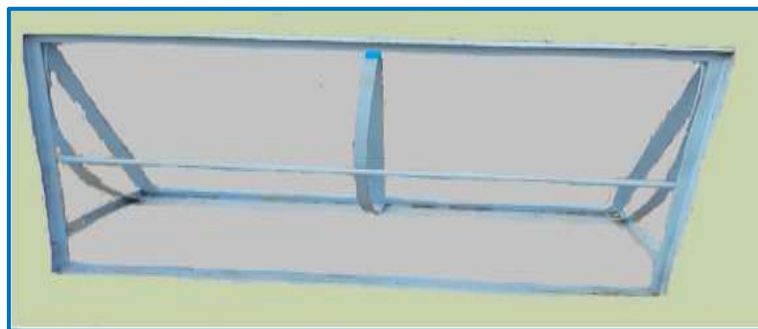


Fig. (3): The structure trough solar collector



A

B

Fig. (4): The trough solar collector parts

2- The Absorbent tube (Absorption surface): This part acts on the principle of converting the solar radiation reflected from the inverter into heat energy absorbed by the fluid flowing inside the absorbent tube. In this research a black-painted iron tube with a length (1.5m), internal diameter (0.023m) and the external diameter (0.027m) has been used, and a two pieces of aluminum on every aspect of the collector was punctured, putting the absorber tube inside the holes accurately along the focus, and during the placement of the tube inside the holes a focal distance (0.183824 m) can be obtained. The absorber tube has been connected with a thermally insulated plastic pipes for the purpose of transportation of water from the tank to the collector and vice versa .

4- Calculation of thermal efficiency of a solar collector:

The performance of the parabolic solar collector has been tested by obtaining the values of the instantaneous thermal efficiency and the thermal efficiency values of the system. For different values of solar radiation, inlet water temperature, and ambient temperature. Useful energy is calculated practically from the measurement of the inlet and outlet temperature of water and the mass flow rate for a water is as follows [16,17]:

$$Q_{u,exp} = \dot{M} C_p (T_{f,o} - T_{f,i}) \dots\dots\dots (9)$$

$Q_{u,exp}$ = The experimental useful energy (W) .

\dot{M} = The mass flow rate for the water (kg / sec) .

C_p = The specific heat at a fixed pressure of the water (J / kg.K).

T_{fo} = The temperature of the water exit (°C).

T_{fi} = The temperature of the water entrance (°C).

Instantaneous thermal efficiency (η_{exp}) is calculated practically as follows:

$$\eta_{exp} = \frac{Q_{u,exp}}{I_b A_a} \dots\dots\dots (10)$$

η_{exp} = The experimental thermal efficiency .

I_b = The intensity of a solar radiation and its unit is (W/m²).

A_a = Aperture area (m²).

$$\eta_{exp} = \frac{\dot{M} C_p (T_{f,o} - T_{f,i})}{I_b A_a} \dots\dots\dots (11)$$

The beneficial energy is calculated theoretically ($Q_{u,th}$) and as follows :

$$Q_{u,th} = (W - D_{r,ext}) L F_R \left[\eta_o I_b - \frac{U_l (T_{f,i} - T_{amb})}{c} \right] \dots\dots\dots (12)$$

$Q_{u,th}$ = Theoretical useful energy (W) .

W = The collector width (m).

$D_{r,ext}$ = External diameter of receiver (m).

L = The collector length (m).

F_R = The heat removal coefficient

η_o = The optical efficiency.

U_l = The overall heat loss coefficient (W/m².°C) .

T_{amb} = The ambient temperature (°C).

C = The concentration ratio .

$$c = \frac{A_a}{A_{r,ext}} = \frac{(W - D_{r,ext}) L}{\pi D_{r,ext} L} \dots\dots\dots (13)$$

$A_{r,ext}$ = The area of the recipient (m²).

$$A_a = (W - D_{r,ext}) L \dots\dots\dots (14)$$

$$A_{r,ext} = \pi D_{r,ext} L \dots\dots\dots (15)$$

The theoretical efficiency (η_{th}) is calculated as follows:

$$\eta_{th} = \frac{Q_{u,th}}{I_b A_a} \dots\dots\dots (16)$$

η_{th} = The theoretical thermal efficiency.

$$\eta_{th} = F_R \left[\eta_o - \frac{U_l (T_{f,i} - T_{amb})}{I_b \cdot c} \right] \dots\dots\dots (17)$$

