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EXPERIMENTAL STUDY THE EFFECT OF ABSORBING TUBE DIAMETER ON THE PERFORMANCE OF COMPOUND PARABOLIC CONCENTRATOR SOLAR COLLECTOR

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Abstract: A system of test rigs of solar collectors with the compound parabolic concentrator (CPC) have designed to study the performance namely (heat flux and efficiency) for all the solar collectors. The acceptance angle of the CPC taken at 45^0 for all the solar collectors. The system used to study the effect of absorbing tube diameter on the solar collector performance. A halogen light used as energy source with different absorber tube diameters (0.75, 1, and 1.5) inch used. It has observed that the relationship between the time with the readings of water temperature inside the absorber tube and the performance results show that there are three regions for variation for all collectors. The variation for the water temperature, heat flux and efficiency in the first region varied sharply, in the second region varied gradually and in the third region remained constant. The compering performance results between the different solar collectors with different absorber tube diameters show that the collector with 1.5-inch absorber tube diameter gives the best performance than the others. Where the percentage increase in the temperature for the collector with absorber tube diameter of 1.5 inch compering with the other diameters (0.75 , 1) inch are (28.3 and 20.7) respectively While in case of heat flux are (69.8 and 53.4) and for the efficiency are (68.8 and 28).

Keywords: *Solar collector, Compound parabolic concentrator, Absorbing tube diameter.*

دراسة مختبرية لتأثير قطر أنبوب الامتصاص على أداء المجمع الشمسي ذو قطع مكافئ مركب

الخلاصة: تم تصميم نظام مختبري متعدد الاختبارات بمجمع شمسي ذو قطع مكافئ مركب لدراسة الأداء لكل من الفيض الحراري والكفاءة لجميع المجمعات المصممة. يستخدم هذا النظام لدراسة تأثير قطر الانبوب على أداء المجمع الشمسي وتم اخذ زاوية القبول للمجمع الشمسي بزاوية 45^0 درجة. استخدم مصباح الهالوجين كمصدر للطاقة مع جميع المجمعات المصممة بأنابيب امتصاص ذات اقطار مختلفة (0.75 و1 و1.5) انج. عند ملاحظة العلاقة بين الوقت وقراءات درجة حرارة الماء داخل الانبوب الممتص ونتائج الأداء أظهرت وجود ثلاث مناطق متغيرة لجميع المجمعات المصممة حيث ان التغييرات لدرجة حرارة الماء والفيض الحراري والكفاءة تتغير بصورة حادة في المنطقة الأولى وفي المنطقة الثانية يكون التغيير تدريجياً الى ان تستقر في المنطقة الثالثة وتبقى ثابتة. المقارنة بين نتائج الأداء لجميع المجمعات الشمسية المصممة بأقطار مختلفة أظهرت ان المجمع الشمسي ذو قطر أنبوب 1.5 انج يعطي أفضل أداء من المجمعات الأخرى. حيث الزيادة المئوية لدرجة الحرارة الماء للمجمع الشمسي بقطر أنبوب 1.5 انج مقارنةً بالمجمعات ذات اقطار 0.75 و1 انج هي (28.3 و20.7) على التوالي وفي حالة الفيض الحراري هي (69.8 و53.4) وللكفاءة هي (68.8 و28).

1. Introduction

Iraq has an outstanding solar resource, solar intensity in summer is approximately the twice of solar intensity in winter, so the solar energy can be used in very large scale in Iraq.

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A thermal solar collector, it is a device absorbing sun light to collect the heat. A compound parabolic concentrator is the main component of the present system, which is non-imaging concentrators, have the capability of reflecting all the sun radiation to the absorber tube with a large range of incident angle of the sun.

The special mirror geometry ensures that direct and reflect light, travelling from all orientations, falls onto the absorber. this is considered as an advantage of no needing for the sun tracking system at unfavorable conditions it's a great improve of the energy yield of a solar collector.

