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Performance Analysis for the Double-Pass Solar Air Collector with and Without Porous Media

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ABSTRACT

a The double-pass solar collector with porous media in the lower channel provides a higher outlet temperature compared to the conventional double-pass collector without porous media. As a result, the thermal performance of the solar collector with porous media is higher. A literature survey was conducted to specify the design parameter and based on this survey a collector was designed and constructed where the porous media has been inserted to increase the total heat transfer rate and contact area. Moreover, the effects of mass flow rate and temperature rise on the thermal efficiency of the double-pass solar collector have been studied. In addition, pressure drop and heat transfer relationships have been developed for airflow through the porous media. The experiment concluded that the presence of porous media in the second channel increases the thermal performance of the overall system by 24%.

Keywords— **a Double-pass solar collector, Heat Transfer, Porous media, Pressure drop, Thermal performance**

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I. INTRODUCTION

Solar air heaters are cheap and most widely used solar collection devices because of their inherent simplicity. It has been found in literature. In searching of a suitable design for different applications, various designs of solar collectors have been the subject of many theoretical and experimental investigations [1–24]. There are many alternative designs to the conventional double- pass collector. These designs must be able to reduce the heat losses from the collector to increase the operating temperature and collector efficiencies of the system. Therefore, double-pass solar collector with porous media has been introduced. The double-flow types of solar air heater have been introduced for increasing the heat transfer area. This increases the thermal energy between the absorber plate and the air to improve the thermal performances of the solar collectors with obstacles arranged into the air channel duct. A simulation study of a double-pass solar collector with porous media has been analysed by Mohamad [4]. He presented an analysis for novel type solar air heater. The main idea is to minimize the heat losses from the top glass cover of the collector and maximize heat extraction from the absorber. This can be done by forcing the air flow over the front glass cover before passing through the absorber. Hence, they proposed the design in which extra cover is employed to form a counter flow heat exchanger. In order to make it more efficient, porous media is placed in the second passage. The porous absorber forms an extensive area for heat transfer, where the volumetric heat transfer coefficient is very high. Hence, use of porous absorber increases the rate of heat transfer from the absorber to the air stream. In the proposed design, which combines double air passage and porous media, care should be taken to minimize pressure drop. The pressure drop is not high if high porous medium is used. However, the thermal efficiency of the proposed design is found significantly high.

Sopian et al. [26] theoretically and experimentally evaluated the thermal efficiency of a double pass solar collector with porous and nonporous media. The testing facility consisted of a solar collector and a solar simulator. The simulator used 45 halogen lamps, each with a rated power of 300W. A maximum average radiation of 642 W/m2 could be reached with this simulator. The collector was of 2400 x 1200 mm in dimension. In the design of the collector, a single glass cover and a black painted aluminum plate were used. The solar collector was operated at varying inlet temperature and radiation conditions. The airflow rate was between 0.03 - 0.07kg/s, the upper channel depth was between 35-105 mm, and the lower channel depth was between 70-140 mm. The results of theoretical and experimental studies were compared based on the outlet temperatures and the thermal efficiencies of the solar collector. The study concluded that the presence of porous media in the second channel increased the outlet temperature. This also caused the thermal efficiency of the system to be increased.

Bashria .et al.[19]had presented the paper which describes the effect of mass flow rate, flow channel depth and collector length on the system thermal performance and pressure drop through the collector, on V-groove absorber at single and double flow. A mathematical simulation is predicted to estimate the effect of different parameters on system thermal performance and pressure drop for V-groove absorber in single and double flow mode with and without using a porous media. It is found that increasing the mass flow rate through the air heater results on higher efficiency but also it increases pressure drop. On the other hand decreasing the channel flow depth results in increasing the system efficiency and outlet temperature at the same time, it increases the pressure drop. The channel length also has effect on the thermal efficiency. Hence, the system efficiency is more increased for short channel length than long one, while the pressure drop is less than the pressure drop in long channel length .The double flow is more efficient than the single flow made and using of porous media increase the system efficiency and outlet temperature. This increment will result in the increase of the pressure drop thus increasing the pumping power expanded in the collector.

