Performance and Cost Aspect of Double Pass V-Groove Absorber with and without Porous Media

Bashria A. A. Yousef [1*]
[1*]Sustainable and Renewable Energy Engineering Department,
College of Engineering, University of Sharjah,
Sharjah, UAE.

M. El-Haj Assad[1]
[1]Sustainable and Renewable Energy Engineering Department,
College of Engineering, University of Sharjah,
Sharjah, UAE.

***Abstract*— This article presents a model to investigate the effect of mass flow, channel depth and collector length on the thermal performance and the cost aspect for double pass V-groove absorber with and without porous media. The thermal performance was determined over a wide range of operating conditions. It is found that the use of porous media increase the efficiency of v-groove absorber by 2% -3% and the outlet temperature is increased, at the same time it is found that the higher power electrical consumption by the fan is due to the increase of pressure drop due to the use of porous. On the other hand it is concluded that the higher in cost energy for any particular combination of flow depth, collector length and mass flow rate is at short collector length, small flow depth with high quantity of mass flow rate. Moreover, the values of duct lengths and depths for which the cost of solar energy is minimized are different for different values of mass flow rates.**

Keywords*— *V-groove absorber; Double pass solar air heater; Thermal performance; Cost of solar energy.

I. INTRODUCTION

Solar air heaters are one of the potential solar applications of solar energy in the world, thus extensive investigations have been carried out in order to search for efficient and inexpensive designs suitable for mass production for different practical applications. Although, air heaters can be designed using cheaper as well as lesser amount of material and is simpler to use than the solar water heaters, they have certain disadvantages. The foremost being the poor heat transfer properties of air.

In order to overcome and improve the poor convective heat transfer between the flowing air and the absorber plate, various types of absorber plates are suggested and studied, such as roughness elements [1], cross corrugated plates [2, 3], v-groove absorber plate [4, 5], attached fins to absorber plate [6, 7, 8].

The double pass flow type of solar air collectors have been used also to increase the heat transfer area, in order to improve thermal performance of the solar air heaters [9, 10, 11, 12]. Qahtan, et.al. 2016 [13], investigated the thermal performance of two types of solar air collectors: “V”-corrugated porous absorber and “U”-single pass corrugated absorber. They conducted transient mathematical models or both solar air heaters under the same weather conditions.

However, the availability of a tool to be used for supporting the designs of solar air heaters, application of mathematical models for the analysis of descriptive data from the domain experts would facilitate the task. A developed Mathematical model to predict the thermal performance and cost effectiveness for different designs of solar air heaters was developed in this study, and used to find the influence of different parameters, such as mass flow rate, flow channel depth and collector length on the system thermal performance and the cost benefit for different types of solar air heaters.

The main objective of the present study is to investigate the thermal performance and the cost effectiveness of two types of solar air heaters with V-groove absorber in double pass mode with and without porous media in the lower duct. To validate the theoretical model, comparisons between the experimental and theoretical results are made

II. THEORETICAL ANALYSIS

A. Steady State Energy Balance

The heat transfer and the cost factors of the double V-groove absorber are presented below, this analysis lead to annual thermal energy gain (ATEG) and annual cost (AC) of the systems. The cross sectional views and the thermal network of the double V-groove are illustrated in Figure 1.

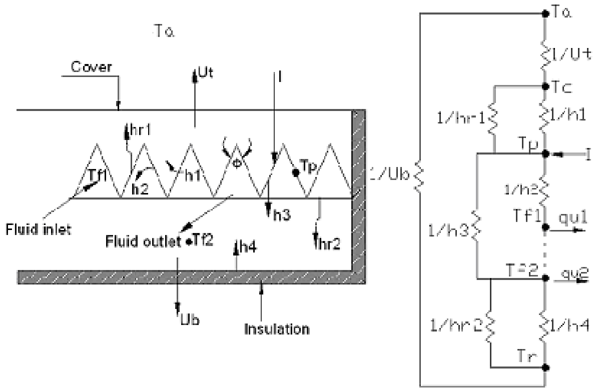
In the two types, the air heaters are composed of three plates, the cover, the absorber and the rear or back plate. The lower duct has been packed with a porous media of 0.80 porosity in type 2.

To model the solar air types and obtain their relative equations, analysis is based on energy balance at various components of the collector models, along with the different heat transfer coefficients at their surfaces. The assumptions made are:

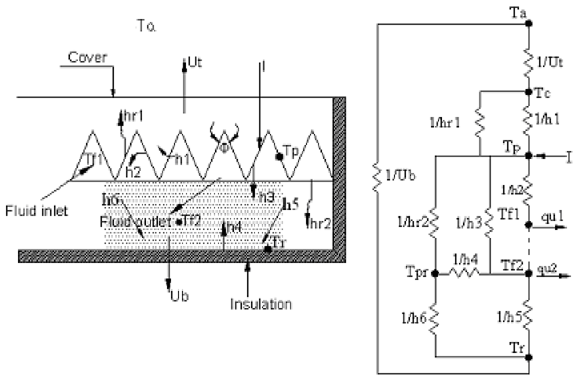
i. Heat transfer is steady and one dimensional
ii. The temperatures of the glass, absorber and bottom plates vary only along the x-direction of the air flow
iii. There is no leakage from the smooth flow channels
iv. The absorption of solar radiation in the cover is neglected insofar as it affects loss from the collector
v. Heat losses through the front and back of collector are to the same ambient temperature

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 12, December-2016

The absorbed solar energy heats up the plate to a temperature T_p. Energy is transferred from the plate at T_P to the cover through the radiation heat transfer coefficient h_{r1} and the convection heat transfer h_1, and to the fluid in the upper duct flowing through the V-groove at a temperature T_{f1} through the convection heat transfer coefficient h_2, and to the fluid in the lower duct flowing between the absorber plate and the base plate at a temperature T_{f2} through the convection heat transfer coefficient h_3.