Among the pioneer work of CPC, those carried out by (C.K. Hsieh , 1981) developed mathematical study formulations to study the collector performance with the CPC concentrator. (Hussam Khonkar, 1955) optimized the absorber tube of the CPC of the solar collector**.** (Gao hong et. al.,2011) analyzed and predicted the performance of the collector with the CPC and an evacuated absorber tube with and without glass cover, (Rolf Meissner ,2011) used a collector with a CPC evacuate absorber systems for heating water of 80- 160 °C along the year and with all condition of the weather. (Mansi G. Sheth et. al.,2013) designed and developed a collector with CPC and the absorber of a flat plate.

(Devanarayanan, K. and Kalidasa Murugavel, K.,2014) they studied the effect of many parameters as (position of the storage tank, absorber surface ,reflector types ,glazing and without glazing and other parameters) on the performance of the heater collector.

(Al-Ghasem, A. et. al., 2013) investigated experimentally the performance of the CPC with and without tracking system. (M. Gajic et. al., 2015) calculated the losses of reflection by using ray-tracing method as a function of the incidence angles in both the transverse and longitudinal planes of a CPC. The losses found approximately constant, except at maximum angle of acceptance.

(Gian Luca Morin et. al., 2014) studied the theory of the thermal power generation station by using steam turbine.

(Muhammad umair et. al.,2013) study the optimum settings for the collector with CPC in the direction toward east and the west the objective of the study was to increase the time of duration of the period of the effective temperature by capturing maximum energy in the afternoon and morning without using tracking system.

They increased the effective duration of 2.53 hours in the summer and 2 hours in the winter.

(Gang Pei et. al., 2012) study experimentally a comparison between the collector with evacuated tube water heater systems without and with CPC reflector.

(Posgrado en Ingeniería and Centro de Investigación, 2011) compared a numerical simulation results for a compound parabolic concentrator (CPC).

(Réné Tchinda, 2008) solved the governing equations of the energy to predicted the performance of air heater collector with the CPC having an absorber with flat plate.

(Naghelli Ortega et. al., 2004) has designed a CPC to generate a vapor in a solar water ammonia refrigerator to obtain instantaneous efficiency and the useful heat.

(Ari Rabl , 1976) developed an analytical technique to calculate the average value of radiation reflections that passing the collector with CPC.

Where the radiative and convective heat transfer calculated through a CPC, also the optical losses were computing in this study.

This paper present a system of test rigs of solar collectors with the CPC have been designed to study the performance namely (heat flux and efficiency) for all the solar collectors with different tube diameter (0.75 ,1 ,1.5) inch.

2. Experimental Work

The experimental work performed on a solar collector with the compound parabolic concentrator (CPC) ,the test rig shown in Figure (1).

The main parts of the test rig are the CPC, halogen light and a digital thermometer. The compound parabolic concentrator as shown in Figure (2) consists of many parts such as absorber tube, reflector plate and the external structure.

“Table 1” shows the different types of the CPC with different absorber tube diameters.

The reflector plate used from the aluminum, which reflects the ray of the radiation, by about 92%.

The copper pipes were used as absorber tube with thermal conductivity (K= 385 W/m.K) and coated with matt black paint to increase the capacity of absorption of the radiation that falls on the surface of the tube. The external structure, which installed the CPC on it, made of the rigid polyurethane foam with thickness of 1 cm.

A halogen light used as energy source, which consumes (1000) Watt.

A digital thermometer with range of (-10 ~ +110℃) was used to measuring the temperature inside the absorber tube with a high accuracy and time responded at high temperature.

To test the accuracy of the CPC, a laser beam projected on the CPC plate.

The beam reflected from the CPC plate to the absorber tube at any angle.

This indicated that the design of the collector with high accuracy as shown in Figure (3).

Table 1.different types of the CPC with different absorber tube diameters

Absorber tube diameter (inch)	Length (cm)	Wide (cm)	Area(cm^2)
0.75	20	9	180
1	20	12	240
1.5	20	17	340

