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Design and Performance of Solar Air Collector With Triangle Channel

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ABSTRACT

Practically everyone knows the benefits of using solar energy as a renewable energy. In this paper we are trying to compare and performance triangle channel air collector (TCAC) with other collectors, Specially flat plate and V-Shape. By this we mean that the effect of different parameter on efficiency and outlet temperature of collector are investigated. By testing collector we could plot the efficiency and temperature curves and compare them with theoretical data and results, as an acceptable exact. The advantages of this project shows that the TCAC cause to increase heat transfer and heat absorption coefficient efficiency and outlet temperature ccomparing to other collectors. By increasing the flow rate of fluid the efficiency of collector is increased but the fluid outlet temperature and heat dissipation are decreased. After a certain flow rate this variation can be neglected. According to temperature limitation of agricultural crops derive about 0.04 (kg/m^{2}s)

KEYWORDS: Solar Collector, Triangle Channel, Efficiency, Dryer.

1. INTRODUCTION

Using solar energy is one of the best choices for dryers and heat system in the low range temperatures because the fresh and hot air will be produced by collectors without using heat exchangers the main part of solar heating systems are collectors. In order to system be economical, they should have suitable design. The main part of economy optimization in almost all of solar dryers and air heater, the flat plate collectors are used but the air collectors have less efficiency than liquid collectors. However, there are different designs of collector with the aim of increasing heat coefficient between air and absorption surface but without increasing pressure fall. Varury et al., [1] Studied on roughness geometry used in solar air heater. Ho et al., [2] performed the analysis of finned collector and collector with channel for drying applications. Azharul and Hawlader [3] investigated the evaluation of a V-groove solar collector. Chamoli and Chauhan [4] had presented a review on the performance on double pass solar air heaters. Gupta and Kaushik [5] Performance evaluation of solar air heater having expanded metal mesh as artificial roughness on absorber plate. Layek et al., [6] analyzed the effect of chamfering on heat transfer and friction characteristics of solar air heater. According to the advantage in secure [3, 7, 8, 9] the V-shape air collector comparing to others, like flat plate have 12% more efficiency and high temperature. In line with this designing and investigation of air collector with triangle channel started in Izeh city. However, by realizing efficiency and temperature limitation this collector can be suitable and useful more than other collectors in house heating systems and drying main agriculture product such as tea which is very important to agricultural economy of the country. Also by using triangle channel solar air collector in the packed bed dryer system and drying vegetables, rice and wheat the efficiency of this collector is tested.

2. Mathematical Model of TCAC

The efficiency of a collector define as the ration between output energy per all of input solar energy, in the same time [8]:

$$\eta_i = \frac{\dot{m} C_P \int_{t1}^{t2} (T_o - T_i) dt}{A \int_{t1}^{t2} I_T dt} \tag{1}$$

So by Hotel-Viler ration, the efficiency of solar air collector in steady state is calculated [3]:

$$\eta = \frac{Q_u}{A I_T} = F_R(\tau\alpha) - F_R U_L \frac{(T_i - T_a)}{I_T} \tag{2}$$

where, Q_u is the useful energy gain of collector $\tau\alpha$ is transmittance-absorptance product of cover system for beam and diffuse radiation, I_T =800 W/m^2 is the radiation on tilted surface. The heat removal factor F_R of a solar collector is defined as the ratio of actual heat transfer to the maximum possible heat transfer and can be expressed as [7]:

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$$F_R = \frac{\dot{m}C_p}{AU_L}[1 - e^{-(AU_L F' / \dot{m}C_p)}] \quad (3$$

Here, $\dot{m}$ is the mass flow rate, A (m[2]) area of collector, C_p is the specific heat of fluid and F' collector efficiency factor. To calculate the overall loss coefficient while using as fluid collector, one can use the equation which expressed as follows :

$$U_L = U_t + U_b + U_e \quad (4$$

For finding the value of F' and U_L with written energy equation for absorb plate, insulation and fluid should be calculated according to figure 1 the equation written as 5 - 7 in the following.

