An Experimental Study of the Thermal Performance of Solar Air Collector Inclined (75^o) on the Horizontal Plane

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Abstract

In this paper, an experimental study of the thermal performance of the solar air collector manufactured of galvanized iron sheet with dimension 100×120cm, frame width 20cm, has holes 0.5cm arrangement on horizontal and vertical, the collector inclined at an angle (75^o) on the horizontal plane. All author faces of the collector (four sides and background) are insulations in order to minimize the thermal losses .All the result recorded in winter season for two different days one of them sunny and the other was cloudy. The result shows the effect of the angle of collector gives more heat to the collector, hence higher outlet temperature, especially in sunny day. Maximum outlet temperature of the collector (35.5^o when inlet temperature 18^o) and maximum Nusselt number(Nu) at twelve o'clock of the sunny day more than the cloudy day. At the end its high system efficiency and good collector effectiveness.

Keywords: Perforated absorber flat plate, Unglazed solar air collector, Force convection, Solar air heating.

الخلاصة

تمت في هذا البحث دراسة عمليه للأداء الحراري لجهاز مجمع الهواء الشمسي المصنع من صفائح الحديد غبر المغلون وبأبعاد (100 × 120 سم) ، وعرض الإطار 20 سم، وبثقوب 0.5 سم مرتبة افقيا ورأسيا، والمجمع يميل بزاوية (75^o) على المستوى الأفقي. جميع الجوانب الاخرى من الجامع (أربعة جوانب والخلفية) هي معزولة حراريا من أجل تقليل الخسائر الحرارية . جميع القراءات تمت في فصل الشتاء لمدة يومين مختلفين واحد منهم مشمس والآخر كان غائما. واظهرت النتائج تأثير زاوية ميل المجمع بامتصاصه مزيدا من الحرارة ، وبالتالي ارتفاع درجة الحرارة الخارجة، وخاصة في اليوم المشمس اعلى اعظم درجه خارجة من المجمع (35.5 درجه عندما تكون درجة حرارة المحيط 18 درجة مئوية)، اعلى (Nu) في الساعة الثانية عشرة من اليوم المشمس أكثر من اليوم الغائم. واخيرا كفاءة عالية وفعالية جيدة للمجمع الشمسي.

الكلمات المفتاحية : لوح ماص مثقب ، جامع شمسي غير مزجج ، حمل قسري ، تسخين الهواء بالطاقة الشمسية .

1. Introduction

The basic principle of the work of this type of solar air collector is that cooling air outside enters through a series of holes in the board absorber by the pressure generated by the work of the clouds fan on top of the system back side teams and at the same time be the board absorber of solar radiation incident during the daylight hours and proposing to the heat acquired by the air within the system and at the same time, the air inside is working to reduce the thickness of the boundary layer generated due to differences in temperature.

(Amer Jameel Shareef , 2010) Studied the effect of shape absorber surface for solar air collector inclined (30^o)on the horizontal. The results show that the different air temperature between inlet and outlet was(13.65^o C), the enhancement heat transfer coefficient for (V-Corrugated plate) is(63%).Also results shows that the maximum skin friction coefficient (C_f) is occurred with R_e=8000(V-Corrugated) which comparing with flat plate.

(Jinan Mahdi , 2010) studied a process for a solar collector with an antenna board Flat absorption contain occasional barriers to obstruct the passage of air inside the solar collector, and these Symptoms triangular and the upper plate absorbed and uniformly distributed along the board, it has been reached that the compound increases the efficiency of the existence of these symptoms because of the increased turbulence in the airflow.(Augustus and Kumar , 2007) presented the results mathematical model to prediction the thermal performance of an unglazed transpired collector, and known as perforated collector- anew development in solar collector technology. The results shows that the solar absorptive, collector pitch, and air discharged have the strongest effect on collector efficiency as well as heat exchange effectiveness. (Leow and Kumar , 2007) Studied the factors affecting on solar air unglazed ,these factors include all of the separation between the holes, air speed, diameter holes on the compound efficiency and the efficiency of a plate absorption (heat exchanger), the result shows that the increase in diameter holes and the distance interval lead to a decline in the efficiency of absorption plate and when increasing air velocity, the collector efficiency increases and causes minimum temperature of air outside. (Holland's and Iynkaran , 1993) studied an analytical model and also an experimental validation for the thermal conductance of compound honeycomb transparent insulation and performed. (Kumar and Kaushika , 2005) developed the convective effects in inclined air layers bounded by cellular honeycomb arrays. (Smart *et.al.*, 1980) investigate experimentally free convection heat transfer across rectangular celled diathermanous honeycombs. The orientation of flat plate collector and slope of the collector towards the horizontal plane is one of the factors that affecting on the collector's performance that can be considered. So knowing and determining the amount of slope and surface azimuth angle is important in collector area and effectiveness of system , (Lave *et.al.*,2011).