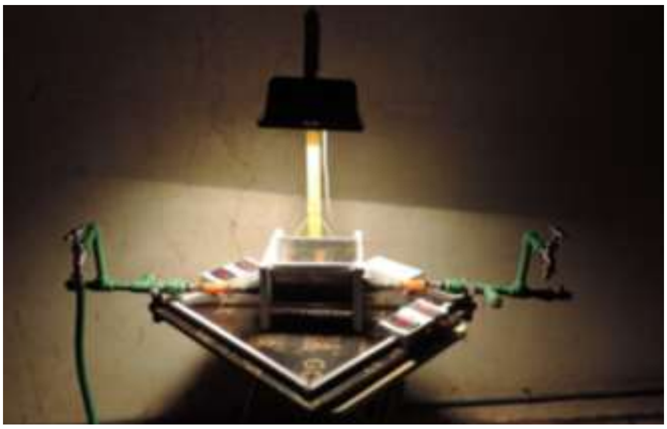

Figure.1 The system test rig

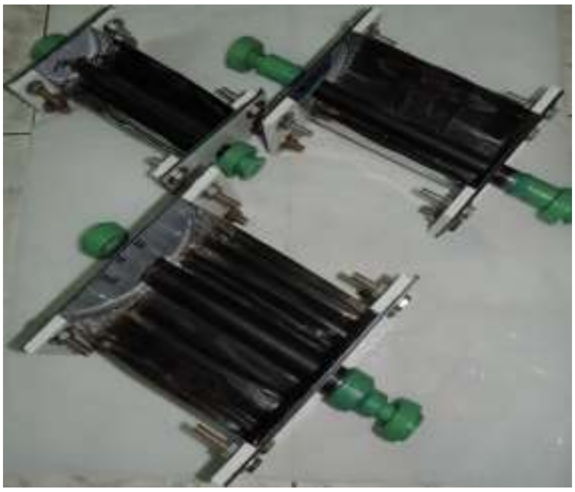

Figure.2 CPC with (1.5, 1, 0.75) inch.

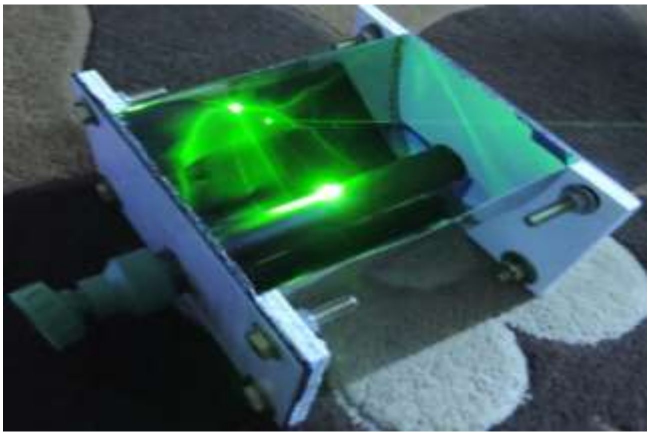

Figure.3 laser radiation test

3. Mathematical Simulation of CPC

The shape of CPC depend on two parameter, the first one is the acceptance angle (θa) and the second one is the radius of the absorber tube *(r)* .as shown in figure (4).

The angle (θ) can varied from zero to 180°. The shape of the CPC is symmetric with the Y-axis and construct from two equation.

The first equation is from A to B, where:

$$\rho = r.\theta \qquad \text{for } |\theta| \leq \theta\, a + \pi/2 \qquad \ldots\ldots.(1)$$

The second equation is from B to C, where:

$$\rho = r.\frac{\theta + \theta_a + \pi/2 - \cos(\theta - \theta_a)}{1 + \sin(\theta - \theta_a)} \qquad (2)$$

$$for \quad \theta_a + \frac{\pi}{2} \leq |\theta| \leq \frac{3\pi}{2} - \theta_a$$

Where :(ρ) is the distance from point R to point S

The CPC concentration ratio is a function of the acceptance angle given by following equation

