IJBPAS, August, 2015, 4(8), Special Issue: 186-204

ISSN: 2277–4998

International Journal of Biology, Pharmacy and Allied Sciences (IJBPAS)

'A Bridge Between Laboratory and Reader'

www.ijbpas.com

NUMERICAL INVESTIGATION OF THERMAL PERFORMANCE OF DOUBLE PASS SOLAR AIR HEATERS

MILAD BAYANDOR

Department of Mechanical Engineering, Islamic Azad University, Sahneh Branch. Iran, Sahneh

ABSTRACT

In this study, the thermal performance of a double pass solar air heater with the dimensions of 1 meter by 2.5 meters to the south was investigated numerically. Considering the heat network for each of the components of air heater and the air flows in the channel, the energy equation got written, and then in the form of a computer program got analyzed implicitly and by using the up-wind method in Matlab.

This approach can, with regard to the daily intensity of solar radiation and air temperature in different cities, calculate the temperature of different components of the collector, received heating rate and thermal efficiency of the collector.

In this study, the influence of parameters such as air mass flow rate, the ratio of absorption coefficient of the absorber plate, channel depth and wind speed on components of the collector, received heating rate and thermal efficiency were evaluated for the city of Kermanshah on days of 15th of Tir and 15th of Dey. The maximum efficiency for 15th of Tir was %55, and for the 15th of Dey it was %45. With a reduction in the export coefficient compared to absorption coefficient of the absorber plate from 0.02 to 1, the efficiency for 15th of Tir and 15th of Dey increased by 12 and 17 percent respectively.

Keywords: Thermal Performance, Double Pass, Solar Air Heaters

INTRODUCTION

Solar energy applications

Solar energy applications can be separated into two categories: Power Plant. Non-Power Plant.

Power Plant applications:

1. Plants th at have parabolic channel mirrors on their receptors (Figure 3).
2. Plants that have their receptors located in a tower and the sunlight are being reflected on the tower by large mirrors which are called Heliostats. (Central Receptor) (Figure 1).
3. Plants with parabolic dish receptors (Figure 2).

Non-power applications

Non-power applications of solar thermal energy, includes several categories, which the most important of them all are: 1. solar water heater and solar bathhouses. 2. Solar cooling and heating systems. 3. Solar water desalinators.

4. Solar dryers.
5. Solar cookers.
6. Solar furnaces.
7. Solar homes.

Figure 1- power plant with central receptor

Figure 2 - power plant with dish receptor

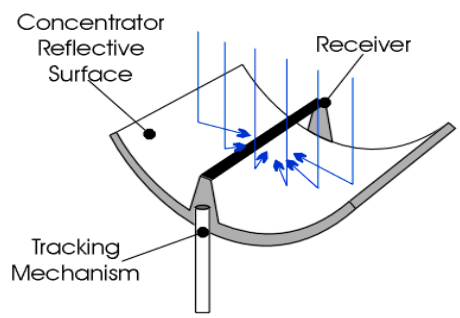


Figure3 -plant with parabolic channel mirrors

2- Solar air heater:

Solar air heating systems are one of the passive solar systems which have been used in buildings in recent years as a heating system in order to optimize the energy consumption. Solar air heaters are made out of one or two layers of glass, an air channel to transfer heat, the absorber plate, plate holders and insulation. Solar air heating systems are structurally much like Trump walls, except that in trump walls the transfer of heat from air channels into the room is done mostly through conduction (conductivity). But in most solar air heaters the heat transfers by natural methods or thermosiphon.

Solar energy produced by solar radiation collector is a particular type of solar radiation energy production. There are essentially two types of solar heating, water heating and the air heating. The second type compared to the first type has been less studied and developed due to lower thermal efficiency. Thermal efficiency is low due to high levels of heat loss and low amount of displacement between the heat sinks and air flow between them. That is why during this period a lot of work has been done to improve the performance of air heaters by applying different designs in the air flow.

3- The works that have been done to improve the performance of solar air heaters

In recent years a lot of research have been done to enhance the frequency of free convection heat transfer and reduce heat losses and ultimately increase the efficiency of this type of air heaters. Down below, several examples are mentioned.

In 2003, Ong introduced a numeric model for solar air heaters. Energy equations have been solved in a steady state on the glasses of air channels and absorption plates by using the inverse matrix method. In this equation, the effect of height and intensity of the sun on the temperature of the various components of air heaters, efficiency and mass flow rate has been shown [25].

In 2007, Habeb and Burek reported results of an experiment that showed the efficiency of heat, heat transfer and the mass flow in a solar air heater. Heat input was supplied by an electrical heater and in the steady state; it ranged from 200 to 1000 Watts and depth of the channel changed from 20 to 110 mm. The results show that the thermal efficiency of the system is a function of the heat input and does not depend on the depth of the channel [26.]

In 2008, Bassiouny and Nader Koura conducted an analytical and numerical study on air heaters used for the air conditioning of the room, and investigated the effects of geometric parameters on the air conditioning of the room, the results showed that the channel width has a more significant effect on the changes in the air conditioning of the room than the size of the air inlet of the heater. Also, the average temperature of the absorber plate and the average temperature of the glass, respectively, are related to the intensity of solar radiation by Tg= 9.15 I 0.199 and Tw=3.5 I 0.461 equations. In addition, it was shown that the speed of the air outlet of the channel is heavily dependent on sun's radiations. Vex=0.13I0.1 [27.]