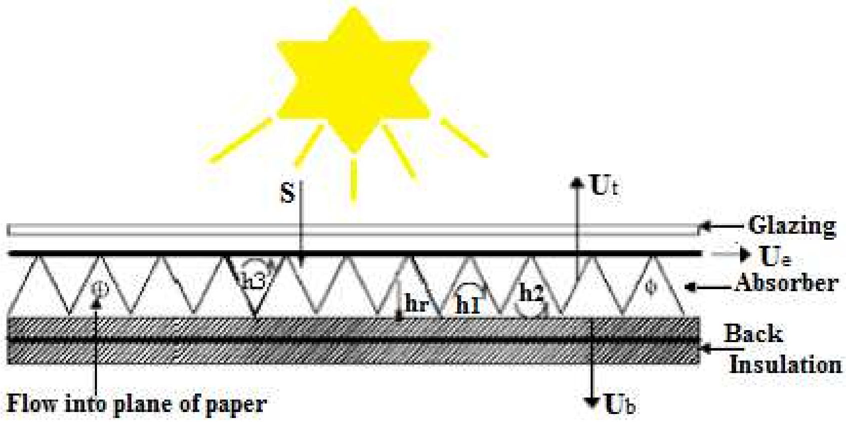

Fig 1. Air collector with triangle channel

$$-U_L(T_P - T_a) + h_r(T_b - T_P) + h_1(T_F - T_P) + (\tau\alpha)I_T + h_3(T_F - T_P) = 0 \quad (5$$

$$h_2(T_F - T_b) + U_b(T_a - T_b) + h_r(T_P - T_b) = 0 \quad (6$$

$$q_u = h_2(T_b - T_f) + h_1(T_P - T_f) + h_3(T_P - T_F) \quad (7$$

By solving 5 - 7 we can find F' and U_L. For obtaining the temperature increase we can use equations 1 and 2, which the result will be as follows [8]:

$$\Delta T = (T_o - T_i) = \frac{F_R A(\tau\alpha)I_T}{\dot{m}C_p} - \frac{F_R AU_L(T_i - T_a)}{\dot{m}C_p} \quad (8$$

$$\Delta T = (T_o - T_i) = \frac{F_R A(\tau\alpha)I_T}{\dot{m}C_p} - \frac{F_R A(\tau\alpha)I_{th}}{\dot{m}C_p} \quad (9$$

where

$$I_{th} = U_L \frac{(T_i - T_a)}{\tau\alpha} \quad (10$$

This temperature rise equation is useful for the estimation of the temperature rise across the collector. If the inlet air temperature and surrounding air temperature be equal the value $(T_O - T_i)$ will be linear in relation to I_T and $F_R(\tau\alpha)$ will be the steepness of this line that can be derive from equation 9. Also if $(\tau\alpha)$ be fixed the efficiency will be linear in relation to $\frac{(T_i - T_a)}{I_T}$ these equations are very important and useful for suitable design of a solar collector.

2.1. Simulation method

Numerical calculation is used according to the condition of Izeh city weather. The calculation started by assuming that the temperature of absorb surface is fixed. By this assumption and according to the geometer correctors of collector and system properties $(\tau, \alpha, C_P, K, etc)$ the above equations for finding η, Q_u will be solved: we assume that heat transfer coefficient is fixed between air and all sides of triangle channel and calculate it, the outlet temperature of collector can be find by equation 11.

$$T_O = T_i + \frac{Q_u}{\dot{m}C_P} \quad (11$$

By using this value for new absorb surface temperature this process will be repeated until finding final temperature.

3. MATERIAL AND METHODS

TCAC was design, in addition to increasing efficiency, outlet temperature, heat coefficient convection, and heat transfer coefficient it also produce natural and suitable air convection in triangle channel. Triangle channel was made of joint two piece of V-shape and flat absorbed surface that is shown in figure 2.