2. Experimental Work

In the Figure (1) the solar air collector system can be seen. This system has solar air collector manufactured of galvanized iron sheets with dimension 100×120cm and frame width 20cm, inclined at angle (75^o) on the horizontal plane. The basic components of the test rig show schematically of the experimental test rig in a photo.

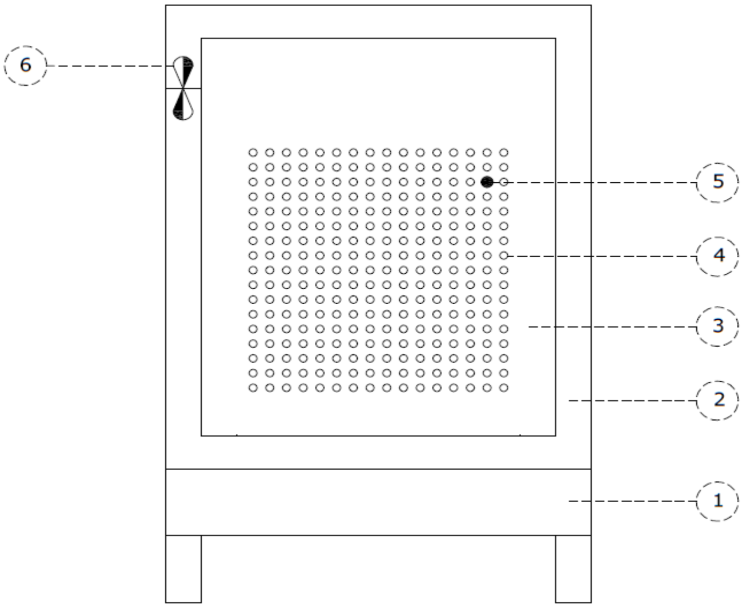
The absorber flat plate has holes arrangement in vertical and horizontal with equal distances from center to center of any two holes limited (50mm) , each hole diameter (5mm), (Wissam *et.al.*, 2012) The absorber flat plate was coating the front face from the outside in black and dark colure to portability increases absorption and to prevent solar radiation and reflection that leads to get loss of thermal energy.

The system contains a fan with controller to control the velocity of air pass through the system to the outlet , The hot and cool air temperatures are measured by using a digital thermometer with the aid of thermocouples type- K .

All author faces (four sides and background) are insulations in order to minimize the thermal losses, as well as to prevent the entry or exit of air into the compound to reduce the occurrence of the load current over the plate heated by solar energy.

(a)

1.stand.
2.Insulation Frame.
3.Collector.
4.Hole.
5.Theromcuple.
6.Fan.



(b)

Figure (1): The test rig:

(a)The photo of the test rig.
(b) The basic components of the test rig

3. The Governing Equation

The heat transfer equation: is the amount of heat that transfers per unit time (usually per second). If a hot metal plate has a surface temperature of on one side and Ti on the other side, the basic heat-transfer rate due to conduction can be given Myer (2006):

$$Q = UA(T_o - T_i) \qquad \text{……….. (1)}$$

Furthermore ***Q*** is the total heat transferred to air by forced convection and is given by:

$$Q = hA(T_s - T_m) \qquad \text{.................. (2)}$$

Heat transfer coefficient (h) can be determined:

$$N_u = \frac{hL_c}{k} \qquad \text{…………. (3)}$$

Reynolds Number calculates:

$$R_e = \frac{\rho u D_h}{\mu} \qquad \text{…………. (4)}$$

The overall heat-transfer coefficient U due to combined conduction and convection heat transfer is given ,Wissam et al (2012):

$$U_t = \left[\frac{1}{h_{r\infty} + h_w} + \frac{1}{h_{cb-p} + h_{rb-p}} \right]^{-1} \qquad \text{…..…….(5)}$$