In 2000, Wao used a new absorbent instead of the usual absorbent and examined its numerical models and its performance for a solar air heater with one passage. [35] In 2003, Naphon and Kongtragool used a mathematical model to predict heat transfer and performance levels of the various forms. [42]

In 2007, Ramadan examined thermal performance of a solar air heater with two passes. [43]

In 2000, Spain studied the equations for performance of solar air heaters with two passes with prousemedia. [44] The use of metal parts (Packing Material / Prous) to increase and improve the performance of a solar air heater happened by Bhmradwaj in year 1981, Shomaker in 1961, Mishara in 1981 and Tahakur in 2003, when there was just one passage. But no tests or reports were reported for the case of two passes by that time. [45].

4- A review of the history of the performance, relations and equations identified for solar air heaters with two passes in different states

Air flows mainly solar air heaters with two passes are available in two forms. 1. One is that the flow channnels are parallel to each other. 2. The other, flow channels are available in reciprocating form, shown in Figure 4.

Thermal analysis of upper and lower channels in each small part of the channel is defined by the following relations.

1) $Q_l = m_l c_p (T_{l,fo} - T_{l,fi})$

2) $Q_u = m_u c_p (T_{u,fo} - T_{u,fi})$

3) $\eta = \dfrac{Q_t}{AS_t}$

Qu and QL, show the heat or heat transfer in the upper and lower channels.

Total heat transfer and thermal efficiency are defined as follows:

4) $Qt = Q_L + Q_u$

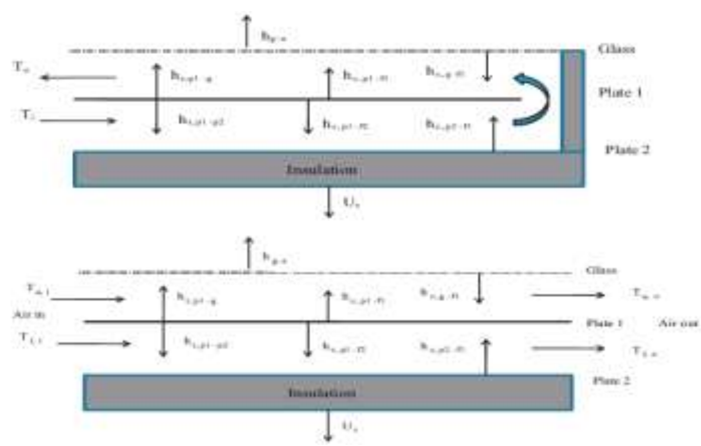


Figure 4 - The flows of air in air heaters with two passes.

5- Different types of mathematical models for air heaters

5-1- parallel passage solar air heater. This design includes glass coatings, absorbent page, wall or screen and insulation. There is two air flows, one between the cover glass and the absorbent page, and the other is between the absorbent page and insulation which is shown in the figure below. Forson, in the year 2001, came up with the energy equations for the cover glass, the first channel, second channel, page absorbent and the insulator.[31]

(5) For the absorbent plate we have:

$$MgCg\frac{\partial Tg}{\partial t}=\alpha_g S+h_{rpg}(Tp-Tg)$$
$$-h_{cgw}(Tg-Tw)-h_{rga}(Tg-Ta)$$

(6) For the first air flow between the absorber plate and the first glass layer we have:

$$Mf1Cf\frac{\partial Tf1}{\partial t}=-\frac{G1Cf}{W}\frac{\partial Tf1}{\partial x}+$$
$$h_{cpf1}(Tp-Tf1)-h_{cf1g}(Tf1-Tg)$$

(7) For the absorber plate we have:

$$M1Cp\frac{\partial Tp}{\partial t}=\alpha_p\tau_g S-Kp\delta p\frac{\partial^2 Tp}{\partial x^2}+h_{rpg}(Tp-Tg)-$$
$$h_{cpf2}(Tp-Tf2)-h_{rpb}(Tp-Tb)-h_{cpf1}(Tp-Tf1)$$

(8) For the air flow between the absorbent plate and the insulator, we have:

$$Mf2Cf\frac{\partial Tf2}{\partial t}=-\frac{G2Cf}{W}\frac{\partial Tf2}{\partial x}+$$
$$h_{cpf2}(Tp-Tf2)-h_{cbf2}(Tb-Tf2)$$

(9) And finally for the insulator we have:

$$MbCb\frac{\partial Tb}{\partial t}=-Kb\delta b\frac{\partial^2 Tb}{\partial x^2}+h_{rpb}(Tp-Tb)$$
$$-h_b(Tb-Tr)-h_{cbf2}(Tb-Tf2)$$

(10) And for boundary conditions we have:

$$\frac{\partial Tp}{\partial x}\Big|_{x=0}=\frac{\partial Tp}{\partial x}\Big|_{x=l}=\frac{\partial Tb}{\partial x}\Big|_{x=l}=0$$
$$Tf(x=0)=Tfi,Tf2(x=0)=Tfi$$