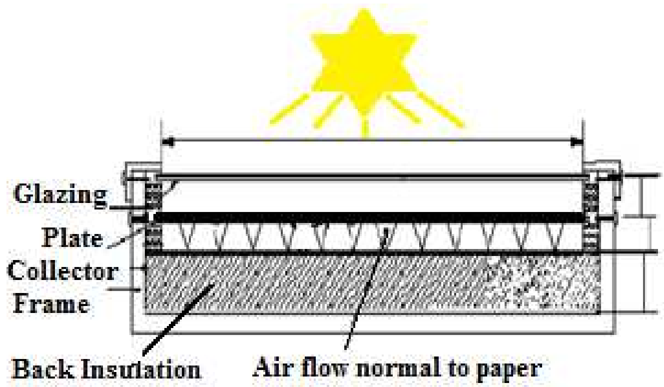

Fig 2. Shematic of triangle channel solar collector (TCAC).

Detail specification of the designed collector is given as follows:

- Absorber material: black-painted mild Aluminum
- Form of air channel–triangle with 60º angle.
- Air channel height : 6 cm.
- Absorbent plate thickness : 1 mm
- Side insulation: Silicon Rubber and Polystyrene (2cm)
- Back insulation: fiberglass Wool and Polystyrene (5cm)
- Glazing: flout glass (thickness 6mm)
- No.of glazing: 1
- Sealant: Silicon Rubber
- Air channel material : galvanized 0.5mm
- Collector mainframe material: Stainless Steel(thickness 1mm and frame Aluminum)
- Dimension of absorber plate: 1.94m × 0.94m
- Collector tilt: 17°

3.1. Experimental setup

At the start of experiment, all the instruments were checked in order to test the calibration. The TCAC was oriented south-facing and exposed to solar radiation at Izeh, Iran (latitude 31.83, longitude 49.87) and angle between the collector and the horizontal line was chosen to be 17º. Measurements of air temperature were done with K-type thermocouples with the accuracy of ±0.1º C. The ambient temperature was as well measured, in the shade, during the days of experiments. The total solar radiation incident on the surface of the collector was measured with Kipp and Zonen pyranometer. This meter was placed adjusted to the glazing cover at the same plane, facing south. Hot-wire anemometer with the accuracy of ±0.1 m/s was used in order to record the air mass flow rate and the velocity of the wind. The data obtained from tests in the TCAC on June from 8:00 to 18:0. Collector has tested as the ASHRAE93-77 standard [10] during several days. In these experiments the flow rate, inlet and outlet temperature of collector, solar radiation wind speed, temperature changing out randemant was measured in deferent conditions during a day. In the following the curves of useful receiving energy, comparing theoretical and experimental temperature results and efficiency, investigation of efficiency variation and outlet temperature in relation to flow rate, comparing the TCAC data with others collectors, and the curve of distribution temperature in absorption surface is shown. Time constant of a collector is the necessary time for a fluid which from the time of out flow from collector involves a change equal to 0.632 compare to total changes of collector. The total or main changes are happening in a fluid from the time of entering up to the time of constant time the way it's designed, the material used, type of fluid, fluid flow and working temperature. Therefore it can be measured in real operation time and should be less than 15 minutes for longer duration work ability and higher efficiency of collector [8]. The time constant measurement of collector is done according to ASHRAE suggestion by using following equation: $\frac{T_{o,t} - T_i}{T_{o,i} - T_i}$, here $T_{o,t}$, $T_{o,i}$ are outlet fluid temperature in steady state time before shading and outlet fluid temperature in, t, time. While the following equation reaches 0.368, then should be considered for time constant evaluation. Finally for efficiency investigation of this collector, a packed bed dryer for agriculture crops was designed and made as in figure 3. In this dryer drying time and quality of materials in different flow rate of air for finding suitable temperature and flow rate was investigated.

Fig 3. Usage of TCAC in a packed bed dryer

4. RESULTS AND DISCUSSION

According to experiments mentioned above the performance of TCAC is explained in this part experiment data will be compared with theoretical data. In figure 4 the maximum outlet air temperature during the day in ratio to value of sunshine are shown. This picture shows that output air temperature can be changeable during a day because of solar flux changing and the maximum temperature accessible dunb 11-13. Luith study of experimental advantages during 60 days, of made collector and comparing outlet temperature in ratio to solar flux value, this experiment equation is suggest to calculate the increasing temperature across air in the collector in convection stare and in ratio to solar flux value.

$$\Delta T = 0.062\ I_T \qquad (12$$

With comparing the advantage of this equation and experiment data we find that the offered equation is fairly exact. Table 1 shows the variation of stable time in ratio to flow rate for triangle channel collector and v-shape collector [3, 7, 8, 9]. This table also shows that in the some flow rate, the stable time of TCAC is less than v-form collector. Because the receiving heat coefficient and heat transfer coefficient in the triangle channel collector are more than others collectors.