5- Analysis of the manufactured collector

This research includes testing the solar collector, which consists of an iron pipe with a glass cover of the system, and in fine days in spring, April (8/4/2018 & 17/4/2018) and in winter in January (18/2/2018 & 25/2/2018) in a site on the surface of building of College of Science, Department of Physics, University of Tikrit. The readings have been taken from 9 AM to 2 afternoon, to measure the necessary data for the analysis of the performance of the solar collector. The temperature of the water was measured by Thermo couple (k-type) connected to a digital thermometer, and the ambient temperature has been measured using a temperature measuring ambient (MODEL: TH101E). The wind speed was measured using an anemometer and the solar radiation was measured using a solar meter. The mass flow rate of a water has been measured using a flow meter. The mass flow rate used in this research was calculated as follows:

$$0.036111 \text{ kg/sec} = \frac{130 \times 1 \text{ kg}}{3600 \text{ sec}} = \text{L/h } 130$$

$$\text{L/h} = \frac{72 \times 1 \text{ kg}}{3600 \text{ Sec}} = 0.02 \text{ kg/sec } 72$$

$$25 \text{ L/h} = \frac{25 \times 1 \text{ kg}}{3600 \text{ Sec}} = 0.006944 \text{ kg/sec}$$

6- Results and Discussions

Figure (5) shows the change of the experimental thermal efficiency of the solar collector with time in the above mentioned days. It is also shows that the minimum experimental thermal efficiency at the first reading at 9 AM, and then gradually increases with increasing of the intensity of solar radiation until it reaches the highest value at a peak time at noon, and then gradually decrease with the low amount of solar radiation at last reading at (2:00) afternoon.

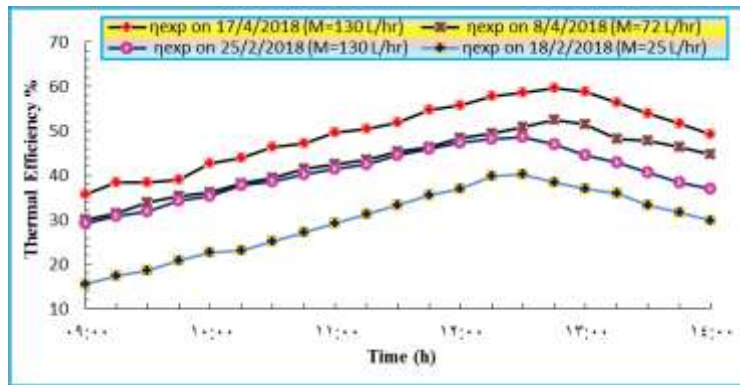


Fig. (5): Variation of experimental thermal efficiency with the time in winter and spring days

Figure (6) shows the comparison between the theoretical results of the thermal efficiency and the experimental results of thermal efficiency. It is also shown that the experimental thermal efficiency gradually increases from (9:00) AM with the increase of the intensity of solar radiation until it reaches the highest value at the peak time at noon, and then gradually decreases with the low amount of radiation at last reading at hour (2:00) PM, while theoretical thermal efficiency is almost constant during daylight hours. The experimental thermal efficiency is less

than theoretical efficiency in varying proportions due to the presence of optical and thermal losses in the system and the assumption that the sky is clear and the conditions of the weather is good, but in reality there is a change in weather such as wind speed change and the appearance of clouds which affecting on the value of practical efficiency [10,16]. The figure also shows that the practical thermal efficiency in the spring is higher than the winter due to the increase in the amount of a solar radiation reaching the earth [17].

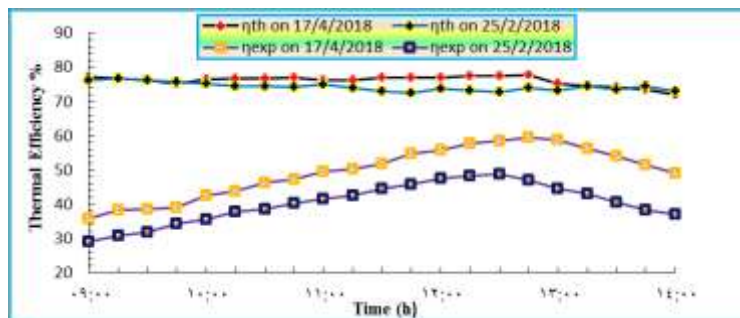


Fig.(6): Variation of experimental with theoretical results of the thermal efficiency during selected winter and spring days

Figure (7) shows a comparison between theoretical useful energy and experimental useful energy. Empirical beneficial energy is less than theoretical useful energy, and useful energy depends on the intensity of solar radiation, it is increased with the increase of the intensity of solar radiation until it reaches the highest value at the peak time at noon, and then gradually decreases with the low amount of solar radiation at the last reading at (2:00) PM, the experimental useful energy is less than theoretical useful energy in varying proportions due to the

presence of optical and thermal losses in the system and the assumption that the sky is clear and the conditions of the weather is good, but in reality there is a change in weather such as wind speed change and the appearance of clouds which affecting on the value of experimental useful energy [10,16]. The figure also shows that the experimental useful energy in the spring is higher than the winter due to the increase in the amount of a solar radiation reaching the earth [17].

