A Two Axis Dish Solar Collector with Two Types of Absorber: Spiral and Helical Conical Absorber as a Comparative Study

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Abstract: -

In this study it has been used 2 m diameter of dish with two axis tracking system and with two types of absorber (spiral coil and helical conical coil) with same geometric concentration ratio (100). It has been used water as a working fluid in the system. The parameters which have been measured are as following: beam solar radiation, ambient temperature, absorber temperature, inlet water temperature , outlet water temperature, air velocity and volumetric flow rate. When volumetric flow rate was 0.33 L/min it has been found the maximum(outlet temperature, useful energy and thermal efficiency) of helical conical coil at 12 am as 101.11ºC , 679.28 W, 24.4 % respectively. Although, the beam solar intensity was decreased but this values with spiral coil was increased with same flow rate 0.33 L/min and same time as 124.34 ºC , 724.38 W and 28.6 % respectively. Experimental results, have been showed that spiral coil absorber more efficient than helical conical absorber.

Keywords: - Solar dish, Tracking system, Spiral absorber , Helical conical absorber

1.Introduction

Problem that facing the world today is the energy sources, and this problem left several discussions and questions to obtain an alternative energy sources instead of fossil fuel energy used today [10]. Moreover, The energy domain is related with many important problems such as depletion in fossil fuel, increase in electricity demand, emissions and problems in irrigation process [12]. Since the fossil fuel energy will run out in the coming years by virtue of great use and high prices began thinking about using renewable energy as an alternative source. Solar energy utilization is a key solution to energy problems, giving efficient, clean and financially viable solutions. Solar energy utilization can be overcoming on energy problems because it cheap , efficient and clean energy [3]

There are many different solar collectors for many applications. The use of suitable collector depend on the required outlet temperature . such as flat plat collector for 100 °C applications [4] , evacuated tubes collector and low concentration collectors for 100 °C applications [14] and above 200 °C applications parabolic trough collectors are used [9]. Abid et al. [11] compared between parabolic trough solar collector (PTSC) and parabolic dish solar collector (PDSC) and show that dish technology results more better than parabolic trough technology energetically and exergetically. This is because more concentration and low thermal losses compared with parabolic trough There are many applications on the PDSC that can be captured by two major groups are thermal energy generation and electric generation. Thermal energy generation is used to generate steam ,hot water and solar cookers, desalination; etc.[2-7]. Electrical generation is generate by use stirling engine , micro turbine or dish / alkali metal thermal to electric converter (AMTEC) system. Reddy et al. [17] , made a simulation of 50 MW power plant consist of 200 unit of (dish _ Stirling engine). Hafez et al. [1] also made a simulation of (parabolic dish _ stirling engine) system to generate 10 kW power output. It has been found the maximum conversion thermal efficiency occurred when used polymeric film nonmetal reflector. Most of the researches attempt to reduce the cost and increase in thermal efficiency of the collectors. Mohamed et al. [5] studied experimentally the effect of tracking system on thermal efficiency of PDSC and they found the increased in thermal efficiency was about (20 - 30) % more than the fixed collector. Other researchers focused on generating steam by dish solar collector to generate electricity. Dascomb.[8] tried to generate 1kW electrical power by generate steam has 6.67 KW thermal power but he found that maximum thermal power output was 5.46 KW. Some researchers have examined the types of receivers and compare them to reduce the amount of heat losses. Daabo et al. [6] studied three types of receiver geometries: a sphere, a cone and cylinder. In each case it has been used a helical tube. It was found that the conical shape is the best choice.

Researchers don't compared between spiral coil and helical coil of PDSC under the same conditions, so that in this study a comparison between spiral coil and helical coil for cavity receiver has been done. The comparisons included outlet water temperature, useful heat energy and effieciency.

Another aspect was achieved in the present work, namely, generate steam.

2. Description of Collector

It has been used a solar concentrator with dish reflector. The collector is shown in Fig. 1 with main parts. The dish continuous dish manufactured from galvanized steel. It has been used a larger diameter of dish available in local markets to gives a greater concentrator radiation center possible thus obtaining high temperature at focus area. Aluminum foil was used as a reflective material because it easily paste, availability and cheap price.

Fig. 1 The used dish solar collector

It has been used Cavity type receiver because it has high efficiency and low heat losses comparing with external receiver [8]. Two types of copper absorbers coil had been used with the helical conical coil and spiral coil with same length of them and housed in galvanized steel shell. The shell was insulated by glass wool insulation as shown in Fig. 2. It has been coated two absorbers with mat black paint to increase the absorptivity and decrease emissivity of copper coil. The geometric characteristics of the dish as well as optical and thermal properties are summarized in table1.