Where:

$$h_{r\infty} = \varepsilon.\sigma.\left(T_p^2 + T_\infty^2\right)\times\left(T_p + T_\infty\right)$$

$$h_w = 5.7 + 3.8u$$

$$hc_{h-p} = \frac{Nu.k}{D_h}$$

$$D_h = \frac{4A}{p_w}$$

$$hr_{b-p} = \frac{4\sigma\left(T_p^3\right)}{\frac{1}{\varepsilon p} + \frac{1}{\varepsilon b} - 1} \qquad \text{………(6)}$$

Heat transfer losses:

$$Q_{th} = Q_{abs} + Q_{loss} = h\left(T_p + T_{out}\right) \qquad \text{…………..(7)}$$

Heat absorber :

$$Q_{abs} = I_b.F_t.A_a$$

$$F_t = \alpha_b.F_{sh}.F_d$$

Heat losses from system:

$$Q_{loss} = U.A\left(T_p + T_a\right) \qquad \text{………..(8)}$$

Theoretical heat transfer:

$$Q_{th} = Q_{abs} - Q_{loss} \qquad \text{…..……(9)}$$

Actual heat transfer:

$$Q_{act} = G.c_p\left(T_{out} - T_{in}\right) \qquad \text{………(10)}$$

Theoretical efficiency:

$$\eta_{th} = \frac{Q_{th}}{Q_{in}} \qquad \text{………(11)}$$

$$\eta_{act} = \frac{Q_{act}}{Q_{in}} \qquad \text{……..…..(12)}$$

Heat exchange Effectiveness of collector:

$$\varepsilon = \frac{T_{out} - T_{in}}{T_p - T_{in}}$$

………..(13)

Nomenclature

A collector area, m^2
D_h hydraulic diameter ,m
F collector heat removal factor
F_t dust coefficient
F_{sh} shadow coefficient
hr radiation heat transfer coefficient (W/m^2 ^oC)
h_{cb-p} heat transfer coefficient (W/m^2 ^oC)
I intensity of solar radiation, W/m^2
K thermal conductivity (W/m ^oC)
Nu Nusselt number
T_p collector average temperature, °C
T_b back temperature ,^oC
T_i inlet fluid temperature, °C
T_a ambient temperature, °C
T_{out} outlet temperature ,^{o} C
u velocity , m
U_L collector overall heat loss coefficient, W/m^2
Q collector heat input, W
Q_u useful energy gain, W
Q heat loss, W
R_e Reynolds number
η collector efficiency
α absorption coefficient of plate
σ Stefan-Boltzmann constant ,W/(m^2 K^4)

4. Result and Discussion

Figure (2), show the distribution of the inlet , outlet temperature and collector temperature during sunny day hours, the record reading begins from 8 am in morning to 4pm.The result show that the collector heat gradually until reached maximum temperature 49.5C^o,while inlet temperature increases gradually from (18C^o) to maximum temperature (33C^o) at twelve O'clock and then decreases gradually at (28C^o) at 4pm, but the outlet temperature increases from (35.5C^o) to maximum temperature (45C^o) at twelve O'clock and then decreases gradually at (33C^o) at 4pm. This means that the collector inclined (75^o) was heated, hence with higher surface area resulted in higher heat transfer. So heat carried away from collector metal will be more, in which higher outlet temperature.

Figure (3), show the collector temperature and the inlet, outlet temperature during cloudy day hours. The collector begins heated until reached maximum temperature (29C^o) at twelve O'clock that because of the sun radiation. Outlet and inlet temperature also increase gradually to maximum temperature (16C^o and 11.9C^o) at twelve O’clock, this according as the collector temperature increases outlet and inlet temperature increases because the collector absorber the radiation of the sun.

Figure (4), show the collector effectiveness at sunny and cloudy day, the results show the maximum value of effectiveness is(0.56 , 0.41) in sunny and cloudy day, respectively at twelve O'clock , this higher value because of the effect of sun radiation.