(a) Type -1



(a) Type -2

Fig. 1. Schematic diagram of the solar air heaters with thermal network

Energy also is transferred to the base plate through the radiation heat transfer coefficient h_{r2}. Energy is transferred from the fluid flowing in the lower duct at T_{f2} to the base plate through convection heat transfer coefficient h_4. Finally energy is lost to the ambient air through the combined convection and radiation coefficient U_t through the cover glass. The steady-state energy balance gives the following equations:

Collector cover

$$h_1(T_p - T_c) + h_r(T_p - T_c) = U_t(T_c - T_a) \quad (1)$$

V-groove absorber

$$h_2(T_p - T_{f1}) + h_1(T_p - T_c) + h_r(T_p - T_c) + h_3(T_p - T_{f2}) + h_{r2}(T_p - T_r) = I\tau\alpha \quad (2)$$

Fluid medium in the upper passage

$$h_2(T_p - T_{f1}) = (\frac{\dot{m}C_{p1}}{W})(\frac{dT_{f1}}{dx}) \quad (3)$$

Fluid medium in the lower duct

$$h_3(T_p - T_{f2}) = (\frac{\dot{m}C_{p2}}{W})(\frac{dT_{f2}}{dx}) + h_4(T_{f2} - T_r) \quad (4)$$

Bottom plate

$$h_4(T_{f2} - T_r) + h_{r2}(T_p - T_r) = U_b(T_r - T_a) \quad (5)$$

For double flow double duct packed with porous media (glass-wool of 0.8 porosity) energy is transferred from the plate at T_p to the porous media through the radiation heat transfer coefficient h_{r2}. Energy is transferred from the porous media to the fluid in the lower duct through the convective heat transfer coefficient h_4 and from the fluid at T_{f2} to the bottom plate through convection heat transfer coefficient h_5. Energy is transferred from the porous media to the bottom plate through the convection heat transfer coefficient heat transfer coefficient h_6. The steady-state energy balance gives the following equations:

Collector cover

$$h_1(T_p - T_c) + h_r(T_p - T_c) = U_t(T_c - T_a) \quad (6)$$

V-groove absorber

$$h_2(T_p - T_{f1}) + h_1(T_p - T_c) + h_r(T_p - T_c) + h_3(T_p - T_{f2}) + h_{r2}(T_p - T_{pr}) = I\tau\alpha \quad (7)$$

Fluid medium in the upper passage

$$h_2(T_p - T_{f1}) = (\frac{\dot{m}C_{p1}}{W})(\frac{dT_{f1}}{dx}) \quad (8)$$

Fluid medium in the lower duct

$$h_3(T_p - T_{f2}) + h_4(T_{pr} - T_{f2}) + h_5(T_{f2} - T_r) = (\frac{\dot{m}C_{p2}}{W})(\frac{dT_{f2}}{dx}) \quad (9)$$

Porous media

$$h_{r2}(T_p - T_{pr}) + h_6(T_{pr} - T_r) = h_4(T_{pr} - T_{f2}) \quad (10)$$

Bottom plate

$$h_5(T_{f2} - T_r) + h_6(T_{pr} - T_r) = U_b(T_r - T_a) \quad (11)$$

B. Annual Energy Gain

The annual thermal energy gain (ATEG) available from the collector can be obtained by multiplying the useful heat by the number of operating days in a year and the number of hours per day during which useful sunshine is available [14].

$$ATEG = \dot{m}C_p(T_o - T_i)t_{op} \quad (12)$$

C. Annual Cost

In order to estimate the annual cost of the collector (AC) of the solar air different cost factors have to be calculated. This includes the annual pump cost or running cost (ARC), annual capital cost (ACC), annual maintenance cost (MC) and annual salvage value (ASV). The annual running cost is calculated as follows:

$$ARC = (m_v \Delta p)t_{op}CE \quad (13)$$

Where P is the pressure drop (Pa), t_{op} is the time of operation and CE is the cost of electricity (RM/KWh)

$$\Delta P = f(\dot{m}^2/\rho)(L/D)^3 \quad (14)$$

$$f = f_o + y\left(\frac{D}{L}\right) \quad (15)$$

The values of f_o and y are

$f_o = 24/\text{Re}$, $y = 0.9$ for laminar flow ($\text{Re} < 2550$)
$f_o = 0.0094$, $y = 2.92\,\text{Re}^{-0.15}$ for transitonal flow ($2550 < \text{Re} < 10^4$)
$f_o = 0.059\,\text{Re}^{-0.2}$ $y = 0.73$ for turbulent flow ($10^4 < \text{Re} < 10^5$)

The annual capital cost (ACC) is given by the following relations:

$$ACC = CRFxCI \quad (16)$$
$$CI = CC + CSSC + FC \quad (17)$$
$$CRF = i(i+1)^n / [(i+1)^n - 1] \quad (18)$$
$$CC = WL*(X1+Y1) + (2D+W)*LZ1 \quad (19)$$

The annual salvage value (ASV) is given as:

$$ASV = SFFxSV \quad (20)$$
$$SFF = i/[(i+1)^n - 1] \quad (21)$$
$$SV = 0.1CI \quad (22)$$

Where CI is the Capital investment, SFF is the salvage fund factor and SV is the salvage value. Therefore, the annual cost of the collector (AC) is calculated as:

$$AC = ACC + MC + ARC - ASV \quad (23)$$

III. RESULTS AND DISCUSSION

To compare the performance of the solar air heaters a similar input data have been entered to give the same configuration for both double pass V-groove absorber. The detailed input data are given in Table 1.