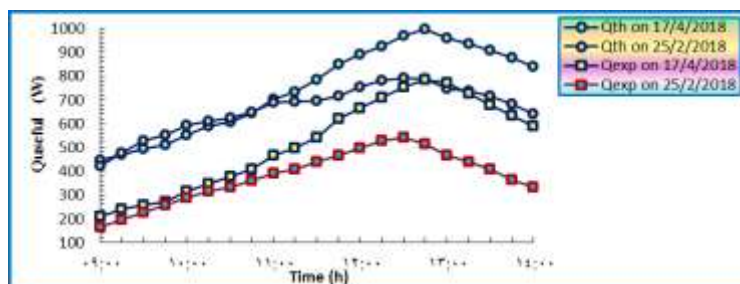


Fig.(7): Variation of experimental with theoretical results of the useful energy during selected winter and spring days

Figure (8) shows the effect of the intensity of solar radiation on the temperature of water inside (T_{in}) and outside of the solar collector (T_{out}) and the temperature of the ambient (T_{amb}) with time in the spring. It has been found that the highest value of the intensity of solar radiation which falls on the solar collector is (880 W / m^2) on the day the readings were taken using the mass flow rate of a water ($m^{\circ} = 0.036111 \text{ kg / sec}$) as for the temperature of the water entering the solar collector (20.3°C) and the

temperature of the water exit from the solar collector (21.7°C) and the ambient temperature was (20.2°C), and increases gradually with increasing the intensity of a solar radiation until reaches the maximum value of the temperature of the water entry the solar collector (51.2°C) and the temperature of water exit of the solar collector (56.3°C) and ambient temperature (32.5°C).

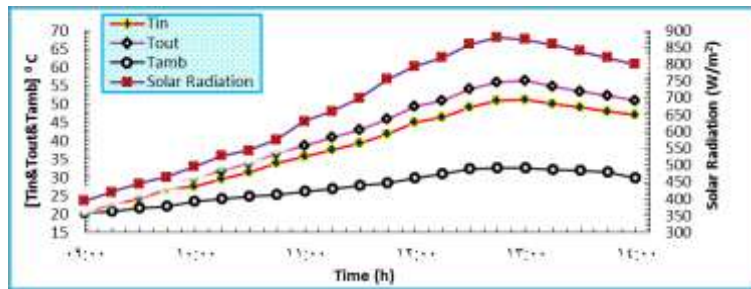


Fig. (8): Changes in the intensity of solar radiation and ambient temperatures and temperatures of water inside and out of the solar collector with the passage of time in the spring

Figure (9) shows the effect of the intensity of solar radiation on the temperature of water inside and outside of the solar collector and the temperature of the ambient with time in the winter where it was found that the highest value of the intensity of solar radiation which falls on the solar collector is (745 W / m^2) on the day the readings were taken using the mass flow rate of a water ($m^{\circ} = 0.036111 \text{ kg / sec}$) as for the temperature of the water entering the solar collector (11.9°C) and the temperature of the water exit from the solar collector (13°C) and the ambient

temperature was (12°C), and then increased gradually with increasing the intensity of solar radiation until reaches the maximum value of the temperature of the water entry to the solar collector (41.6°C) and the temperature of water exit of the solar collector (45°C) and ambient temperature (26.7°C). The figure also shows that the water exit temperature of the solar collector is higher than the water temperature entering the solar collector due to the heating process when the water passes through the absorbent tube .

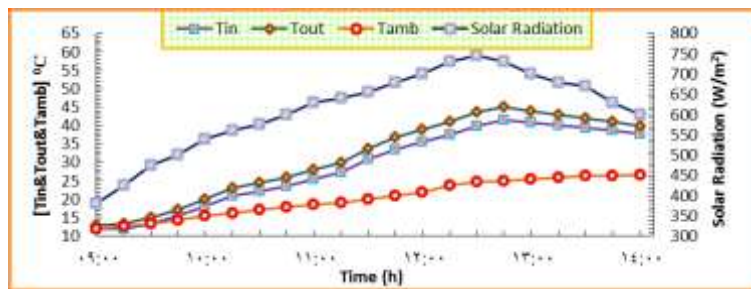


Fig. (9): Changes in the intensity of solar radiation and ambient temperatures and temperatures of water inside and out of the solar collector with the passage of time in the winter

From the comparison of the two figures (8&9), the temperature of the water entering and the exit of the water from the solar collector and the temperature of the ambient in the spring is higher than the winter,

and the difference in temperature in the spring is higher than the winter as shown in figure (10) this is due to the increase in the amount of a solar radiation reaching the earth [10].