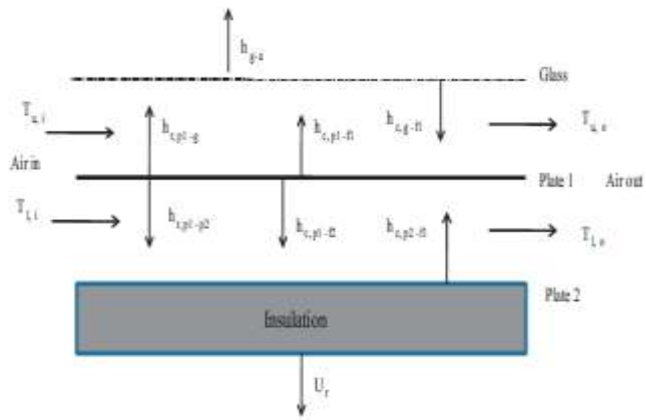


Figure 5 – Air flows in air heaters with parallel flow

6. The main relations of the model that was used in the thesis

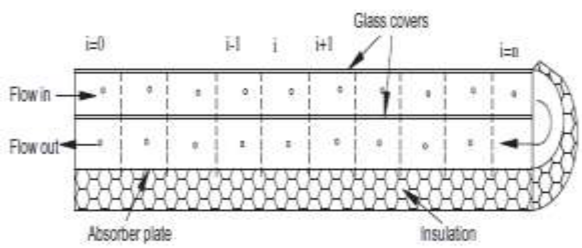


Figure 6 – The studied air heater

The following assumptions were considered in order to create a mathematical model of the air heater:

- Steady state condition is established in the whole system.
- One-dimensional heat transfer for all heat transfer processes through the transparent cover and between the absorber plate and the air inside the canal is considered.
- The temperature at different points along the channel width isn't fixed for the various components.
- Temperature in the entrance channel is assumed to be equal to ambient temperature.
- Because of the low speed of air flow within the channels, the friction has been ignored.
- The heat capacity of the transparent cover and the absorber plate are assumed to be negligible.

- The air inside the channel is considered as a fluid without absorbing radiation.
- All the thermophysical properties (Kinematic viscosity, density, volume expansion coefficient, etc) have been considered for the average constant temperature.

Considering the above assumptions, energy balance equation for each component of Air heater, including coating glasses, air channels, absorbent page and insulator plate is as follows:

6-2 components of the studied air heater

This air heater consists of two passes. The first air flow is flowing between two layers of glass, and the second air flow is flowing between the lower layer of glass and the absorber plate. Lengths of the components of the collector (absorbent page, glass layer, etc.) are 2 meters with a width of 1 meter. Channels depth are 2 cm. absorber plate is a black sheet of aluminum with a thickness of 1 mm to increase the absorption coefficient which on its underside an insulation surface made of fiberglass with a thickness of 6 mm is located to reduce the heat loss. Also, the insulator plate which is located under an absorber plate is completely sealed by a piece of wood with a thickness of 25 mm, which is covered by a layer of glass with a thickness of 12. The glass coating thickness is 4 mm. Two air channels are connected to each other by a U-shaped connector at the end of the channels. Which like other components include an absorber plate, insulation and an air gap channel similar to other areas. Intake air is provided into the channel by a blower that has the power of 2.2 kW or 2 hp.

6-3 Extracted energy equations for Air heater

Energy analysis for the first layer of glass cover

(11) $I\,\alpha_{g1} + h_w (T_a - T_{g1,i}) + h_{ra,I} (T_{skg} - T_{g1-i}) + h_{rg1g2,i} (T_{g2,1} - T_{g1,i}) + h_{f1g1} (T_{f1,i} - T_{g1,i}) = 0$

In this equation

The first term represents the radiation of the sun, the second term represents the radiant heat transfer from the sky, third term represents the radiant heat transfer to the second glass and forth term represents the heat transfer with the first air flow.

Energy analysis for the first channel

(12) $\frac{\dot{m}cp}{\Delta x}.T_{f1,i-1} + h_{f1,g1} (T_{g1,i} - T_{f1,i}) + h_{f1g2} (T_{g2,i} - T_{f1,i}) - \frac{\dot{m}Cp}{\Delta x}.T_{f1,i} = 0$

In this equation

The first term represents the heat transfer rate in the first channel per unit surface area of glass in the previous step; the second term represents heat transfer relocation between the flow (air) in the first channel and first glass cover; The third term represents heat transfer relocation between the flow (air) in the first channel and second glass cover; The fourth term represents the heat transfer rate in the first channel during the current step.

Energy analysis for the glass covers

(13) $I\tau_{g1}\alpha_{g2} + h_{f1g2}(T_{f1,i} - T_{g2,i}) + h_{f2g2}(T_{f2,i} - T_{g2,i}) + h_{rg1g2i}(T_{g1,i} - T_{g2,i}) + h_{rg2p,i}(T_{p,i} - T_{g2,i}) = 0$

In this equation:

First term represents the radiation received from the sun, the second term represents heat transfer between the first channel flow and the second glass layer, the third term represents heat transfer between the second channel flow and the second glass layer, fourth term represents radiant heat transfer between the first and second glass covers and fifth term represents radiant heat transfer between the second glass layer and the absorbent page.

Energy Analysis for the second channel

(14) $\frac{\dot{m}cp}{\Delta x}.T_{f2,i+1} + h_{f2,g2}(T_{g2,i} - T_{f2,i}) + h_{f2g2p}(T_{g2,i} - T_{f2,i}) - \frac{\dot{m}cp}{\Delta x}.T_{f2,i} = 0$

In this equation

First term represents the heat transfer rate in second channel per unit surface area of the second glass layer in the next step; The second term represents heat transfer between second channel and second glass layer; The third term represents heat transfer between second glass and the second channel and the absorber plate; The forth term represents heat transfer rate in second channel per unit surface area of the second glass layer in the current step.

Energy analysis for absorbent page

(15) $I(\tau\alpha) + h_{f2p}(T_{f2,i} - T_{p,i}) + h_{rg2p,i}(T_{g2,i} - T_{p,i}) = 0$

In this equation

First term represents the incoming solar radiation; the second term represents heat transfer between the second channel and absorber page; the third term represents radiant heat transfer between the second glass cover and the absorbent page.