Figure 2 shows the variation of efficiency with mass flow rate for V- groove absorber in double pass with and without porous media. From the figures, it can be seen that the efficiency of the air heater is strongly dependent on the air flow rate. The efficiencies of both air heaters increased constantly up to 0.07 kg/s, then tended to approach a constant value. This increase in efficiency due to the increased heat removal from two flow channels. On the other hand the using of porous media in double flow increase the air heater efficiency to be more 2-3% efficient than the air heaters in double flow mode without porous media. Hence, the use of porous media increases the heat transfer area which contributed to the higher efficiency. This is consistent with Sopian *et al.*, 1999.

TABLE 1: SPECIFICATION OF SOLAR AIR HEATERS

Collector tilt angle	10°
Collector length (m)	2.4
Collector width (m)	1.2
Plate type	V-groove absorber of 45°
Upper depth (m)	0.035 for double pass mode with and without porous media
Lower depth (m)	0.03, 0.045, 0,06 and 0.075 for double pass mode with and without porous media
Absorber material	Black steel, α = 0.9 and ε = 0.85
Cover material	Ordinary clear glass, τ = 0.85
Number of cover	1
Insulation material	Fiber glass , k = 0.045 W/m.k
Back insulation (m)	0.05
Edge insulation (m)	0.05
Porous media	Glass-wool of 0.8 porosity

Hence, the outlet temperature is an important parameter for drying applications; the outlet temperature was investigated for a wide range of flow rates. Figure 3 shows the variation of outlet temperature with flow rate. The outlet temperature of the flowing air through the collector decreased with increased flow rate, but after a flow rate of about 0.065 kg/s for double flow mode the rate of temperature drop become lower.

Figure 4 illustrates the variation of pressure drop with mass flow rate. It shows that the pressure drop is a function of mass flow rate hence it is increased by increasing the mass flow rate. The graphs clearly shows that the use of porous media in the double flow V-groove absorber increase the pressure drop from 4 to 25 Pa more than the pressure drop in double flow V-groove absorber without the porous media.

The effect of different upper channel depth on pressure drop, efficiency and outlet temperature for double pass mode with and without porous media is conducted, for fixed mass flow rate of 0.03 kg/s, constant lower flow depth of 0.025 m channel and two different channel lengths of 1m and 1.5 m. It is found that with the increase of the flow depth the pressure drop decreased as well as the efficiency and the outlet temperature decreased and by increasing the duct length, the efficiency is decreased but the outlet temperature and the pressure drop is increased as illustrated in Figure 5-7. It appeared from Figures 5-7 that the use of the porous media increased the system efficiency by 3-7 %, but the rise in outlet temperature is slightly smaller 2-3°C.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 12, December-2016

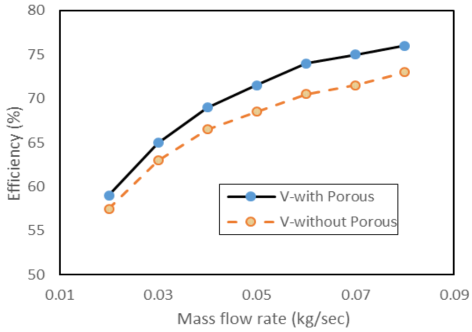


Fig. 2. Efficiency Variation with Mass Flow Rate in Double Pass V-Groove Absorber

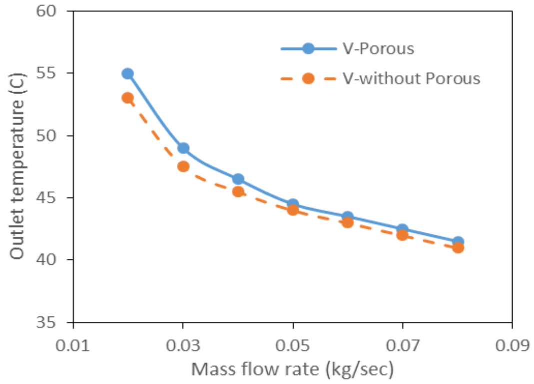


Fig. 3. Outlet Temperature Variation with Mass Flow Rate in Double Pass V-Groove Absorber with and without Porous Media.

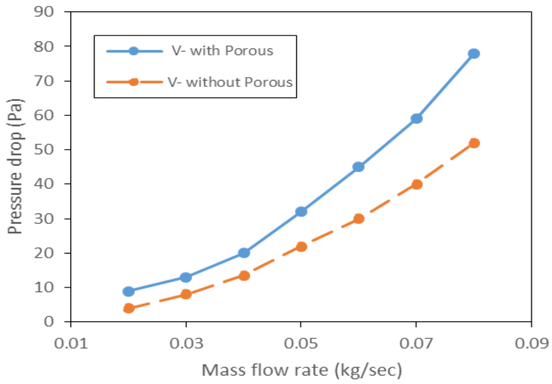
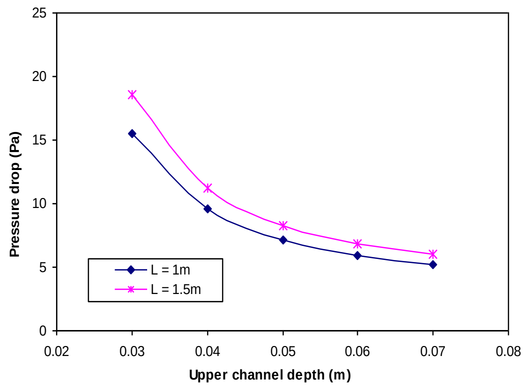
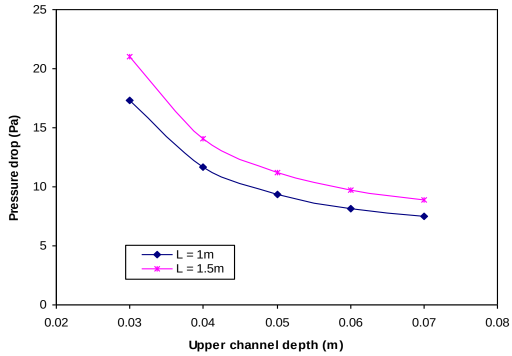


Fig. 4. Pressure Drop Variation with Mass Flow Rate in Double Pass V-Groove Absorber with and without Porous Media.