$$CR_g = 1/\sin\left(\frac{1}{2}\theta_a\right) \tag{3}$$

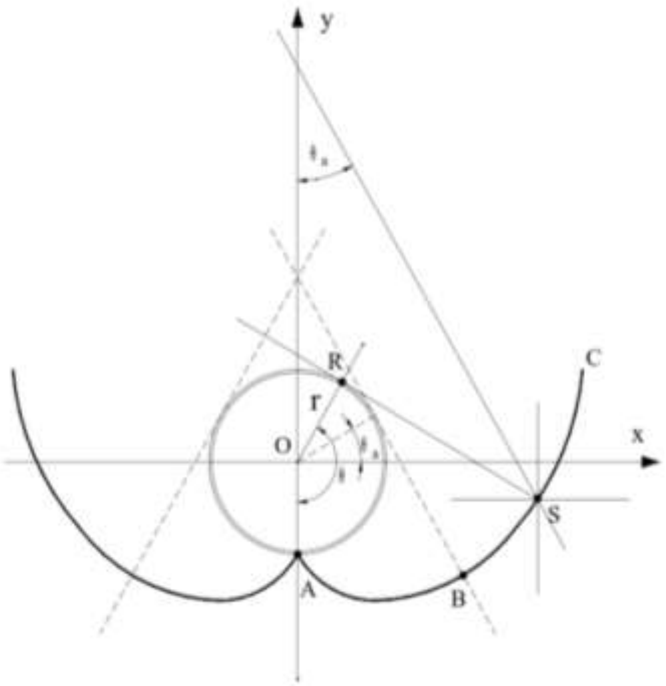

Figure .4 Obtaining of CPC involute

To calculate the water mass (m_w) inside the absorber tube use following equation:

$$m_w = \rho_w \, . V_w \tag{4}$$

Where**:**

ρ_w : Water density (kg / m^3).

V_w : Water volume (m^3).

$$V_w = \pi . r^2 . L \tag{5}$$

Where**:**

r : The radius of the tube (m).

L: The length of the tube (m).

In addition, for the heat flux (Q_u) and efficiency (η) use following equation:

$$Q_u)_{water} = m_w \, . (C_p)_{water} \, . (\Delta T) \tag{6}$$

Where**:**

$(C_p)_{water}$: Specific heat capacity of water (kJ/kg.K).

ΔT**:** Temperature difference between temperatures inside the absorber tube.

$$\eta = \frac{Q_u)_{water}}{A.I_H} \quad (7)$$

Where**:**
Q_u : Useful energy (kJ).
A : Area of the collector (m^2).
I_H: Halogen lamp intensity ($W\ /m^2$).

4. Results and Discussion

Figure (5) shows the comparison between the water temperature inside the absorber tube and the time for the three models of solar collector with CPC . The figure shows there are three regions of variation for all the three cases and have the same time approximately.

In the first region (0- 40) minutes the temperature increase sharply due to the collector absorber tube is cold so it has gained the heat quickly. In the second region (40-100) minutes, the temperature increase gradually due to the absorber tube collector had a higher temperature than the first region.

So its gain the heat slower than the first region . In the third the region (100-120) minute the temperature remain constant due to the absorber tube of the collector was very hot, so therefore it loses heat to the surrounding by convection (heat gained = heat losses).
The figure shows that the collector with the absorber tube diameter 1.5 inch gives the highest temperature than the others.

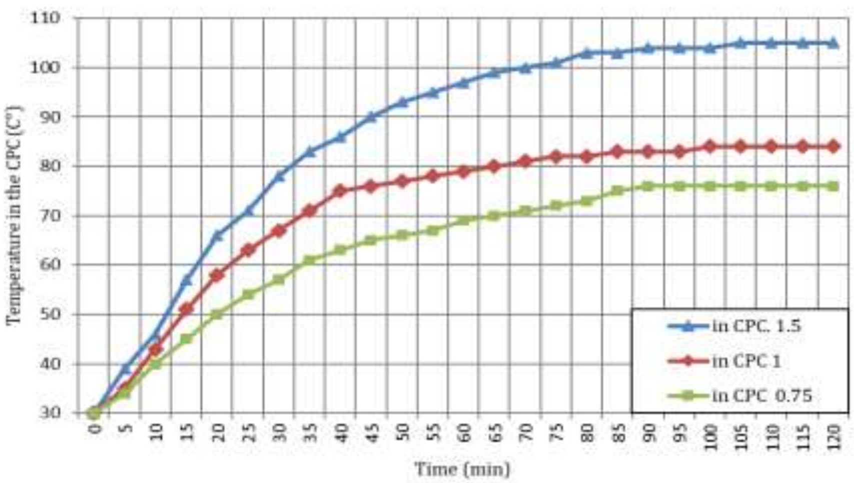

Figure .5 the relationship between the temperatures with the time for the three models of the collector.