Heat transfer coefficients

Radiant heat transfer coefficient of the environment

(16) $h_{ra,i} = \sigma\,\varepsilon_g(T^2_{g,i} + T^2_{sky})(T_{g,i} + T_{sky})$

In this equation

h_{ra}, σ, ε_g, T_g and T_{sky} respectively represent radiant heat transfer, Boltzmann constant, temperature coefficient of glass, temperature of glass cover and air temperature.

Heat transfer coefficient of the wind

(17) $27.7\ V_w + 1.h_w = 5$

In this equation Vw represents the speed of the wind.

Radiant heat transfer between the second glass cover and the absorbent page

(18) $h_{rg2p,i} = \frac{\sigma\left(T_2 g_{2,i} + T_{p2,i}\right)\left(T_{g1,i} + T_{p,i}\right)}{\left[\frac{1}{\varepsilon_{g2}} + \frac{1}{\varepsilon_p} - 1\right]}$

In this equation σ, T_{g2} , T_{g1}, ε_g and ε_p respectively represent the Boltzmann constant, temperature of the first and second glass covers, page absorption coefficient and glass cover coefficient.

Radiant heat transfer between the first and second glass covers

(19) $h_{rg1g2,i} = \frac{\sigma\left(T_2 g_{1,i} + T_{g2,i}\right)\left(T_{g1,i} + T_{g2,i}\right)}{\left[\frac{1}{\varepsilon_{g1}} + \frac{1}{\varepsilon_{g2}} - 1\right]}$

Parameters related to this equation have been explained in the above paragraph.

Heat transfer coefficient between the flows and absorbent Page

(20) $Nu = \frac{h_{fp} D_e}{k} = 0.0333\ (Re)^{./4}\ (Pr)^{1/3}$

In this equation K, Pr, Re, De and Nu respectively represent the coefficient of convective heat transfer flows (air), Prandtl number, Reynolds number, Optimum depth and Nusselt number.

RESULTS

In order to analyze the energy equations (11) to (15), a computer program was written in MATLAB environment. In this program, initial data, including climate and geographical location, day of the year, the air temperature, wind speed and collector's geometric dimensions such as length, width and thickness of each of its components (glass, absorber plate and insulation), channel depth and physical properties of absorbing page and glass (export coefficient, emission coefficient and absorption coefficient) are available. After solving the equations, the temperature of the various components of the collector, received heat and the collector efficiency and were calculated and compared. Figures 7 to 20 show the graphs of the results.

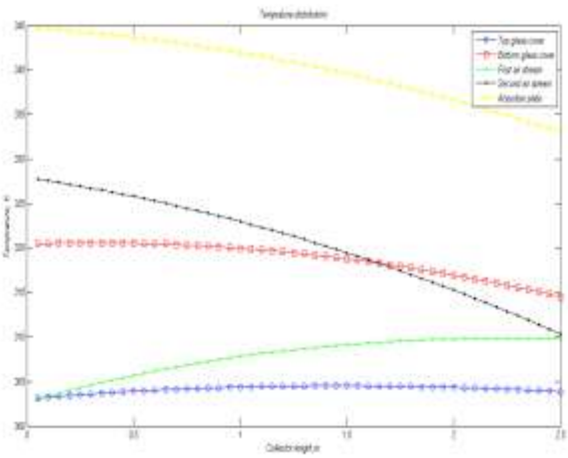


Figure 7 - The daily average temperature distribution of the various components of the collector on Tir 15th

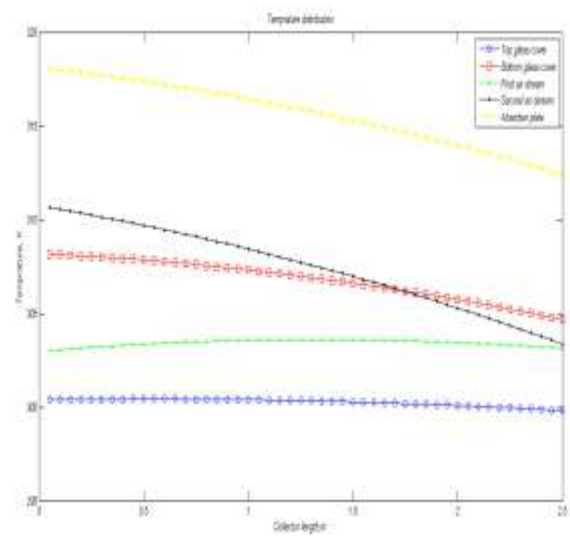


Figure 8 - The daily average temperature distribution of the various components of the collector on Dey 15th

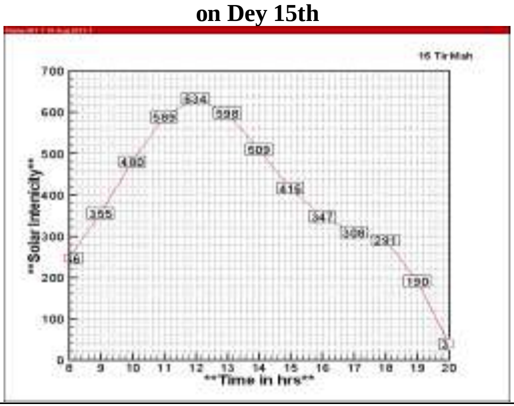


Figure 9 - The amount of solar radiation received at different times of the day on Tir 15th