Figure (5), show the value of Nusselt number(Nu) calculated in theory and experimental in sunny day, the results show (Nu) begin from (37.5 ,44.1) at nine o'clock to maximum value (65.2,78.9) and then reduced gradually to minimum value at 4pm that is according to the eq.(3) as the heat transfer coefficient increases the Nu increases. While figure (6), show the value of Nusselt number(Nu) calculated in theory and experimental in a cloudy day, the maximum value shows at twelve o'clock less than the value of a sunny day at the same time and same season.

Figure (7), show the collector efficiency at sunny and cloudy day, the result shows the efficiency of the collector at sunny day was higher than efficiency of the collector at the cloudy day, that means the sun gives more radiation to the collector in sunny day comparing with cloudy day.

5. Conclusion

This paper an experimental study the thermal performance of the solar air collector inclined (75^o) on the horizontal plane .The following are the main conclusions from this study:

1. The effect of the angle collector gives more heat to the collector, hence higher outlet temperature(35.5^o) especially in sunny day.
2. Maximum Nu (78.9) in sunny day while in cloudy day was (65.2).
3. The system can be supplied heat to building in winter season.
4. Increases the sun radiation increases the performance of collector, so good efficiency and thermal performance.
5. Easy manufacture, easy maintenance and low cost.

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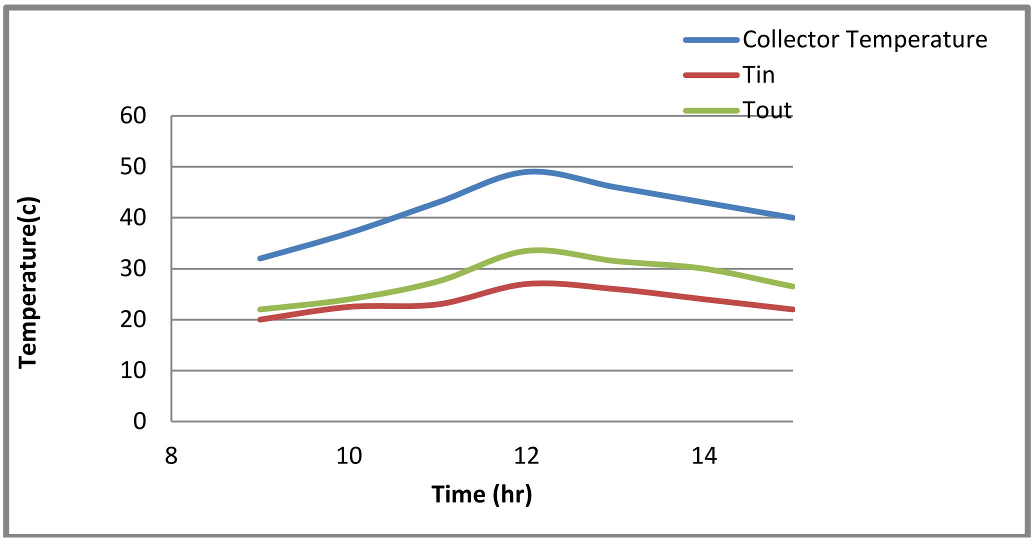

Fig.(2) : Temperatures inlet , outlet and Collector temperature during the Sunny day