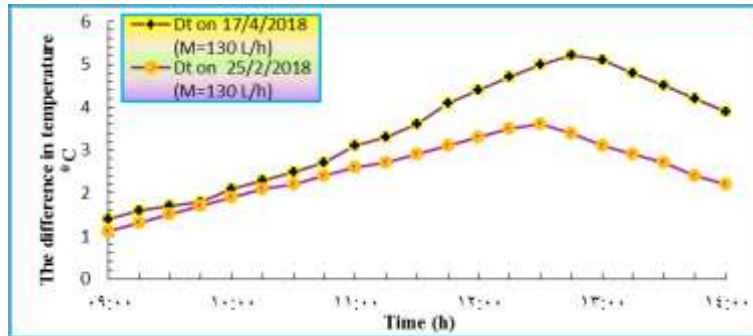


Fig. (10): Changes in the difference in temperature with the passage of time in spring and winter

Figure (11) shows that the difference in temperature increases with a decrease in the flow rate of the fluid. This is due to the fact that the lower amount of fluid flowing increases the period of fluid acquisition of

heat from the absorbent tube, and be the temperature of a fluid exit much higher the temperature of a fluid entry [10,16].

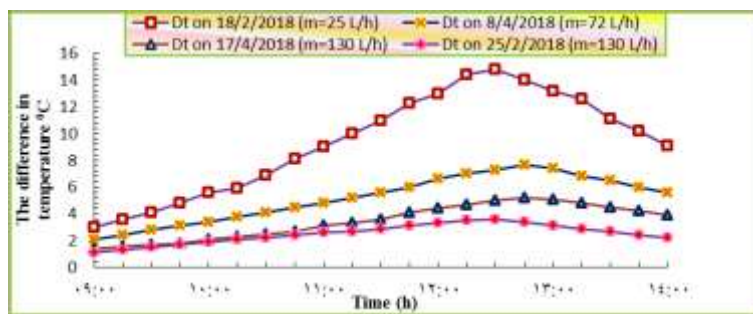


Fig. (11): Changes in the difference in temperature with the flow rate with the passage of time in the spring and the winter

7 - Conclusions

- 1- The efficiency of the solar collector and the beneficial energy gained by the water increases with increases amount of solar radiation.
- 2- The temperature of water entry and the exit of water from the solar collector and the difference in temperature between the entry and exit of water from the solar collector and the temperature of the ambient

increases with increases the amount of solar radiation..

- 3- The thermal efficiency and the useful energy gained for water in the spring is higher than the winter
- 4- The experimental thermal efficiency is less than theoretical thermal efficiency.
- 5- Experimental useful energy is less than theoretical useful energy.

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تصميم وتصنيع ودراسة حوض مكافئ شمسي للتطبيقات الحرارية في تكريت، العراق

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الملخص

تم في هذه الدراسة تصميم وتصنيع حوض تجميع الطاقة الشمسية المكافئ لغرض إجراء دراسة عملية لأداء هذا المجمع، التي تم اختيارها على السطح العلوي لبنائية قسم الفيزياء بكلية العلوم في جامعة تكريت، على خط الطول (43.67°) وخط العرض (34.59°). تم تصنيع المجمع الشمسي بطول (1.5 m) وعرض (1 m) من المواد المتاحة محلياً. استخدمت الأشرطة المصنوعة من الفولاذ غير القابل للصدأ كسطح عاكس، وأنبوب ماص من الحديد قطره الداخلي (0.023 m) وقطره الخارجي (0.027 m) والمصبوغ باللون الاسود كسطح مستلم. تم استخدام خزان سعته 40 لتر لخزن الماء الساخن وتم استخدام الماء الذي تم إعادة تدويره من الخزان الرئيسي كسائل ناقل للحرارة. تم حساب جميع المتغيرات باستخدام برنامج كمبيوتر تم تصميمه لهذا الغرض. ومن خلال القياسات والنتائج، وجد أن نسبة التركيز الهندسي للجامع بمقدار (11.47676)، والطاقة الحرارية المفيدة الممتصة من قبل الماء عند مرورها في الانبوبة الماص بمقدار (786W)، والحد الأقصى للكفاءة العملية للنظام بمقدار (59.5%) عند وقت الظهيرة في شهر نيسان وعندما يكون معدل تدفق السائل (0.036111 kg/sec).