Mittal et al. [17] investigates the thermo hydraulic performance on a packed bed solar air heater having its duct packed with blackened wire screen matrices of different geometrical parameters(wire diameter and pitch). To obtain the effective efficiency a mathematical model has been developed on the basis of energy transfer mechanism in the bed. The following assumptions have been made during the development of the mathematical model.

- Edge and back losses have been neglected.
- Environmental temperature and wind velocity have been assumed to be Constant.

Yousef B A A. [16] had investigated the effect of mass flow rate, flow channel depth and collector length on the system thermal performance and pressure drop through the collector with and without porous medium. It was concluded that thermal efficiency increases by 10-12% in double flow mode than single flow due to the increased of heat removal, and increase by 8% after using porous medium in the lower channel as a result of the increase of heat transfer area. He discussed a mathematical simulation to predict the effect of different parameters on system thermal performance and pressure drop, for flat plate collector in single and double flow mode with and without using a porous media have been conducted. It is found that increasing the mass flow rate through the air heaters results in higher efficiency but also it is increased pressure drop. On the other hand decreasing the channel flow depth results in increasing the system efficiency and outlet temperature at the same time it increased the pressure drop. The channel length also has an effect on the thermal efficiency hence the system efficiency is increased more for short channel length than the long one, while the pressure drop is less than the pressure drop in long channel length.

Elradi et al. [10] had described the correlation of transient heat transfer and pressure drop which has been developed for air flowing the porous media the various porous media are arranged in different porosities to increase heat transfer, area density and the total heat transfer rate. In the double-pass solar collector, the mass flow rate has more effect on the temperature rise. The solar radiation has more effect on temperature rises at low porosity. In addition, the Reynolds number has more effect than the Nusselt number at low porosity. Heat transfer coefficient increases by using more porous media in the lower channel of the double-pass solar collector. Higher porosities in the porous media improved the thermal efficiency. Experimental analysis of the data suggests that due to higher mass flow rate, the thermal efficiency decreases. Pressure drop study indicated that lower pressure losses are encountered with low porosity than with high porosity of the saturated porous media.

Nimr et al. [6] had worked on the thermal performance of a conventional tubeless collector by inserting porous substrates at the inner side of the collector absorber plate. The improvement is investigated numerically and their effects on the efficiency ant the useful gain of the collector are evaluated. It is found that the porous substrates improve the convective heat transfer coefficient between the absorber plate and fluid and as a result,N_u number is improved up to 25 times. It is concluded that the efficiency of the solar collector increase by 3 to 32percent especially at high values of the overall loss coefficient. The investigation concluded that the inserting the porous substrates has the effect of increasing the pressure drop within the collector by 30 times and collector performance with moderate increase in its pumping cost.

Napphon.[2] had described the effect of the porous media on the performance of the double-pass flat-plate solar air heater. The mathematical models described the heat transfer characteristics of the double-pass flat plate solar air heater which are derived from the energy conservation equations. The implicit method of finite-difference scheme is employed to solve these models. The effect of the thermal conductivity of the porous media on the heat transfer characteristics and performance is considered. In this study, it is concluded that the solar air heater with the porous media gives 25.9% higher thermal efficiency than that without porous media. The thermal conductivity of porous media has significant effect on the thermal performance of the solar air heater.

In this paper, an experimental setup has been designed and constructed based on the survey to study the heat transfer characteristics and performance of the double-pass solar air heater with and without porous media.