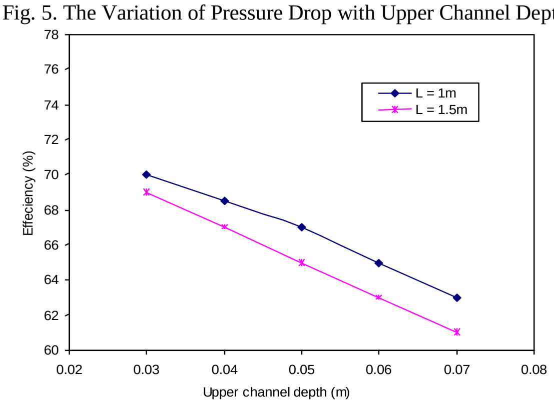


Double pass without using porous media

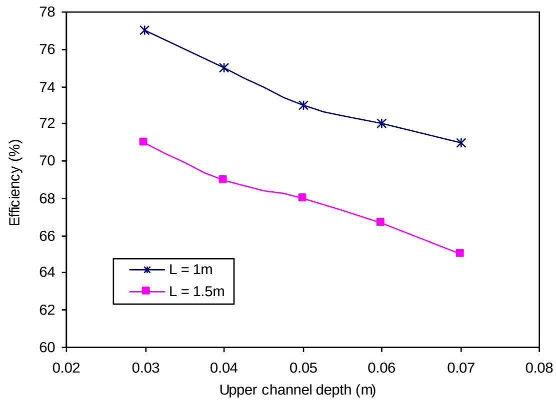


Double pass with using porous media

Fig. 5. The Variation of Pressure Drop with Upper Channel Depth

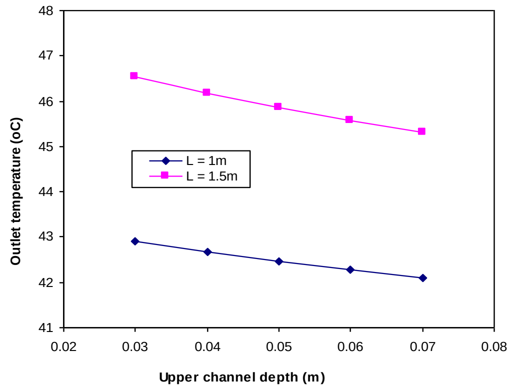


Double pass without using porous media

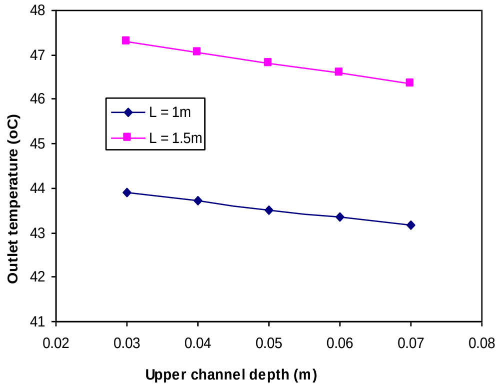


Double pass with using porous media

Fig. 6. The Variation of Efficiency with Upper Channel Depth



Double pass without using porous media



Double pass with using porous media
Fig. 7. The Variation of Outlet Temperature with Upper Channel Depth

A. *Fan Consumption*

Figure 8 shows that the power consumed by the fan is proportional to the air flow rate, but higher power electrical consumption by the fan is needed to overcome the friction losses engendered by the fluid flow through the V-groove. On other hand it is obvious that higher power consumption is due to the increase of the pressure drop which increases with the use of porous media.

B. *Economic Aspect*

By using the developed program the cost of solar energy (i.e. ratio of the annual cost of the collector (AC) / annual thermal energy gain (ATEG) for solar air heaters types were computed at different flow depths, lengths and mass flow rate. Figures 9 and 10 show the cost of solar energy as a function of upper flow depth (for constant lower flow depth) and lower flow depth (for fixed upper depth) with constant flow rate at 0.031 kg/s and 0.03 kg/s for V-groove absorber in double flow mode with and without porous media respectively. The cost of solar energy with respect to flow depth at constant flow length and different mass flow rate is shown in Figure 11. The cost of solar energy decreased by increasing the flow depth, this decrease in the cost continue until it reach the minimum value then it begin to increase by increasing the flow depth.

The graphs shown in figures reveal that the higher in cost energy for any particular combination of flow depth, collector length and mass flow rate is at short collector length and flow depth with high quantity of mass flow rate. Moreover, the values of duct lengths and depths for which the cost of solar energy is minimized are different for different values of mass flow rates. This is consistent with Choudhury et al., 1995.

The cost of solar energy as a function of collector lengths for different flow depth and mass flow rate for is shown in Figure 12.

The cost of solar energy as a function of collector lengths for fixed lower depth with different upper depth and for fixed upper depth with different lower depth for different air mass flow rates for the double pass V-groove absorber with and without porous media are presented in Figures 13-16.