In addition to increasing contact surface between fluid and absorption the triangle channel collector is cause to make a turbulent fluid and increasing convection heat transfer and heat receiving coefficient. Figure 5 shows comparison between theoretical and experimental advantages of outlet air in triangle collected. With different flow rate. In this picture the difference value between theoretical and experimental advantage for temperature and efficiency in different flow rate, increasing efficiency with increasing flow rate increasing efficiency with increasing flow rate, decreasing output temperature with increasing flow rate, are visible. Also by using this figure we can find that the different between theoretical and experimental efficiency is increased in flow rate 5% because of decreasing experimental efficiency after flow rate 42%. In figure 6 the comparing between v-shape collector one of the best collector in the world [3] and triangle channel collector is shown. It is clear in this picture that about 10% of efficiency in the triangle channel collector is more than other one and also it is visible that with increasing difference between inlet and surrounding temperature, the efficiency will be reduce in both collectors. Maximum efficiency is when both surrounding and inlet temperature be equal.

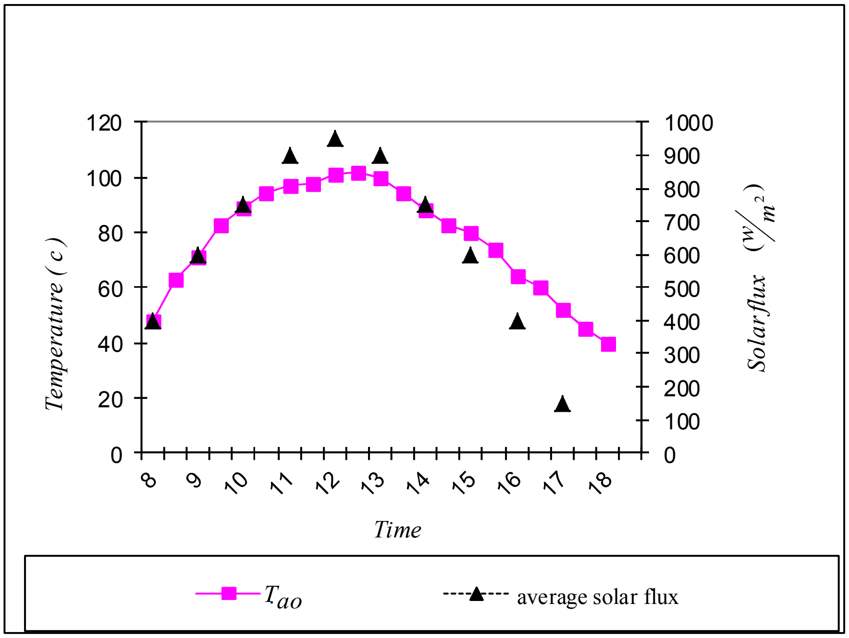

Fig 4. Variation of outlet air temperature with time and solar flux

Table 1. Variation of flow rate both time stable for v-shape and triangle channel

Flow rate (kg/m^{2}s)	Time constant of v-shape collector (min)	Time constant of triangle channel collector (min)
0.011	19.5	17.9
0.0317	13	10.7
0.042	8	6.5