(a) Helical conical absorber coil

(b) Spiral absorber

Fig. 2 absorber coil

Table. 1 Properties and characteristics of PDSC used

Parameter	Value	Unit
Diameter of parabolic dish (d)	2	m
Depth of concentrator dish (h)	0.20	m
Focal length of dish (f)	1.25	m
Aperture area of dish (A_a)	3.141	m^2
Rim angle of dish (Ψ_{rim})	43.6	Deg
Geometric concentration ratio	100	-
Coil length	4	m
Cavity diameter of receiver	20	cm
Inner Pipe diameter	6	mm
Thickness of pipe	2	mm

Absorptivity-transmitivity product of copper	0.7	-
Emissivity of copper	0.725	-
Absorptivity-transmitivity product of coating	0.94	-
Emissivity of coating	0.10 - 0.14	-
Reflectivity of aluminum myler	0.76	-

3. PDSC Performance Analysis

The performance of PDSC is included the following: useful heat energy, collector thermal effieciency and heat losses. The useful heat energy can be calculate as following equations. [6]

$$Q_u = Q_{abs} - Q_l \tag{1}$$

$$Q_u = I_a A_a \rho\tau\alpha\gamma - A_{abs} \times U_l \times (T_{abs} - T_{amb}) \tag{2}$$

Conduction , convection and radiation heat losses are accurse in absorber. Thermal losses by conduction can be neglected on the basis of all surface of absorber was insulated except for the exposed part of the reflected radiation. [9] Thus, the overall heat losses coefficient can be determine as following equation:[15]

$$U_l = [\frac{1}{h_{total}+h_r}]^{-1} \tag{3}$$

The total convection heat transfer coefficient is a sum of two coefficients natural convection and wind or forced convection as following equation:

$$h_{total} = h_{wind} + h_{nat} \tag{4}$$

R. Y. Ma [13] proposed a mathematical model to calculate the

forced heat transfer coefficient at any wind speed and any inclination angle of receiver.

$$h_{wind} = f(\theta)V^{1.401} \tag{5}$$

where ;

$$f(\theta) = 0.1634 + 0.7498\sin(\theta) - 0.5026\sin(2\theta) + 0.3278\sin(3\theta) \tag{6}$$

Where; θ : *is* inclention angle of reciver

Kedare et.al. [15] are putted a correlation to calculate the heat losses by natural convection (no wind) for cavity receiver.

$$h_{nat} = \frac{Nu_{h,nat} K_{air}}{D_r} \quad (7)$$

$$Nu_{h,nat} = 0.21 Gr^{1/3} \left(\frac{T_{abs}}{T_a}\right)^{-1.5} \quad (8)$$

Where ;

$$Gr = \frac{g\beta(Tabs - T_f)L^3}{v^2} \quad (9)$$

$$T_f = \frac{T_{abs} + T_{amb}}{2} \quad (10)$$

The instantaneous thermal efficiency can be calculated for different beam solar radiation and inlet temperature of water. The useful energy can be obtaining by measurement of inlet and outlet temperature of water and select the specified mass flow rate as following equation [16]:

$$Q_u = \dot{m} \times Cp_w \times (T_{out} - T_{in}) \quad (11)$$

The instantaneous thermal efficiency of PDSC can be calculated from following equation [5].

$$\eta_c = \frac{Q_u}{Q_s} \quad (12)$$

Where Q_s is the beam solar radiation falling on aperture area of dish which equal :

$$Q_s = I_a \times A_a \quad (13)$$

4. Experimental setup

Experimental work has been done in Kut city at (32.5 latitude and 45.82 longitude), Iraq. Experimental data are taken between the end of April 2017 and the beginning of May 2017 with four days for each absorber type. The parameters which have been measured are as following : ambient temperature , absorber temperature, inlet water temperature, outlet water temperature with omega data acquisition device , air velocity with hot wire anemometer, volumetric flow rate with flow meter and beam solar intensity with solar power meter which measures total intensity solar radiation and by shading on it determine diffuse solar radiation then by subtracting from total determine beam solar radiation. Any day of examined days include one volumetric flow rate. It has been used an automatic two axis solar tracking system to make dish always direct toward to sun light as shown in Fig.3 which shows tacking system actuators arrangement. Two electrical circuits used for tracking system IC LM 339 and L293D with four LDR sensors.