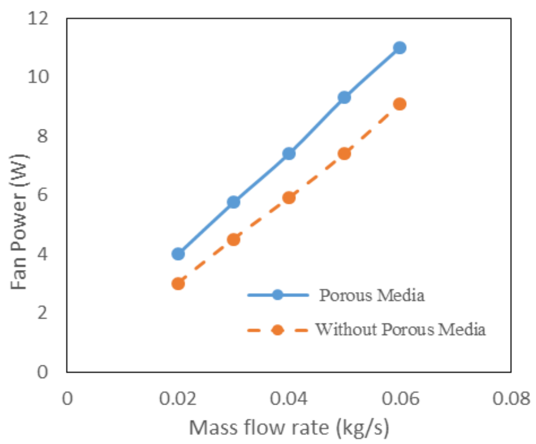
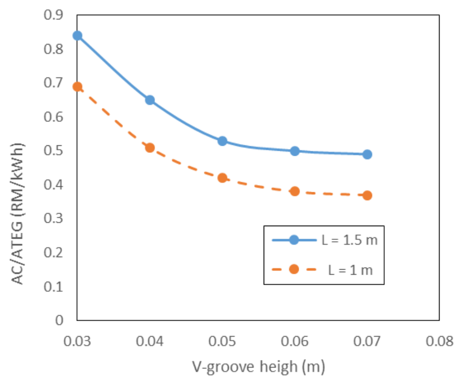
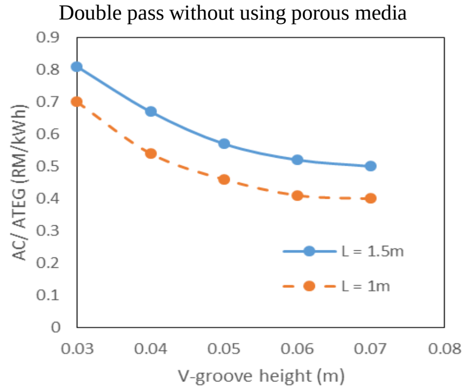


Fig. 8. Fan Power Consumption

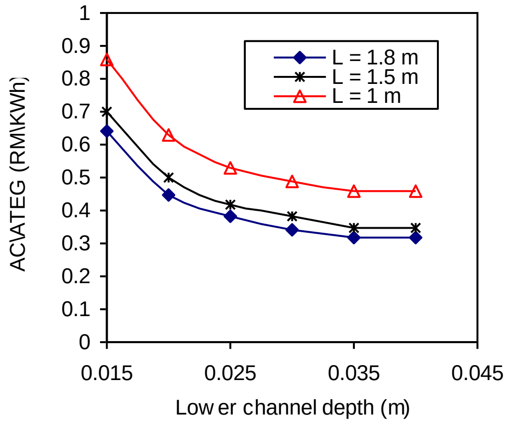


Double pass without using porous media

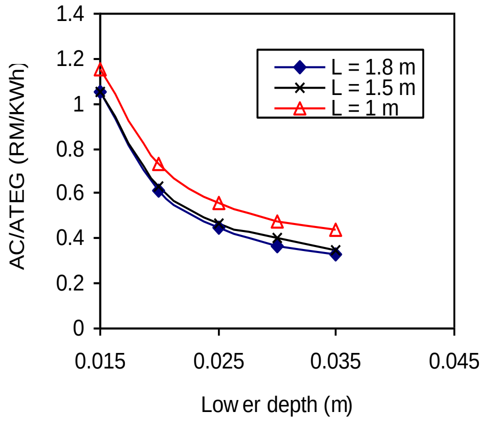


Double pass with using porous media

Fig. 9: The variation of AC/ATEG with respect to upper flow depth in double flow mode for V-groove absorber.

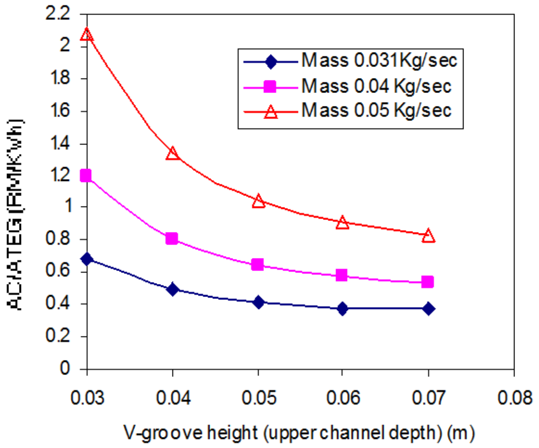


Double pass without using porous media

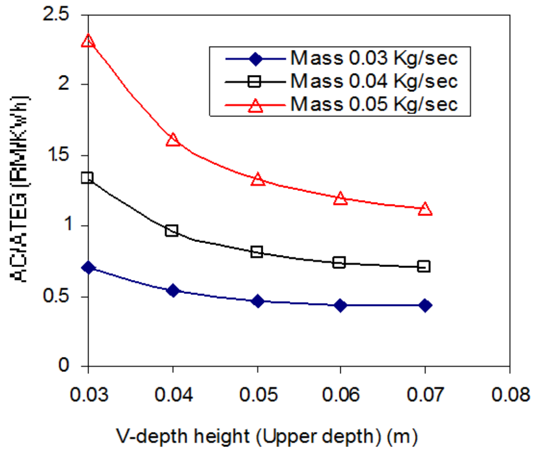


Double pass with using porous media

Fig. 10. The variation of AC/ATEG with respect to lower flow depth in double flow mode for V-groove absorber.

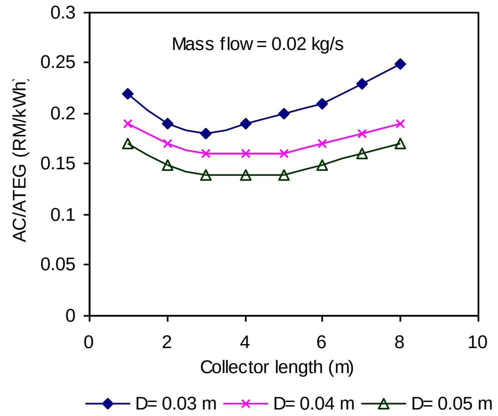


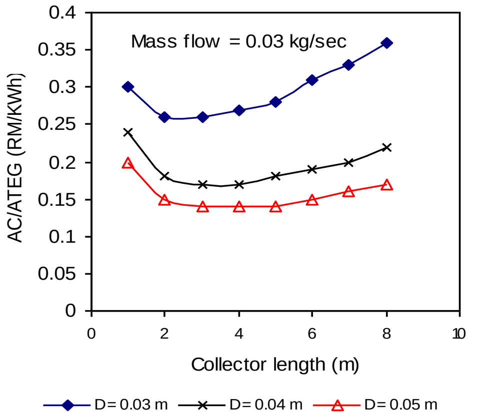
Double pass without using porous media



Double pass with using porous media

Fig. 11: The variation of AC/ATEG with respect to flow depth in double flow mode for V-groove absorber for different mass flow rate.