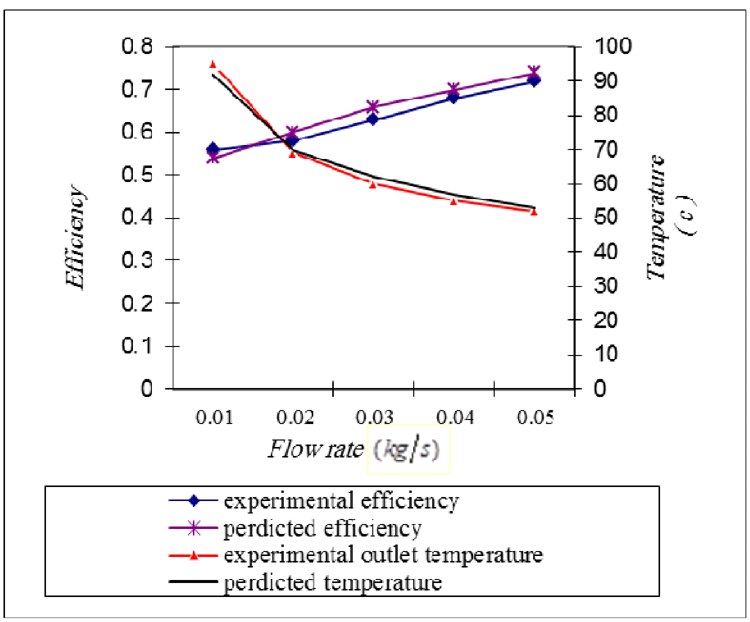

Fig 5. Experimental and predicted of collector efficiency and outlet temperature

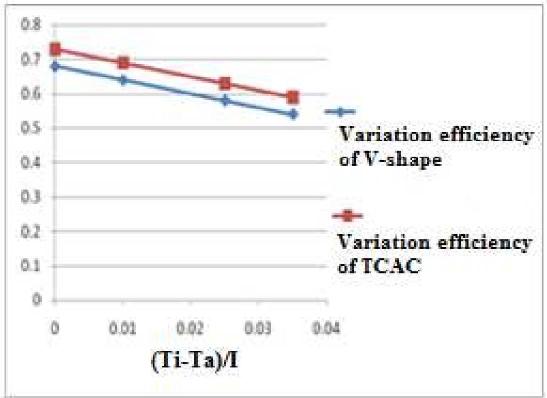

Fig 6. Comparing variation efficiency between TCAC and V-shape collector with increase inlet air temperature

Where solar flux in collector surface, is inlet air temperature and is, surrounding temperature. Figure 7 shows temperature distribution in all off absorption surface. This picture also shows absorption surface temperature in edge sides and air entrance are loss than other places in the collector because the most of heat dissipation is in the sides and the maximum variation of temperature between air inlet and surface absorption. Almost the centre of absorption surface has the maximum temperature. It is important that the maximum temperature of absorption surface decrease if the flow rate increase,one of main reason for decreasing of collector efficiency in low flow rate is increasing the difference between absorption and surrounding temperature.

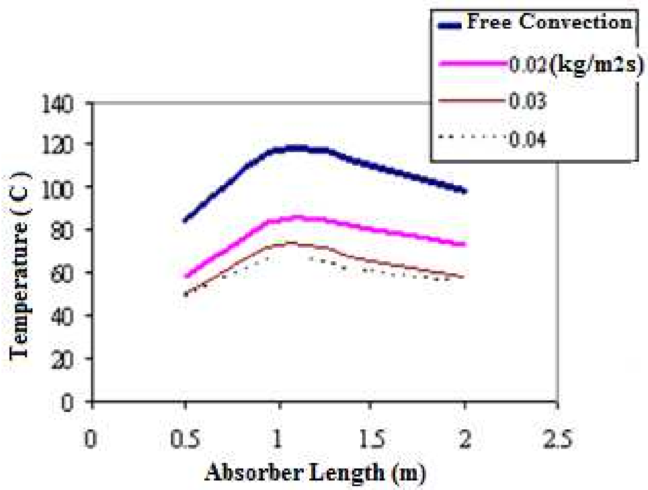

Fig 7. Variation of temperature on absorber with flow rate.

Table 2 shows comparison variation of outlet air temperature in different flow rate in collectors.

Table 2. Comparing oulet temperature in both V-shape and TCAC**.**

Flow rate (kg/m^{2}s)	Outlet temperature of v-shape (ºC)	Outlet temperature of TCAC (ºC)
0.011	72	86
0.02	65	74
0.03	59	68
0.042	51	56
0.054	48	52

The advantage of this table shows that the output air temperature in triangle channel collector is more than v-shape collector. While the v-shape collector is one of the best in efficiency and output temperature [7]. But whereas on of main using of solar air collector is in dryer systems, we use triangle channel collector in paced bed dryer for vegetables and granular materials and test it for finding suitable flow rate and temperature. As we can see in table 2 that according to limitation in deferent flow rate, the 0.04 (kg/m^{2}s) flow rate is useful and suitable flow rate for drying many agriculture crops.