II. EXPERIMENTAL SETUP

To carry out the experimental analysis, a double pass solar air collector was constructed which has been shown in fig. 2. with the size of length 1m, width 0.5m and the total depth 0.06m. The depth of pre-heater is 2.5cm and the lower channel depth is 3.5cm. The two channels are separated by transparent fibre glass of thickness 3mm. The wall of the collector is made from a compressed asbestos sheet with a profile of 10mm thickness insulated by thermo-col with the thickness of 4cm to prevent the heat loss from the wall. The absorber plate is made from aluminium with the thickness of 0.5mm and was painted black. The ordinary transparent glass with a thickness of 5 mm was used as a collector cover. First air was pre-heated in the channel 1 between glass cove and fibre glass and then pass to channel 2 over the absorber plate. To draw the ambient air into the collector through the entrance section a blower (0.5 hp) with a speed control system was modified as suction to the lower channel. To increase the contact surface area with hot air, porous media where inserted in the lower channel which is shown in fig. 1.

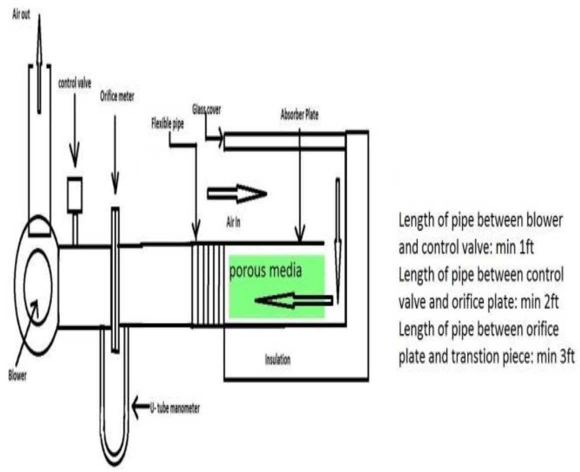

Fig. 1: Block diagram of experimental Set-up

Temperatures are measured at different points along the length of absorber plate and air at different locations is with the help of k -type thermocouple. A digital multi - meter is used to indicate the output of the thermocouples through the selector switch. The temperature was measured four times and it's average values was calculated in one hour. Moreover, a collector was positioned in the 20 degrees latitude in north-to-south direction facing towards sun. A taper duct has been provided at the outlet of the test collectors to stabilize the air flow. The exit section is connected to blower through a PVC pipe. Measurement of mass flow rate of air through collector has been accomplished by 24mm diameter orifice plate.

TABLE I: Component of experimental set-up

S.No	Name of component
01	Solar collector area 1m(length) x 0.5m(width)
02	Glass 1.02m x 0.52m x 5mm
03	Internal dimension of 1m x 0.5m x 0.06m
04	The orifice of 24mm diameter
05	PVC Pipe diameter of 74mm.
06	k-Type thermocouples were used(12 in nos.)
07	U- Tube manometer and Incline manometer

Fig. 2: Experimental Set-up

III.EXPERIMENTAL PROCEDURE

The test runs to collect relevant heat transfer were conducted under quasi-steady state conditions. The quasi-steady state condition was assumed have to been reached when the temperature at the point does not change for about 10 minutes. When a change in the operating conditions (mass flow rate) is made, it takes about 15 min to reach such a quasi-steady state. After each of flow rate, the system is allowed to attain a steady state before the data were recorded. The tests with the solar collector system were carried out for six days, from 21 to 26 May 2015 and 6 hours per day (from 10 a.m. to 4 p.m. local time). The experiments on the efficiency were conducted for a week during which the atmospheric conditions were almost uniform and data was collected from the efficiency calculation. Values of various input parameters and constants are given in table 3.1.

Collector without porous media was evaluated and it's average efficiency was recorded at different hours on 21^{st}, 23^{rd} and 25^{th} of May.

The experiment on efficiency for Collector with porous media (steel wool) was conducted on 22^{nd}, 24^{th} and 26^{th} of May.