International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 12, December-2016

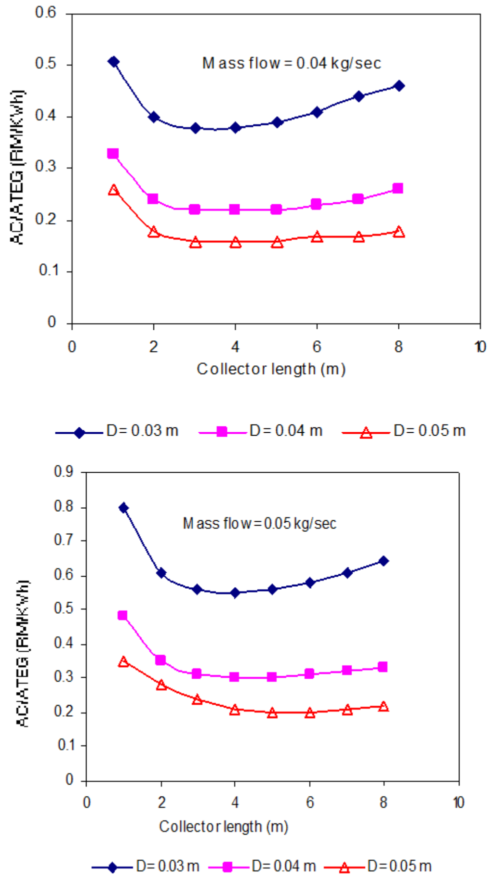


Fig. 12. The AC/ATEG as a function of collector length for different flow depth and mass flow rate in single pass V-groove absorber.

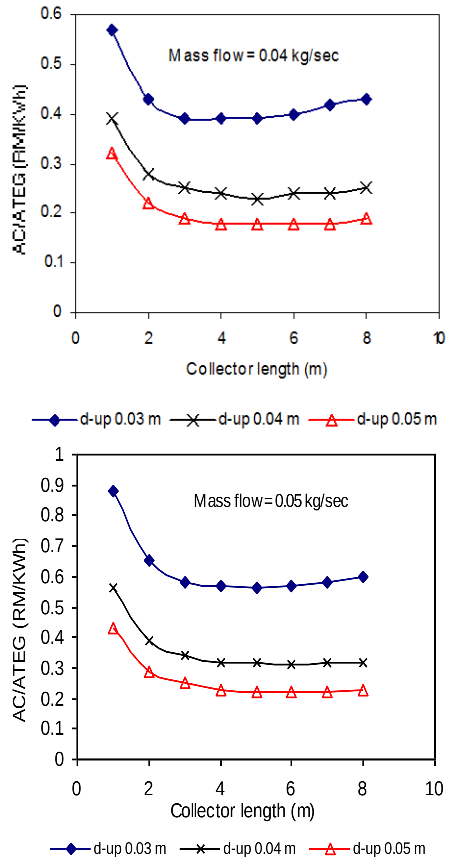
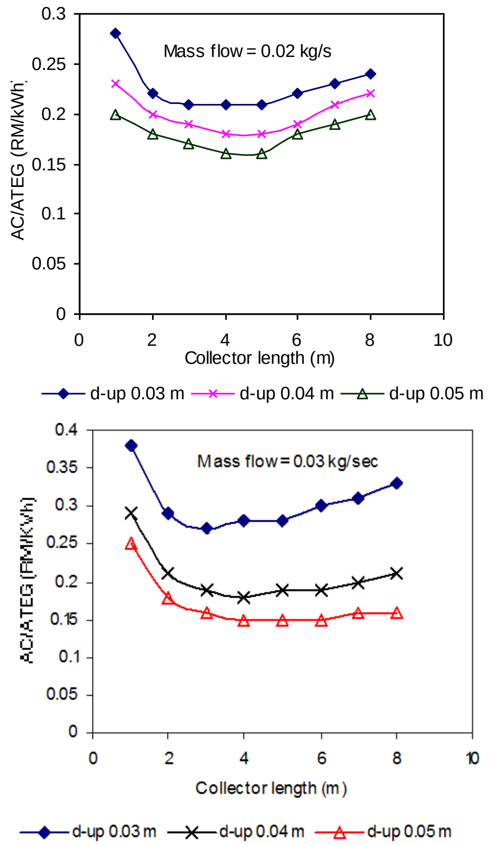
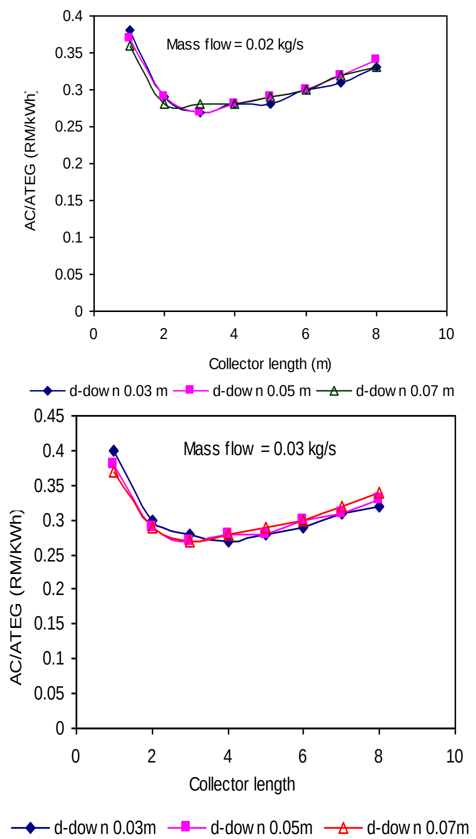


Fig. 13. The AC/ATEG as a function of collector length for different upper depth and mass flow with constant lower depth in double flow pass V-groove absorber.