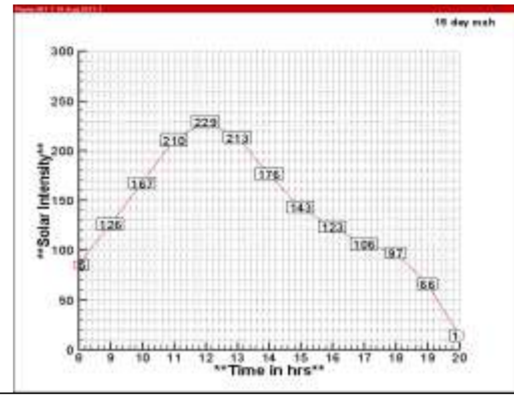


Figure 10 - The amount of solar radiation received at different times of the day on Dey 15th

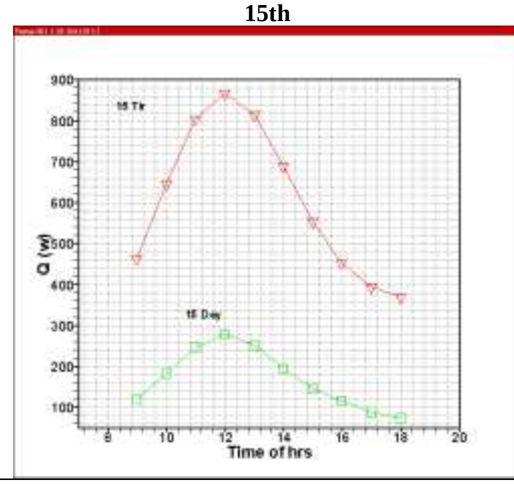


Figure 11- Heating rate received at different times of the day on Tir 15th and Dey 15th

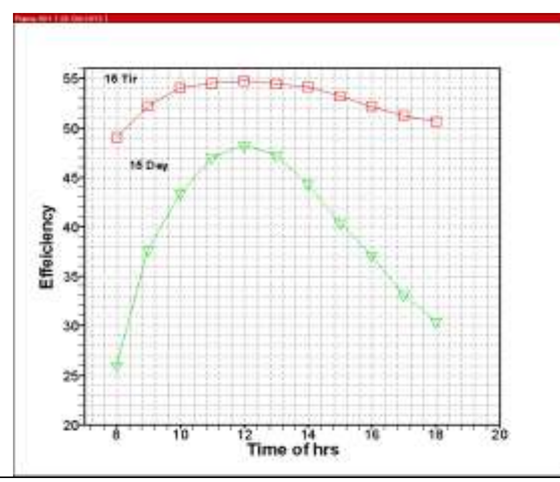


Figure 12 - Thermal efficiency of the collector at different times of the day on Tir 15th and Dey 15th

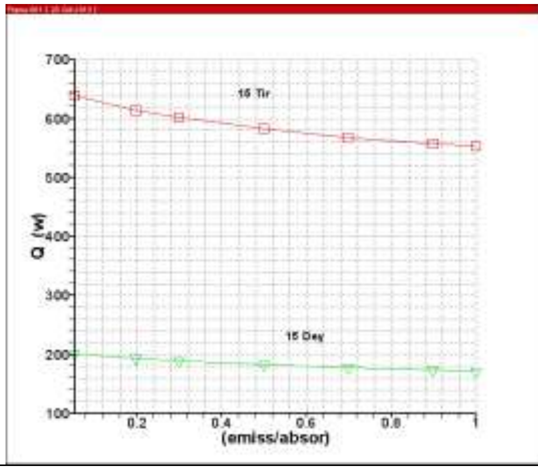
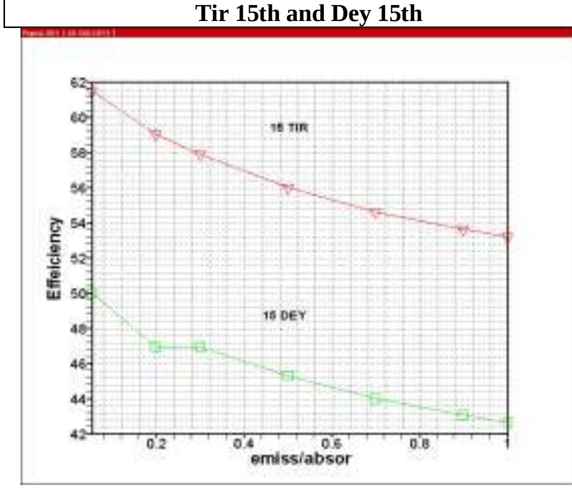


Figure 13- Effect of export ratio of the absorption
ε
coefficient (α) on received heating rate on the days of Tir 15th and Dey 15th



Fi

Figure 14 - Effect of export ratio of the absorption coefficient of absorbent page on thermal efficiency

Figure 15 - The impact of air mass flow rate on the thermal efficiency of the collector