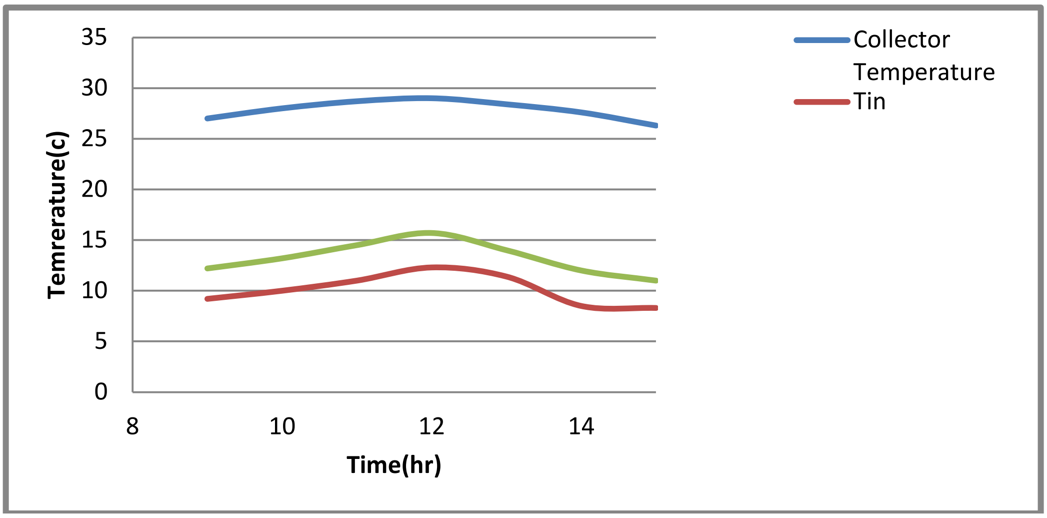

Fig.(3) : Temperatures inlet , outlet and Collector temperature during the Cloudy day