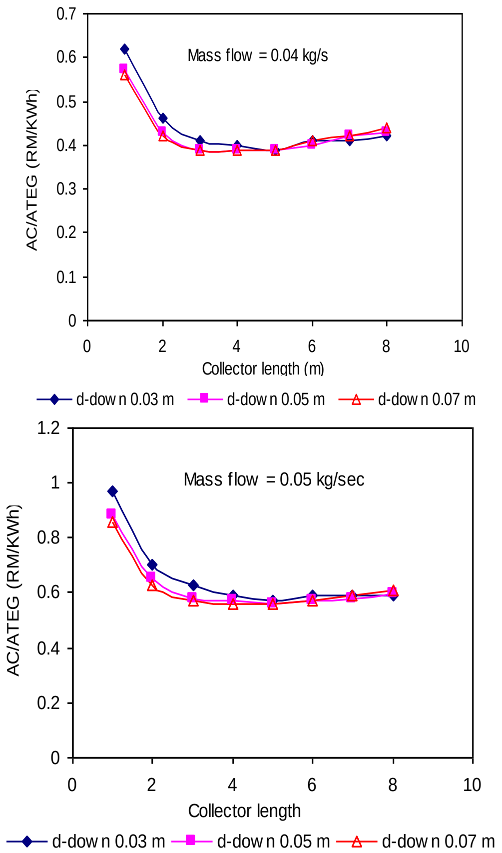
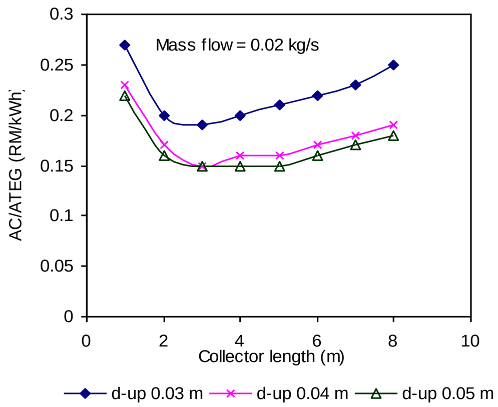


Fig. 14. The AC/ATEG as a function of collector length for different lower depth and mass flow with constant upper depth in double flow pass V-groove absorber.



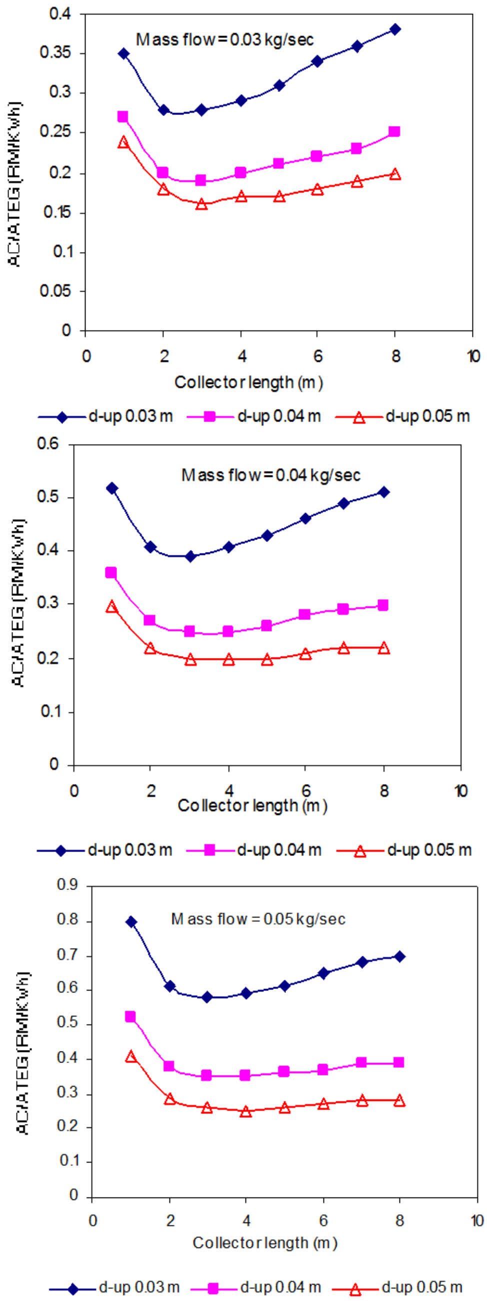


Fig. 15. The AC/ATEG as a function of collector length for different upper depth and mass flow with constant lower depth in double flow pass V-groove absorber with porous media.