TABLE II: Various input parameters and constants

S.No.	Input Parameters	Values
1.	Ambient Air Temperature, T_a(K)	288,303
2.	Ambient Air Pressure, P_a(bar)	1
3.	Specific gas constant for air(J/Kg K)	287
4.	Dynamic viscosity for air, μ(kg/ms)	$1.8X10^{-5}$
5.	Specific heat for air, c_p(J/kgK)	1006.4
6.	Thermal conductivity for air, k_f(W/mk)	0.2624
7.	Thermal conductivity of media, k(W/mK)	386.0
8.	Emissivity of glass covers, ε_c	0.92
9	Emissivity of absorber plate,ε_p	0.92
10	Transmissivity of glass cover and absorber,τ_c and τ_p	0.92
11	Absorptivity of glass cover,α_c	0.06
12	Absorptivity of absorber,α_p	0.92
13	Stephan-Boltzmann constant, σ (W/m^2K^4)	$5.67X10^{-6}$
14	Intensity of solar radiation,(W/m^2)	900-1100
15	Effective thermal conductivity,k_{eff}(W/mK)	0.3
16	Air mass flow rate, m(kg/s)	0.01-.03
17	Porous medium(steel wool) porosity	0.8

IV. EFFICIENCY OF CALCULATION

The efficiency of a solar collector is defined as the ratio of useful gain to the incident solar energy, that is:

$$\eta = \frac{\text{solar energy collect}}{\text{total solar striking collector surface}}$$

$$\eta = \frac{Q_{useful}}{I \times A_S}$$

Where Q is the accumulated energy extracted from the collector during the working period in W, A_s is collector area in m^2. I is solar radiation incident on collector.

Useful heat gain for air collector can be expressed as:

$$Q_{useful} = m\,C_p \Delta T$$

Where, Cp is the specific heat of the fluid.

V. RESULT & DISCUSSION

Results obtained from the experiment of solar air heater without porous media and with porous media are under considerations which are tabulated in Table 3 and 4.

The air was heated with respect to time however the maximum temperature achieved was 47ºC .The heat retentiveness of the collector was relatively poor as compare to collector having porous media .It was generally observed that the efficiency increased with the increase mass flow rate of air. The methods of conducting the experiment for both porous and non porous media were always same. The outlet temperature obtains for steel wool (max 47ºC). From Fig. 3 we can see that the steel wool is more efficient then the non porous media. Efficiency increase about 25% at mass flow rate of (0.01 to 0.035) kg/s when steel wool was used as porous media instead of without porous media. From fig. 5 the pressure drop for solar air heater with porous media is higher, but this factor has no significant for low flow rates. As the mass flow rate increases the temperature difference decreases in both type of collector.

TABLE III. Performance of solar collector without porous media

Time	T_i(°C)	T_o(°C)	ΔT	I	P(Pa)	m(kg/s)	η%
10-11am	21	34	13	900	1	0.01	29.06
11-12pm	22	35.1	13.1	930	1.5	0.018	51.0
12-01pm	22	34	12	980	2	0.024	59.12
01-02pm	22.5	34.7	12.2	1020	2.5	0.031	74.60
02-03pm	23	34.7	11.7	1060	2.5	0.033	73.28
3-4pm	22.2	31.2	9	1110	3	0.04	65.25

TABLE IV. Performance of solar collector with porous media

Time	T_i(°C)	T_o(°C)	ΔT	I	P(Pa)	m(kg/s)	η%
10-11am	21	47	26	900	1.5	0.01	58.12
11-12pm	22	42	20	930	2	0.018	77.88
12-01pm	22	39	17	980	2.8	0.024	83.76
01-02pm	22.5	36.5	14	1020	3.3	0.031	85.60
02-03pm	23	36.6	13.6	1060	3.9	0.033	85.18
03-04pm	22.2	32.7	10.5	1110	4.5	0.04	76.12

1)