5. CONCLUSION

Collector is the main part of a solar system but in the air collectors the efficiency is low, so the triangle channel air Collector (TCAC) is a good design and suitable because the experimental results show it has the maximum efficiency and output temperature in comparing to others. This design has 22% efficiency more than flat plate collector and 10% more than V-form collector (the best collector according to [3, 7, 8, 9]. The difference between experimental, theoretical results is about 6% and the maximum output temperature is about 102ºc by natural convection state. Triangle channel is cause to increase heat transfer and absorb coefficient and output temperature. In addition the triangle channel design increase the contact surface between fluid and absorb plate, the turbulence of fluid flow and also cause to rises heat transfer and absorb heat coefficient. The average constant time of this collector is 7.5 minutes, which is acceptable. To sum up results show that increasing fluid flow rate cause to increase efficiency, absorb heat and fluid flow turbulence, but it cause to decrease output temperature and heat dissipation of collector. The output temperature of this collector is suitable for house heating systems and solar dryers for vegetables and granular materials. By comparing the efficiency and temperature limitation in different flow rates, the suitable flow rate for drying many of agricultural crops is 0.04 kg/m^2 s According to experimental results, some equations is offered for calculation output temperature in relation to solar radiation incident and heat transfer coefficient for triangle channel collector. They are tested by comparing experimental data and they have a suitable and acceptable exact.

Nomenclature

A_c Collector aperture area (m^2)

C_p Specific heat of fluid (j/kgk)

F_R Collector heat removal factor

h, h_1, h_2, h_3 Convective heat transfer coefficients (w/m^2k)

h_r Radiative heat transfer coefficient (w/m^2k)

I_T Radiation on tilted surface (w/m^2)

Q_u Useful energy gain of collector (w)

T_a Ambient temperature (˚c)

T_i Inlet temperature (˚c)

T_p Absorber plate temperature (C°)

U_L Collector total loss coefficient (w/m^2k)

I_{th} Threshold radiation (w/m^2)

F' Collector efficiency factor

$\dot{m}$ Mass flow rate of fluid (kg/s)

REFERENCES

1. Varury, Saini, R.P., Singal, S.K., 2007. A review on roughness geometry used in solar air heaters. J. Sol. Energy. 81, 1340–1350.
2. Ho, C.D., Yeh, H.M., Cheng, T.W., Chen, T.C., Wang, R.C., 2009. The Influences of recycle on performance of baffled double-pass flat plate solar air heaters with internal fins attached. J. Appl. Energy 86, 1470–1478.
3. Azharul.K, A.Hawlader," performance evaluation of a V-groove solar air collector ", Applied Thermal Engineering 26 (2006) 121-130.
4. Chamoli.S, R. Chauhan, N.S. Thakur, and J.S. Saini, 2012,"A review of the performance of double pass solar air heater", Renewable and Sustainable Energy Reviews, Vol. 16, No. 1, pp. 481-492.
5. Gupta, M.K., Kaushik, S.C., 2009. Performance evaluation of solar air heater having expanded metal mesh as artificial roughness on absorber plate. J. Therm. Sci. 48, 1007–1016.
6. Layek, A., Saini, J.S., Solanki, S.C., 2009. Effect of chamfering on heat transfer and friction characteristics of solar air heater having absorber plate roughened with compound turbulators. J. Renew. Energy 34, 1292–1298.
7. Koyuncu.T ," Performance of Various design of Solar air heaters for crop drying applications " , Renewable Energy 31(2006) 1073-1088.
8. Karim.M "Development of solar air collectors for drying application ", Energy conversion and Management 45 (2004) 329-344.
9. Kalogirou.A ," Prediction of Flat - Plate collector performance parameters using artificial neural networks",Solar Energy 80 (2006) 248-259.
10. ASHRAE, Standard 93-77 American Society of Heating, Refrigeration, and Air Conditioning Engineers,New York (1977), Methods of Testing to Determine the Thermal Performance of Solar Collector