Fig. 3 Tracking system actuators

The schematic of the system with main parts shown in Fig.4 .The mass flow rate used in experimental analysis is given in the following equation: [6]

$$\dot{m}\left(\frac{kg}{s}\right) = \frac{\rho\left({kg}/{m^3}\right)\cdot V\left({L}/{min}\right)}{1000\left({L}/{m^3}\right)\cdot 3600\left({s}/{h}\right)} \qquad (14)$$

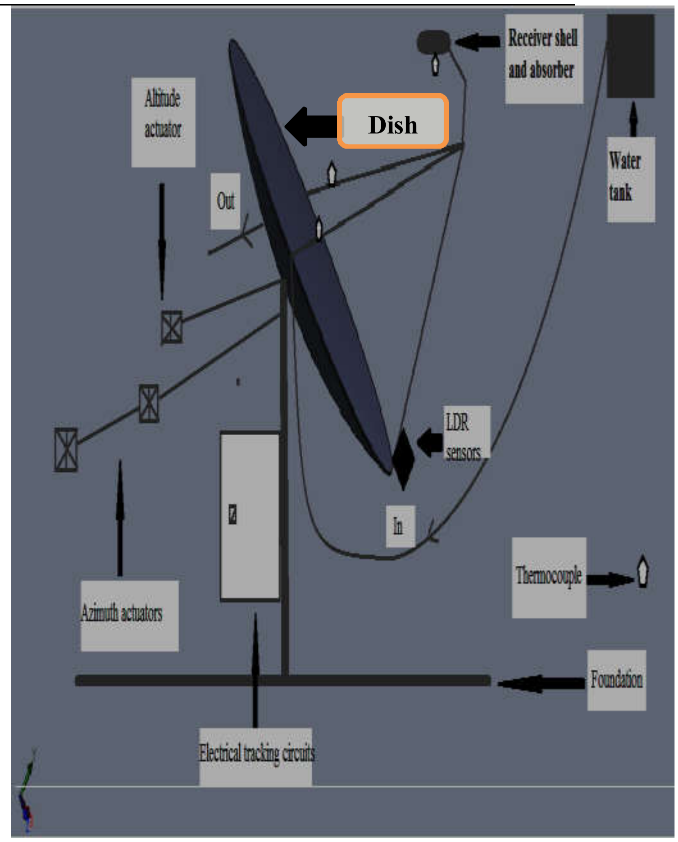

Fig. 4 Schematic of the system

6. Experimental procedure

The inlet valve opens the water coming from the tank on a high-rise building. The flow rate of the inlet water is then measured by an enclosed bottle and a stopwatch so that it is time for a minute to fill the bottle with the desired volumetric rate. Water enters the inside of the coil in the receiver and then goes outside. In the three stages we mentioned, the temperature of the water input, the temperature of the surface of the absorber and the temperature of water output are measured. Temperatures, solar radiation and wind speed with ambient temperature are measured after each hour from 9 am to 3 pm.

5. Results and discussions

The results were found from experimental tests of many clear-sky days for the months of April and May with different volumetric flow rates. A Period of four days with clear-sky (26^{th} , 30^{th} of April and 14^{th} , 16^{th} of May) have been chosen to measure the experimental data to investigate the performance of PDSC with helical conical absorber. Four volumetric flow rates were chosen (1 L/min , 0.5 L/min , 0.33 L/min , 0.1 L/min) with one volumetric flow rate for each day. Fig. 5 shows that the beam solar intensity increase from 615W/m^2 at 9:00 am until reach maximum value 885 W/m^2 at 12am and decreased after solar noon at 14 May with 0.33 L/min volumetric flow rate. The temperatures also increased with beam solar radiation increase. Maximum absorber and outlet temperature were 120 ^oC and 101.11^oC respectively at solar noon

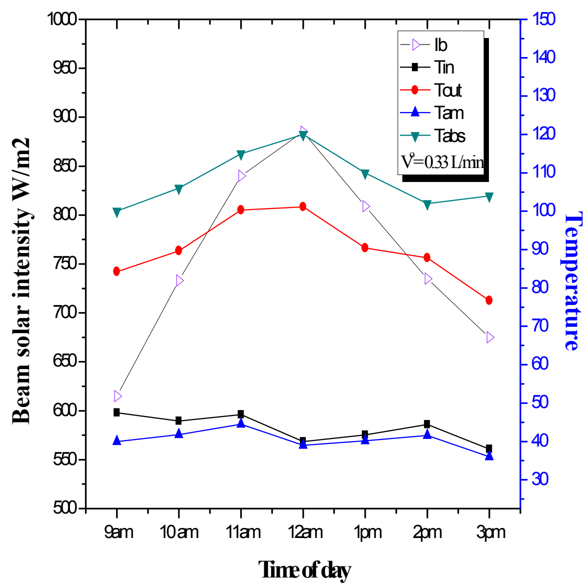

Fig. 5 Beam solar intensity and temperatures of PDSC with helical conical coil (14/5/2017)