Figure (6) shows the comparison between the heat flux and the time for the three models of the collectors with CPC. The heat flux for model (1.5) inch absorber tube diameter, gives the highest value of the heat flux . Also figure (7) show the highest value of collector efficiency was for the collector with 1.5-inch absorber tube diameter. This due to the absorber tube with diameter 1.5 inch has the biggest surface area than the others , which heat transfer by conduction depend on the surface area of the tube. In addition, the figure (6) and (7) show the three regions of variation as explained above for the figure (5).

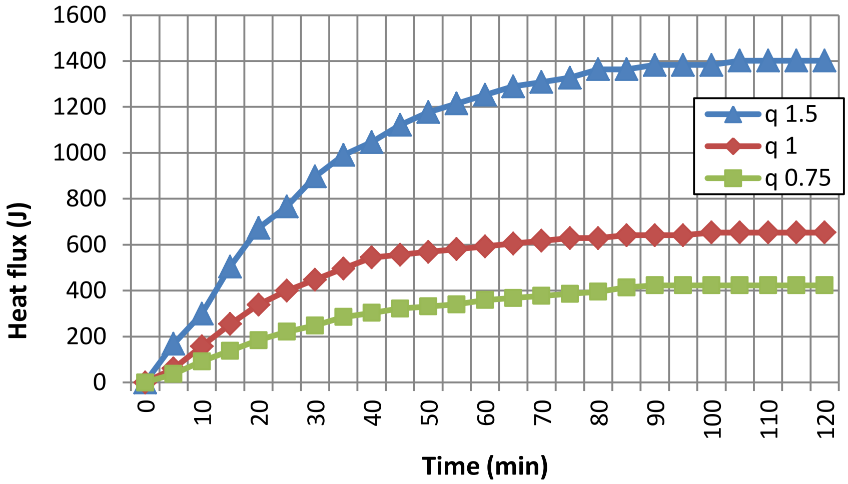

Figure. 6 The relationship between the heat flux and the time for the three models of the collector.

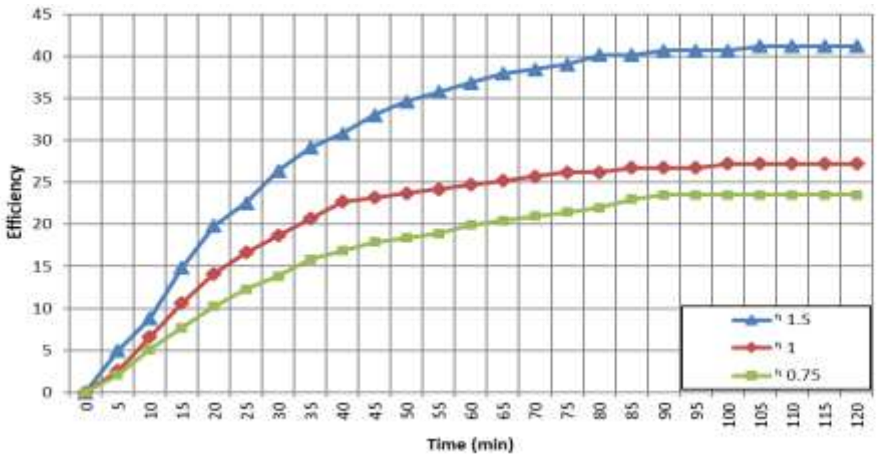

Figure .7 the relationship between the efficiency with the time in the three models of the collector

5. Conclusions

1. The temperatures reading and the results show that there are three regions for all the CPC collectors with different absorber tube diameter. The first region increase sharply (approximately linearly), the second one increase gradually and the third one approximately remain constant.
2. The percentage increase in the temperature, heat flux and efficiency for the collector with the absorber tube diameter of 1.5 inch comparing with (1 and 0.75) inch are (20.7 and 28.3) respectively, (53.4 and 69.8) and (28 and 68.8).
3. The compering results show that the CPC collector with absorber tube diameter of 1.5 inch give better performance than the other tubes.

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