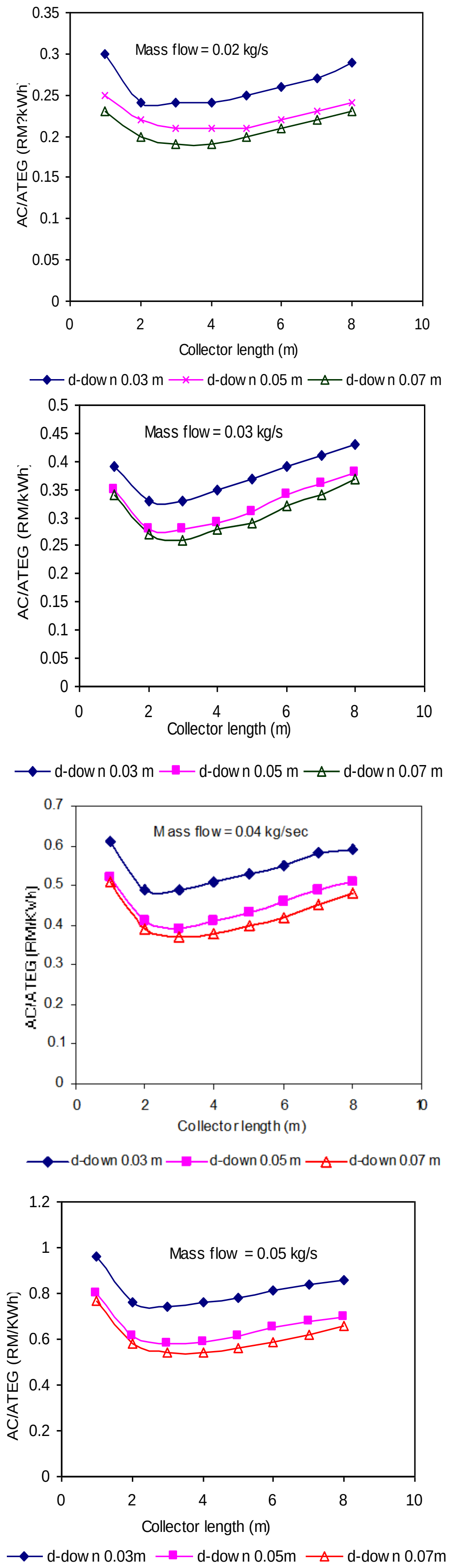


Fig. 16. The AC/ATEG as a function of collector length for different lower depth and mass flow with constant upper depth in double flow pass V-groove absorber with porous media.

All the graphs 12-16 show at first a fall in the cost then a rise with an increase in length, the effect being greater with an increase in mass flow and a decreased in flow depth (Choudhury et al., 1995). The collector length for which the cost is minimized is observed to decrease with a decrease in collector depth and an increase in mass flow rate.

The aforementioned discussed results on the effect of flow depth, length and mass flow rate on the cost of solar energy have the same trend of other studies conducted by Choudhury and Garg, (1991); Ratna *et al*., (1991); Ratna *et al.*, (1992); Choudhry *et al.*, (1995).

IV. CONCLUSION

From this study it is found that the parameters that affect thermal performance and the solar energy cost of the solar air heaters are mass flow rate, channel flow depth, collector length and the porous media. Their affective appears in the following:

Increasing the mass flow rate result in increasing the collector thermal efficiency, decreasing the outlet temperature, increasing the pressure drop, yet increase the cost of solar energy.

Decreasing the flow depth cause, increasing the collector thermal efficiency, increasing the outlet temperature and increasing the pressure drop which lead to an increase in the pumping expand in the collector thus increase the cost of solar energy.

Increasing the collector length result in decreasing the collector thermal efficiency, increasing the outlet temperature and increasing the pressure drop.

Using of porous media result in increasing the collector thermal efficiency, increasing the outlet temperature and increasing the pressure drop which lead to an increase in the pumping expand in the collector thus increase the cost of solar energy.

REFERENCES

[1] B. Bhushan, R. Singh. “A review on methodology of artificial roughness used in duct of solar air heaters”. Energy, 2010; 35:pp. 202-212.

[2] WX. Lin, WF. Gao, T. Liu. A parametric study on the thermal performance of cross-corrugated solar air collectors. Applied Thermal Engineering 2006; 26: pp. 1043-1053.

[3] T. Liu, WX. Lin, WF. Gao, X. Chaofeng. A comparative study of the thermal performances of cross corrugated and v-groove solar air collectors. International Journal of Green Energy 2007; 4: 427-451.

[4] MA. Karim, MNA. Hawlader, Performance evaluation of a v-groove solar air collector for drying applications. Applied Thermal Engineering, 2006, 26, pp. 121-130.

[5] B. A. A. Yousef, N. M. Adm, Performance Analysis for V-groove absorber. Suranaree Journal of Scientific and Technology. 2007, 14(1) pp. 39-52

[6] G. Tanda. Performance of solar air heater ducts with different types of ribs on the absorber plate. Energy, 2011, 36 pp. 6651-6660.

[7] JJ. Hu, XS, Sun, Xu. JL, Li ZX. Numerical analysis of mechanical ventilation solar air collector with internal baffles. Energy and Buildings 2013, 62, pp. 230-238.

[8] F. Chabane, N. Moummi, S. Benramache, D. Bensahal, O. Belahssen. Collector Efficiency by Single Pass of Solar Air Heaters with and without Using Fins. Journal of Engineering 2013, 17 (3), pp. 43-55.

[9] Y. Ho-Ming, H. Chii-Dong, L. Chi-Yen. Effect of Collector Aspect Ratio on The Collector Efficiency of Upward-Type Baffled Solar Air Heaters. Energy Conversion and Management. 2000, pp. 941- 971.

[10] H. Chii-Dong, Y. Ho-Ming, C. Tsung-Ching. Collector Efficiency of Upward-Type Double-Pass Solar Air Heaters with Fins Attached. International Communication of Heat and Mass Transfer. 2011, 38, pp. 49-56.

[11] E.M. Languri, H. Taherian, K. Hooman, J. Reise, Enhanced Double-Pass Solar Air Heater With and Without Porous Medium. International Journal of Green Energy, 2011, 8, pp. 643-654.

[12] P. Dhiman, S. Singh, Thermal performance of double pass packed bed solar air heaters–A comprehensive review. Renewable and Sustainable Energy Reviwers, 2016, 53, pp.1010-1031

[13] Qahtan A. Abed, Adrian Ciocanea, Iuliana Soriga, Dorin L. Buretea and Viorel Badescu. Dynamic thermal Performance Analysis of two Solar Air Collectors without Porous Media. Renewable Energy and Environmental Sustainably, 2016; 1, 24: 1-4

[14] Choudhury, C. Hauhan, C.P. M., and Garg, H.P. Performance and cost analysis of two –pass solar air heaters, *Heat Recovery System &CHP*, 15 (8) 1995 pp 755-773.