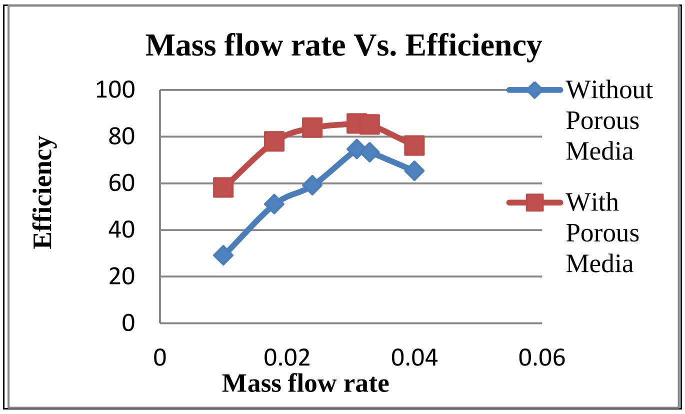

Fig. 3: Variation of efficiency with mass flow rate

2)

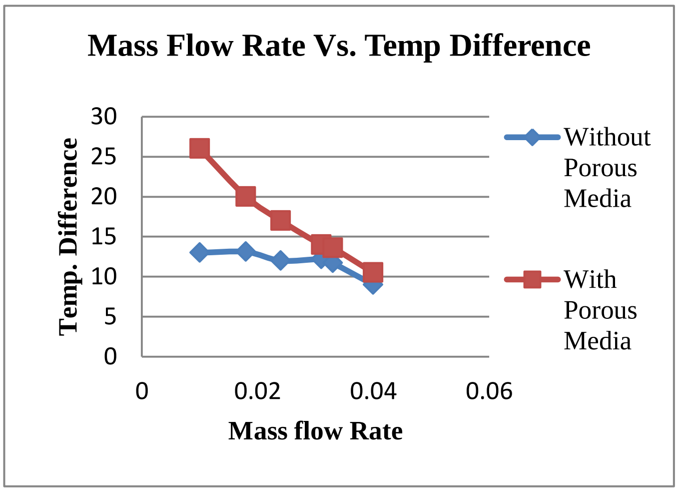

Fig. 4: Variation of temp. difference with mass flow rate

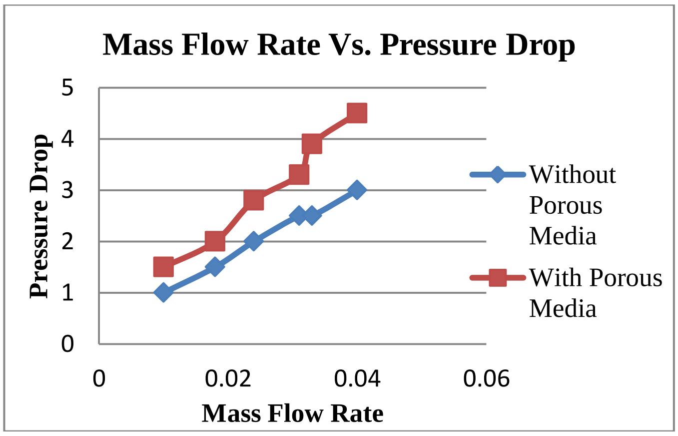

Fig. 5: Variation of pressure with mass flow rate

VI. CONCLUSION

The solar air heater with porous media gives 25% higher thermal efficiency than that without porous media.

The thermal conductivity of porous media has significant effect on the thermal performance of solar air heater.It was found that the thermal efficiency is maximum in between the air mass flow rate (0.03 to 0.035 kg/sec). The thermal efficiency of solar air heater with porous media is more than solar air heater without porous media of same construction cost.

The major drawback of solar air heater without porous media is the poor heat convection from the absorber to the stream. Whereas, the performances of solar air heater with porous media minimizes heat loss to the atmosphere and maximizes heat transfer to the airstream. The pressure drop (pumping power) for solar air heater with porous media is higher, but this factor has no significance for low flow rates

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