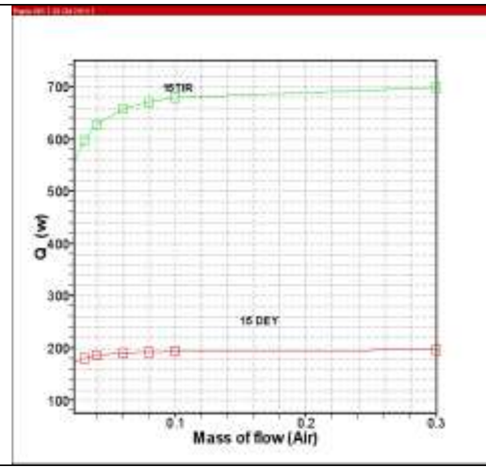


Figure 16 - The impact of the mass flow rate of air on received heating rate

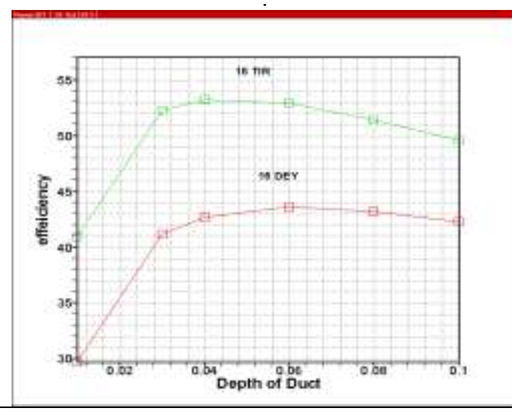


Figure 17 - The impact of the channel depth on thermal efficiency on days of Tir 15th and Dey 15th

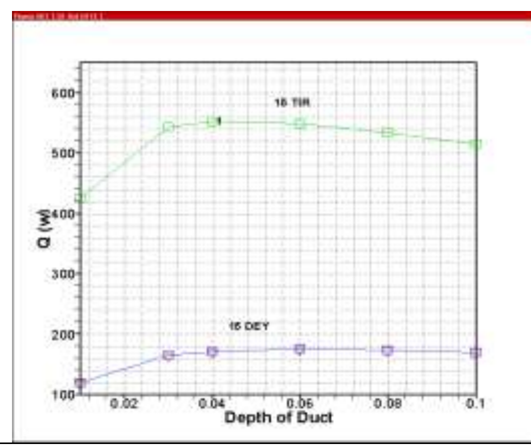


Figure 18 - The impact of the channel depth on heat rate received on days of Tir 15th and Dey 15th

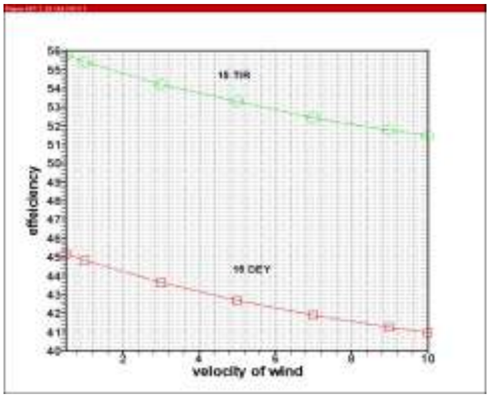


Figure 19 - Effect of wind speed on thermal efficiency on days of Tir 15th and Dey 15th

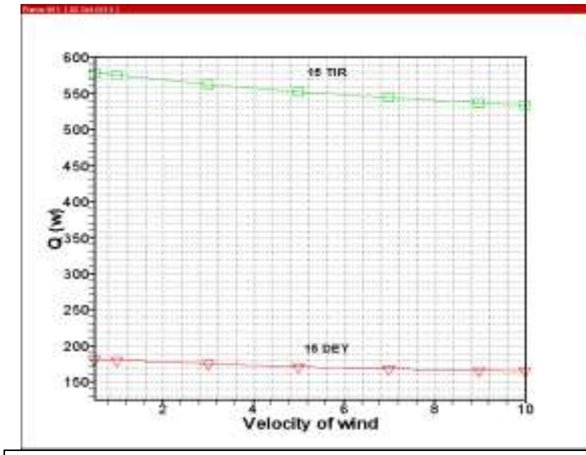


Figure 20 - Effect of wind speed on rate of received heat on days of Tir 15th and Dey 15th

To investigate the thermal performance of a solar collector with two passes, the energy equation for the various components, including two covering glasses, absorber page and the air inside the two channels was written and then an algorithm was provided for solving the equations in MATLAB environment with Up-Wind numerical method. With the implementation of the program, the impact of parameters such as air mass flow rate, the ratio of export coefficient absorption coefficient of the absorber plate, channel depth and wind speed on the temperature of various components of the collector, received heating rate and thermal efficiency of the collector were reviewed and the following results were obtained: By increasing the intensity of solar radiation, thermal efficiency and received heat rate increases.

With a reduction in the rate of absorption coefficient of the absorber plate from 0.9 to 0.0543, heat production increases especially in summer by 15 percent and in winter by 30 percent.

With a reduction in the rate of absorption coefficient of the absorber plate from 0.9 to 0.0543, efficiency increases especially in summer by 15 percent and in winter by 30 percent.

Increment in mass transfer through the channels has a very important impact on increasing the rate of received heat and thermal efficiency in summer and winter. Increasing mass flow rate through the channel more than 0.1 kilograms per second has virtually no effect on the received heating rate and thermal efficiency, and the amount of received heat remains almost constant. Increasing mass flow through the channel

caused an increase in efficiency and heat production in a certain range and fixed the temperature of components of the collector throughout the page. Thermal efficiency and received heat rate increases, by increasing the channel depth to 30 mm, then with increasing the channel depth to 80 mm thermal efficiency and received heat rate gets fixed and after that with increasing the depth of the channel, thermal efficiency and received heat rate declines.
Optimum depth for the channel has been achieved for 0.04 meters.
The wind speed has little effect on the temperature of the components of the collector, heat production and efficiency.