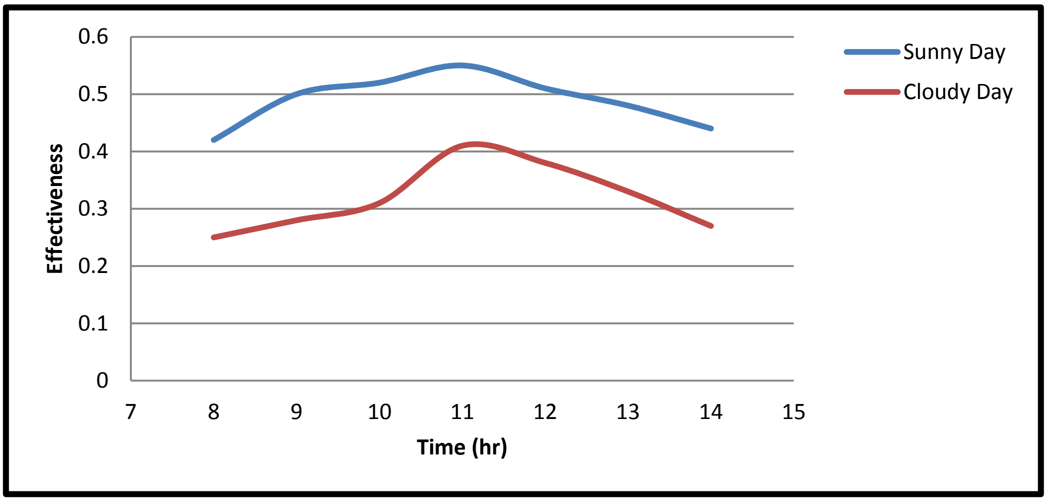

Fig.(4):Collector Effectiveness At Sunny And Cloudy Day

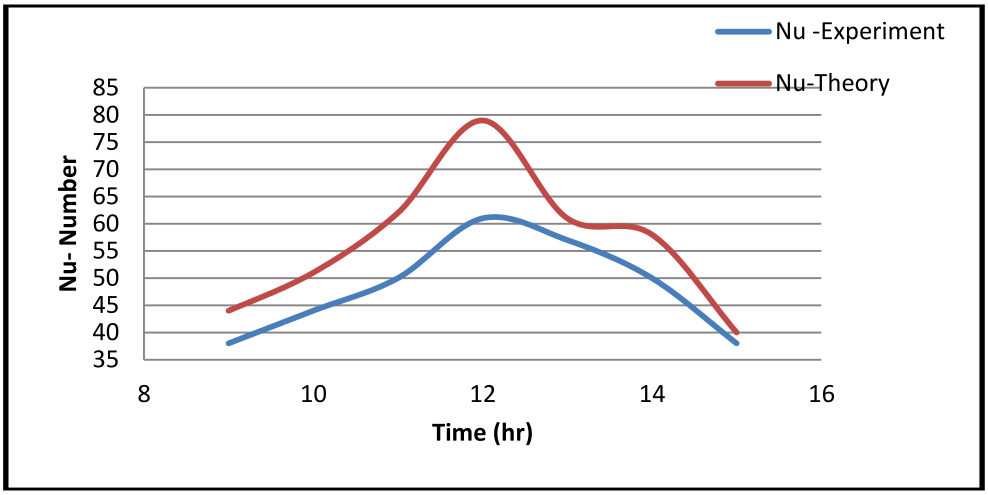

Fig.(5): Nu along the collector during Sunny day

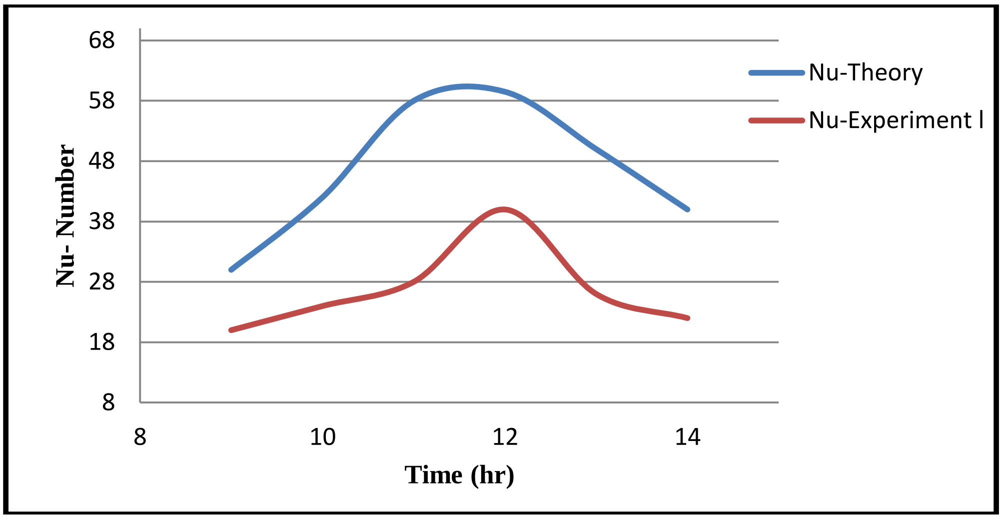

Fig.(6): Nu along the collector during Cloudy day

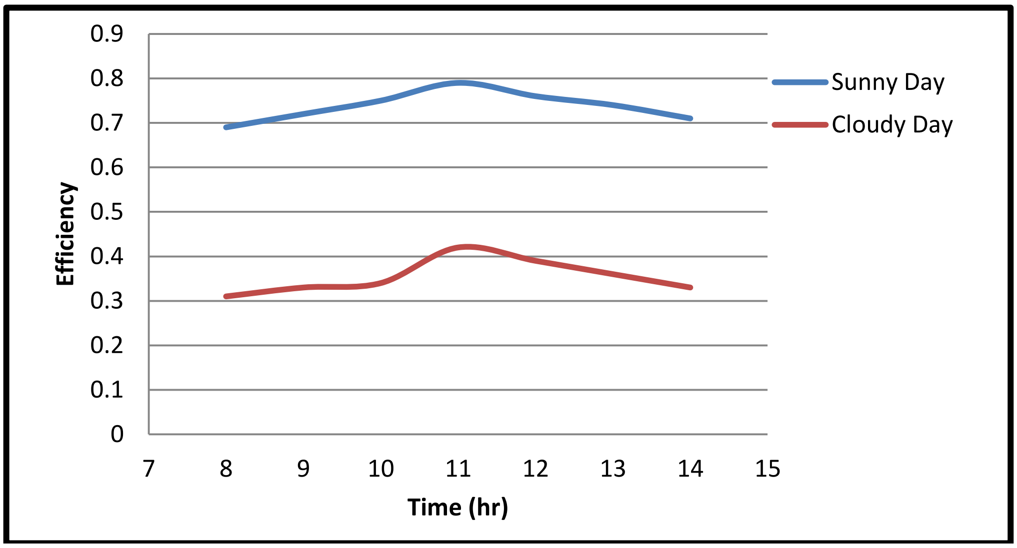

Fig.(7) :Collector Efficiency at Sunny and Cloudy Day