A period of four days with clear- sky (18^{th} , 19^{th} , 21^{th} , 25^{th} of May) with same volumetric flow rates for helical conical absorber to take the necessary data and study the effect of changing the absorber type to the spiral coil on the performance of PDSC. Fig. 6 show that although the beam solar intensity decreased which varied from 575 W/m^2 at 9:00 am to 805 W/m^2 at 12am ,the spiral absorber type was more efficient than the helical conical absorber with the same rate of flow (0.33 L/min). Maximum absorber and outlet temperature were 310 ^oC and 124.34 ^oC respectively at solar noon.

This is because the reflected radiation falls close to the entire length of the coil. Although the day was clear, but in the last two hours of the test began intermittent clouds which greatly reduced the amount of radiation falling and thus led to a clear drop in the temperature of the absorber and outlet. In general, despite the differences in temperature between the two types of absorbers used, the outlet water temperature of the two types was high and this means that the steam was generated already. All these values along the hours of taking readings are observable in Table.2 and Table. 3 at the

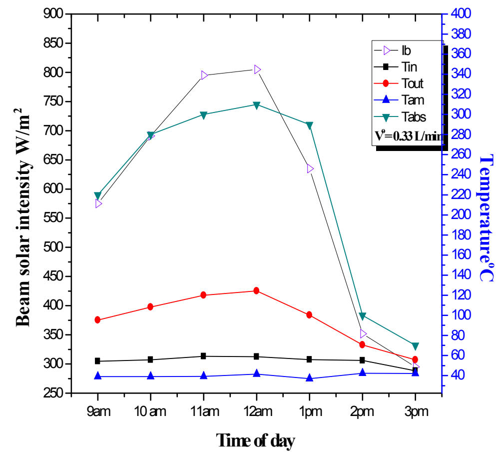

Fig. 6 Beam solar intensity and temperatures of PDSC with spiral coil (19/5/2017)

Table. 2 Variation of temperatures , beam solar intensity and air velocity of PDSC with helical absorber at 14/5/2017

Time	I_b (W/m^2)	T_{in} (°C)	T_{out} (°C)	T_{am} (°C)	T_{abs} (°C)	Vair (m/s)
9am	575	54.2	95.32	39	220	0.8
10 am	691	55.75	108.32	39	280	0.85
11am	795	59.11	120	39.2	300	0.655
12am	805	58.78	124.34	41.4	310	1.45
1pm	635	55.87	100.21	37	290	0.55
2pm	352	55.07	70.43	42.3	275	0.28
3pm	295	44.66	55.76	42.1	205	1.05

Table. 3 Variation of temperatures, beam solar intensity and air velocity of PDSC with spiral absorber at 19/5/2017

Time	I_b (W/m^2)	T_{in} (°C)	T_{out} (°C)	T_{am} (°C)	T_{abs} (°C)	Vair (m/s)
9am	615	47.5	84.2	40	100	3.5
10 am	733	45.32	89.63	41.8	106	1.8
11am	840	47	100.31	44.5	115	4
12am	885	40	101.11	45.1	120	5.65
1pm	809	41.7	90.43	44.1	110	3.65
2pm	735	44.42	87.87	47	102	6.2
3pm	675	38	76.7	46	104	2.55

Fig.7 shows the useful heat energy with time of day for helical conical absorber and spiral coil absorber with same volumetric flow rate (0.33 L/min). It shows that the useful heat energy varied between 408.55 W to 679.28 W when the beam solar intensity varied between 615 W/m^2 to 885 W/ m^2 for 14 May by using helical conical absorber. Although, the beam solar intensity was dropped in 19 May but the useful heat energy increased to 724.38 W when using spiral coil absorber. The sudden decrease of useful energy for spiral coil after 1 pm because appearance of some clouds pieces which led to a decrease in amount of solar radiation. The results show that the spiral is better than the helical and has increase in useful energy about 45.1 W at 12 am more than helical this is as mentioned previously, because the spiral absorber is exposed to the radiation reflected more than the surface of the helical absorber.