ABBREVIATIONS

haf,hbf	**Heat transfer coefficient displacement (w/k.m²)**
Nu	**Nusselt number**
S	**The average distance between the surfaces (m)**
Ra	**Riley number**
β	**Air thermal diffusivity**
Ts	**Pages temperature (K)**
ϑ	**(m²/S) Kinematic viscosity coefficient**
α	**(1/k) Volume expansion coefficient**
h	**Air convection transfer coefficient (W/m².k)**
K	**Temperature convection coefficient (W/m.k)**
q1,q	**(W/m²) Thermal flux**
Pr	**Prandtl number**
hcob	**Heat transfer coefficient free displacement between the collector W/m².K) plates**
Q	**Heat production**
Cp	**(J/kg.K) Specific heat capacity of air**
A	**(m²) collector surface**
ɳ	**Thermal efficiency**
D	**(m) Channel depth**
Dh	**Optimum depth (m)**
T	**Temperature**
a	**ambient**
c	**convection**
g	**glass cover**
fluid	**air**
P	**Page absorbent**

r	radiation
V	Wind speed
Ɛ	Export coefficient
α	Absorption coefficient
m,ṁ	(Kg/m.S) Mass transmission fluid (air)
ρ	(Kg/m^3) Density
σ	(5.67*10^-8 W/m^2.K^3) Stefan Boltzmann constant
U	The overall thermal dissipation factor from the covering glass to (W/m^2.K) the environment
Tsky	(K) The temperature of the sky
μ	(Kg/m.s) Viscosity

REFERENCES

[1] Daniel Halas, the era of solar energy, translated by Hussein Ejlali, Translation and Publication firm, 1356.

[2] Asghar Haj Saghati, principles and applications of Solar Energy, University of Science and Technology, 1380.

[3] Official website of the organization of optimization of fuel consumption, www.ifco.com

[4] Bina Bagher, optimization of fuel consumption in under construction buildings with intelligent use of energy, The fifth National Conference for optimization of fuel consumption, May 1385, Tehran.

[5] architecture with minimal energy, translated by Omid Saberi and Parisa Sanei, optimization of fuel consumption, Eastern Green Look Publication,

[6] - Ozisic MN, "HEAT TRANSFER", Ms Graw- Hill, 1998

[7] - Incropera FP, Dewitt DP., "Fundamentals of heat and mass transfer", 3rd ed., Wiley; 1990.

[8] - Kusuda, "Thermal response factors for multi - layer structure of various heat counduction system", ASHRAE, trance, 246- 271, 1969.

[9] attitude Review on solar energy systems along with a guide to make a few simple systems, translated by M. Raufi Rad, Talvin Organization, 1364.

[10] Edward Mazrya, inactive solar architecture, translated by Bijan Aghazadeh, 1385.

[11] - Elenbaas W., "heat dissipation of parallel plates by free convection", Phisica 9, Holand, 1942.

[12] - Bodia JR, Osterle J. F, "The development of free convection between heated vertical plateds, Transactions of ASME", Journal of heat and mass Transfer 15, 1972.

[13] - Aung W., "Fully developed Laminar free convection between vertical plates heated asymmertically", International Journal of heat and mass transfer 15 (1972), 1577-1580.

[14] - Bar-Chon A., Rohesnow WM, "Thermally optimum Spacing pf vertical, Nutral convection cooled, parallel plates", J. Heat Transfer, Vol. 106,1984, pp.116-123.

[15] - Azevedo LFA, Sparrow EM, Natural convection in open-ended inclined channels ", International Journal of heat and mass transfer 29 (6), 1985.

[16] - Incropra FP, Dewitt DP, "Fundamentals of heat and mass transfer" $ th eddition. New York: John Wiley, 1996.

[17] - Mac Garegor RK, Emery AP, "Free convectio therough vertical plane layers: Modern and high prantel number fluids", j. Heat Transfer, Vol. 91, 1691, 391

[18] - Holands, Unny, Raithby, Konick, "Free convection heat transfer across inclined air layers", ASME paper, No. 75-HT-55,1975.

[19] - Bevil D., Brandt H., "A solar energy collector for heating air", Solar energy, Vol. 12, 1968, pp. 19 -25.

[20] - Hamid YH, Beckman WA, "Performance of air cooled radiativly heated screen matrices", J. Eng. For power, Transe, ASME, Vol 93, 1971, pp. 221- 232.

[21] - Satcunanathan S, Deonarine S. A two pass solar air heater. Solar Energy, 1973; 15: 41-9.

[22] - Duffie J. A, Beckman WA, "A two pass solar air heater", solar energy, vol.15, No. 1, 1973, pp. 41-49.

[23] - Hollick JC, "Worlds largest and tallest solar recladding", Renewable Energy, Vol. No 1-4, 1966, pp. 703-707.

[24] - Medhlopa A., Jones SA, Kalenga Saka, J D., "A solar air heater with composite absorber system for food dehydration", Renewable Energy, Vol. 27, 2002. Pp. 27-32

[25] - Ong KS, "A mathematical model of a solar chimney", Renewable Energy 28 (2003) 1047- 1060.

[26] - Burek. SAM, Habeb A., "Air flow and thermal efficiency in solar chimney and trombe alls", Energy and buildings 39 (2) (2007) 128-132.

[27] - Nader. SA Koura, Ramadan Bassiouny, "An analytical and numerical study of solar chimney use for room natural ventilation", Energy and buildings 40 (2008) 865-873

[28] - Tamimi A., "mass flow rate prediction of thermosiphon solar air heater", Canadian journal of chimical Engineering, Vol. 68, 1990, pp.1103-1117

[29] - La Pica A., Rodon G., Volpes R., "An experimental investigation on natural convection of air in vertical channel", International journal of heat and mass transfer 36 (3), (1993), 611-616.

[30] - Chen ZD, Bandopadhayay P., Halldorsson J., Byrjalsen C., Heiselberger P., Li Y., "An

experimenal investigation of a solar chimney model with uniform heat flux", Building and enivironment 38, (2003) , 893-897.

[31] - Mathure J., Bansal NK, Mathur S., Jain M., "An upma Experimental investigation on solar chimney for room ventilation", Solar energy 80 (2006) 927-933.

[32] - Duffie JA, Beckman WA, "Solar engineering of thermal processes", Wiley and Sons, New York, 1980 and 1991.

[33] - Wijeysundera NE, Lee AH, Tjioe LE. Thermal performance study of two-pass solar air heaters. Solar Energy 1982; 28: 363-70.

[34] - Persad P, Satcunanathan S. The thermal performance of the two pass. Two Glass Cover Solar Air Heater. J Sol Energy Eng 1983; 105 (3): 254.

[35] - Ho CD, Yeh CW, Hsieh SM. Improvement in device performance of multipass flat plate solar air heaters with external recycle. Renewable Energy 2005; 30: 1601-21.

[36] - Ho CD, Yeh HM, Wang RC. Heat transfer enhancement in double pass flat plate solar air heaters with recycle. Energy 2005; 30: 2796-817.

[37] Paisarn Naphon. Effect of porous media on the performance of the doublepass flat plate solar air heater. International Communications in Heat and Mass Transfer 2005; 32: 140-50.

[38] EI-Sebaii AA, Aboul-Enein S, Ramadan MRI, EI-Bialy E. Year round performance of double pass solar air heater with packed bed. Energy Conversion and Management2007; 48: 990-1003

[39] Ramani BM, Akhilesh Gupta, Ravi Kumar. Performance of a double pass solar air collector. Solar Energy 2010; 84: 1929-37

[40] Ramani BM, Akhilesh Gupta, Ravi Kumar. Performance of a double pass solar air collector. Solar Energy 2010; 84: 1929-37.

[41] - Paisarn Naphon. Effect of porous media on the performance of the doublepass flat plate solar air heater. International Communications in Heat and Mass

[42] - EI-Sebaii AA, Aboul-Enein S, Ramadan MRI, EI-Bialy E. Year round performance of double pass solar air heater with packed bed. Energy Conversion and Management 2007; 48: 990-1003. Transfer 2005; 32: 140-50.

[43] - Ramadan MRI, EI-Sebaii AA,

Aboul-Enein S, EI-Bialy E. Thermal performance of a packed bed double pass solar air heater. Energy 2007; 32: 1524-35.

[44] - Naphon P. On the performance and entropy generation of the double-pass solar air heater with longitudinal fins. Renewable Energy 2005; 30: 1345-57.

[45] - Tchinda R. A review of the mathematical models for predicting solar air heater systems. Renewable and sustainable energy reviews 2009; 13: 1734-59

[46] - Sopian K, Supranto WRW, Daud MY, Othman B, Yatim. Thermal performance of the double-pass solar collector with and without porous media. Renewable Energy 1999; 18: 557-64.

[47] - Forson FK, Nazha MAA, Rajakaruna H. Experimental and simulation studies on a single pass, double duct solar air heater. Energy Conversion and Management 2003; 44: 1209-27.

[48] - Tiwari, G.N., 2002. Solar Energy; Fundamentals, Design, Modeling and Applications. Narosa Publishing House, New Delhi.

[49] - Sukhatme, SP, 2003. Solar Energy: Principles of Thermal Collection and Storage. Tata McGraw-Hill Publishing Company Ltd., New Delhi (9th reprint).

[50] - Wao, Wenfeng et al., 2000. Numerical study on natural convection inside the channel between the flat-plate cover and sine-wave absorber of a cross-corrugated solar air heater. Energy Conversion and Management41, 145-151.

[51] - Esen H. Experimental energy and exergy analysis of a double flow solar air heater having different obstacles on absorber plates. Building and Environment2008; 43: 1046-54.

[52] - Forson FK, Nazha MAA, Rajakaruna H. Experimental and simulation studies on a single pass, double duct solar air heater. Energy Conversion and Management2003; 44: 1209-27.

[53] - Naphon, Paisarn, 2005. Effect of porous media on the performance of the double pass flat-plate solar air heater. International Communications in Heat and Mass Transfer 32, 140-150.

[54] - Karwa et al., 2001. Thermo-hydraulic performance of solar air heaters having integral chamfered ribs

roughness on absorber plate. Energy26, 161-176.
[55] - Sopian K, Alghoul MA, Alfegi EM, Sulaiman MY, Musa EA. Evaluation of thermal efficiency of double pass solar collector with and without porous media. Renewable Energy 2009; 34: 640-5.
[56] Ho CD, Yeh CW, Hsieh SM. Improvement in device performance of multi-pass flat plate solar air heaters with external recycle. Renewable Energy2005; 30: 1601-21.
[57] Ho CD, Yeh HM, Wang RC. Heat transfer enhancement in double pass flat plate solar air heaters with recycle. Energy 2005; 30: 2796-81
[58] Forson FK, Nazha MAA, Rajakaruna H. Experimental and simulation studies on a single pass, double duct solar air heater. Energy Conversion and Management2003; 44: 1209-27.
[59] Official weather report website www.Weather.ir
[60] Tchinda R. A review of the mathematical models for predicting solar air heater systems. Renewable and sustainable energy reviews 2009; 13: 1734-59.