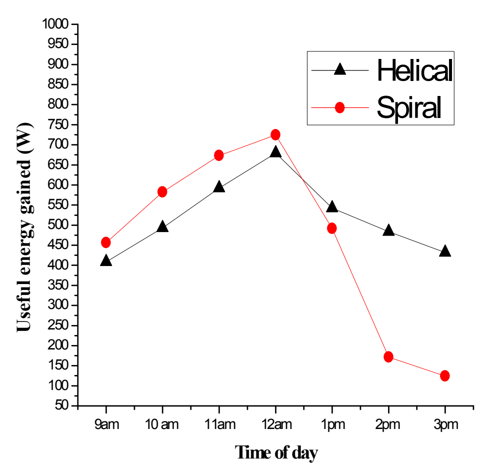

Fig. 7 Useful energy with time for helical conical absorber and spiral absorber

The instantaneous thermal effieciency can be calculated from equation (12). The effieciency of these absorber shown in Fig. (6).Thermal effieciency of helical conical absorber varied from 0.211 to 0.244 for interval time (9 am to 12 am) when the beam solar radiation varied between 615 W/m^2 to 855 W/m^2. Thermal effieciency of spiral coil absorber is increased although of decreasing beam solar radiation and varied from 0.252 to 0.286 for the same interval time and same volumetric flow rate (0.33 L/min). The Fig. 8 also shows as mentioned early the sudden decrease in the efficiency of the spiral coil due to the appearance of some pieces of clouds after 1 pm, which led to a decrease in amount of solar radiation. Although , the variation shown in the results between two types of absorbers but, the two types were generated steam with different temperatures as shown in previous diagrams. Also when the flow rate decrease the outlet water temperature increase, this means increasing the chance of generating steam. In this study, steam was also generated at high temperatures when the volumetric flow rate was 0.1 L/min

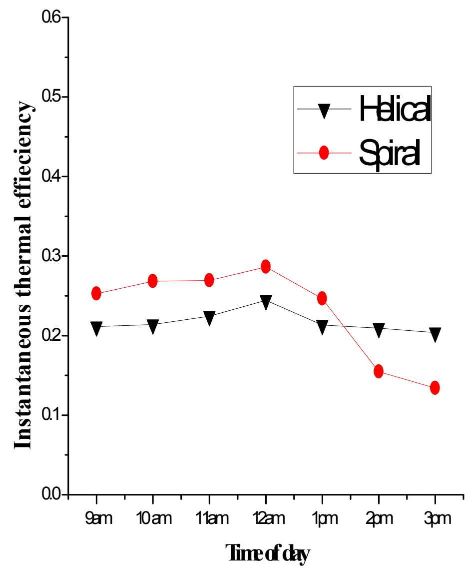

Fig. 8: Variation of instantaneous thermal efficiency with time of day for helical conical and spiral coil

The heat losses from absorber increased with solar radiation increased also with increased of temperature of absorber. The heat losses of helical conical absorber was more than heat losses of spiral absorber coil with same volumetric flow rate 0.33 L/min as shown in Fig. 9. This is due to the fact that the surface of the helical absorber was exposed to heat exchange with the air more than in the case of the spiral coil. Another factor that affects heat loss is air velocity. This factor is not controlled and heat losses increased when air velocity increase. Thus, the fluctuation of heat losses curve because the fluctuation in air velocity.

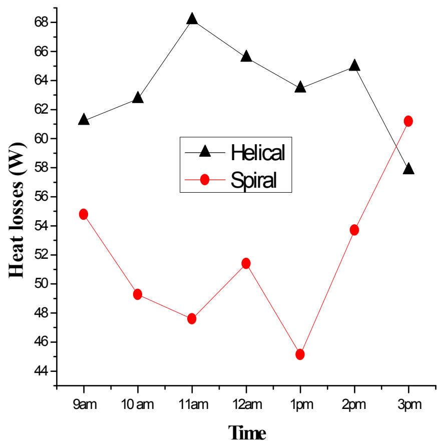

Fig. 9 Heat losses of helical and spiral coils.

As compared with previous studies, Sada et al. [14] they used 1.7 m dish diameter with helical absorber with 3m length of copper coil. They produced steam at 115.7 °C maximum temperature but not direct steam. The water was inters the pipe and not flow. In our this study produced steam at101.1 °C with helical conical coil but this direct steam which mean the water not stop and flow in the pipe.

6. Conclusion

1- The world today suffer from depletion in energy sources so that must be to obtain an alternative energy sources instead of fossil fuel energy.

2- PDSC is an important type of concentrating systems to generate high amounts of heat.

2- In this study , it has been used dish solar collector with two axis tracking system with two types absorber (spiral coil and helical conical coil) and investigated of performance experimentally.

3- The two types were compared at a flow rate of 0.33 L/min.

4- The outlet water temperature of spiral coil was higher than helical coil at the same volumetric flow rate which was 101.11°C for helical absorber and 124.34 °C for spiral absorber ,this means that the required steam is generated in both types

5- Maximum amount of useful heat energy for helical absorber was 679.28 W and for spiral coil was 724.38 W.

6- Maximum instantaneous effieciency of helical conical coil and spiral coil were 24.4 % and 28.6 % which means thermal effieciency of collector with spiral absorber higher than helical absorber.

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Symbol	Description	Units SI
Aa	Aperture area of dish	m^2
I_a	Solar heat flux on aperture area of dish	W/m^2
A_r	Receiver or absorber area	m^2
Q_a	Radiation absorbed by receiver	W
Q_u	Useful energy	W
Q_l	Heat losses energy	W
η_c	Collector thermal efficiency	-
U_l	Overall heat transfer coefficient	$W/m^2.K$
T_{amb}	Ambient temperature	^oC
T_{abs}	Absorber temperature	^oC
T_f	Film temperature	^oC
$Nu_{h,nat}$	Nusselt number of natural convection	-

Gr	Grashof number	-
G	Gravitational acceleration	m/s^2
L	Characteristic length	m
β	Thermal expansion	-
T_f	Film temperature	^oC
h_r	Radiation heat transfer coefficient	
h_{wind}	Heat transfer coefficient of forced convection	W/m^2 K
h_{nat}	Heat transfer coefficient of nature convection	W/m^2 K
h_{total}	Total heat transfer coefficient	W/m^2 K
K_{air}	Thermal conductivity of the air	W/m K
n_c	Collector efficiency	-
$\dot{m}$	Mass flow rate	Kg/s
Cp_w	Specific heat of water vapor	KJ/Kg.K
$\rho \tau \alpha \gamma$	Reflectivity, transmittance , absorptivity and Intercept factor respectively	-
θ	Inclination angle of receiver	Deg

مجمع شمسي طبقي بمحورين مع نوعين من الملفات الماصة : اللولبي الهرمي والحلزوني كدراسة مقارنة

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الخلاصة:-

المجمع الشمسي ذو الطبق المزود بنظام تتبع ثنائي المحاور يعتبر نوع جيد من انظمة التركيز للتغلب على مشكلة مصادر الطاقة. تولد كميات كبيرة من الحرارة بسبب نسبة التركيز العالية التي تمتلكها مقارنة بالأنواع الاخرى. تم استخدام طبق بقطر 2 متر مع نظام تتبع ثنائي المحاور وباستخدام نوعين من الملفات الماصة (ملف لولبي هرمي وملف حلزوني) وبنفس نسبة التركيز الهندسي(100). تم استخدام الماء كمائع تشغيل في المنظومة. المتغيرات التي تم قياسها هي كالاتي : الاشعاع الشمسي الحزمي , درجة حرارة الجو , درجة حرارة الملف الماص , درجة حرارة دخول الماء , درجة حرارة خروج الماء , سرعة الهواء ومعدل التدفق الحجمي للماء الداخل. عندما كان معدل التدفق الحجمي 0.33 لتر/ دق تم ايجاد اعلى درجة حرارة خروج , اعلى حرارة مستفادة و اعلى كفاءة لحظية للملف اللولبي عند الساعة 12 ظهرا و كانت القيم كالتي 101.11درجة مئوي, 679.28 واط ,% 24.4 على الترتيب. بالرغم من هبوط معدل الاشعاع الحزمي في يوم استخدام الملف الحلزوني الا ان القيم المذكور كانت قد ازدادت بنفس معدل التدفق وبنفس الوقت وكانت القيم كالاتي : 124.34 درجة مئوي , 724.38 واط و % 28.6 على الترتيب. من خلال النتائج العملية تبين ان الملف الحلزوني له

اداء اعلى من الملف اللولبي الهرمي.

الكلمات المفتاحية: طبق شمسي , نظام تتبع ثنائي المحاور , ملف لولبي هرمي , ملف حلزوني