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DESIGN AND PERFORMANCE ANALYSIS OF A DOUBLE PASS SOLAR AIR HEATER USING BLACK COATED WIRE MESH IN BANGLADESH PERSPECTIVE

Md. Abdul Monem[1*], Md. Washim Akram[2], Md. Mofassel Hossain[3] and Md Redwan Islam[2]

[1] Department of Electrical and Electronics Engineering, Bangladesh Army University of Engineering and Technology, Bangladesh
[2] Department of Mechanical Engineering, Bangladesh Army University of Science and Technology, Bangladesh
[3] Department of Mechanical Engineering, Rajshahi University of Engineering and Technology, Bangladesh
amruet112115@gmail.com*, washimme11ruet@gmail.com, mofassel112100@gmail.com, redwanislam98@gmail.com

Abstract- *In this study, the design and performance analysis of the double pass solar air heater using black coated wire mesh as packed bed on the absorbing plate has been inspected experimentally. When the mass flow rate is lower than the temperature difference between inlet and outlet is high but the thermal efficiency is decreased compared to higher mass flow rate. The maximum efficiency of this experiment is 79.30% at the rate of mass flow 0.0323 kg/sec and minimum efficiency is 67.98% at the same mass flow rate. To improve thermal efficiency, high conductive porous materials have been used. On the other hand, higher insulating materials have been used to minimize the heat loss to the surroundings.*

Keywords: Solar energy, Double pass solar air heater, Packed bed, Thermal efficiency

1. INTRODUCTION

The consumption of energy is increasing continuously with the growth of population day by day thus the conventional energy sources decrease gradually which are limited. So, we have to found another energy sources which are renewable in nature. The renewable energy resources are solar, wind, tide, bio-mass, geothermal, biofuel etc. Solar energy is available among all of them. This vast quantity of renewable energy is twice than the conventional energy sources such as fossil fuel, crude oil, mined uranium and natural gas which are obtained by one year [1]. This huge amount of energy is quite cheap, clean, environment friendly, pollutants free, safe and available in nature. There are various ways to harness solar energy for heating purposes. Two types of solar technologies are indirect (passive) and direct (active) solar techniques. Without using any mechanical arrangement, passive solar techniques are performed for heating and cooling of living spaces. These types of technique contain simple mechanism and the lower installation cost. Active solar air techniques are the processes in which direct electrical energy is obtained. This electrical energy is used for different purposes such as to drive pumps, fans, lights etc. In these processes, the materials used which installation cost is higher. Solar air heating technology uses an absorbing medium. The efficiency of the solar air heater depends on the properties of the absorbing medium. This absorbing medium captures the sun’s energy. When air is passed through the absorbing medium it became heated and density is decreased. The applications of air heater are used to dry fruits, seeds, vegetables, room heating and for industrial purposes [2]. The advantages of solar air heater are simple design, easily maintenance, no fuel cost, low construction cost, environmentally friendly, zero greenhouse gas emission, less corrosion. Though this energy is available and massive in the amount it has some drawbacks. The main drawback of solar air heater is the poor heat transfer rate from the porous media to the air. Another disadvantage is the lower heat transfer coefficient of air than the solid conductor [3].

B. M. Ramani, Akhilesh Gupta, Ravi Kumar worked on the performance of double pass solar air collector and investigated that performance of double pass solar air collector is 25% higher than that of without porous absorbing materials and 35% higher than that of single pass collector [4]. L.B.Y Aldabbagh, F. Egelioglu, M. Ilkan worked on single and double pass solar air heater with wire mesh as packed bed and got maximum thermal efficiency 83.64% (double pass) and 45.93% (single pass) at mass flow rate 0.038 kg/sec [5]. Ebrahim M Ali Alfegi *et al.* worked on transient mathematical model of both side single pass and double pass photovoltaic thermal air collector [6]. They found efficiency of that combined photovoltaic thermal efficiency is increasing from 26.6% to 39.13% as the mass flow rate varies from 0.0316 to 0.09 kg/s [7]. Wijeysundera et al. represent experimental and analytical analysis on a double-pass solar air collector with two glass covers. They show that the collector thermal efficiency is increased from 10 to 15% [8]. Ehsan Mohseni Languri et al. presented that thermal efficiency for a double pass solar air heater (DPSAH) with porous material is 40% higher than the non-porous air heater [9]. Manish Parmar et al. presented that the combined rib-groove roughed geometry gives 10% more efficiency as compared to the smooth absorber plate used in the DPSAH [10]. Yeh HM et al. presented that for a double pass solar air heater, the thermal efficiency can be achieved very well when the cross sectional area of the upper and lower channels are constructed equally and the air mass flow rates is same [11]. Sopian K. et al. works on porous-nonporous media and evaluates thermal efficiency of double pass solar air collector. They obtained high thermal efficiency solar air collector [12]. Mohamad who referred the conventional double pass collector as a counter-current solar collector showed that the thermal efficiency can be improved by 18% compared to the conventional solar heater. The study also suggested an extra fan power of 2±3 W, which is not high [13]. Madhukeshwara. N et al. represent the performance of a solar air collector with different surface coating and they recommended that the black paint is the most absorptive and less reflective coating [14]. B. M. Ramani, Akhilesh Gupta, Ravi Kumar recommended that the double pass arrangement without porous media is more efficient than the single pass arrangement [15]. Also L.B.Y Aldabbagh, F. Egelioglu, M. Ilkan suggested that the double pass solar air heater with wire mesh as packed bed gives the maximum efficiency compared to nonporous media [16].

The thermal efficiency of air heater depends on the dimension of collector plate, the material of collector plate, solar radiation, tilting position, environmental condition, insulation etc. If the collector medium is highly conductive, the tilting position is at a right angle with the solar radiation and the insulation is proper then we can get the highest thermal efficiency of the solar air heater. From the best of the author's knowledge, it would have been found that there is no literature available which is related to the black coated wire mesh as packed bed in the double pass solar air heater. The aim of this study is to design a double pass solar air heater and to improve the efficiency of the air heater by using black coated wire mesh as packed bed on the absorbing plate.

2. DESIGN AND FABRICATION

2.1 Design of Solar Air Heater

The following equation was used to calculate the heat energy at the outlet of the air heater.

Heat of the outlet air, $Q = \dot{m}C_p\Delta T = \rho AVCp\Delta T$ (1)

Where, ρ is the density of air, C_p is the specific heat at constant pressure, ΔT is the temperature difference, A is inlet pipe area and V is the velocity of air.

2.2 Porosity

The porosity of the wire mesh can be calculated by using equation (2).

$$\text{Porosity}=\frac{A}{B} \quad (2)$$

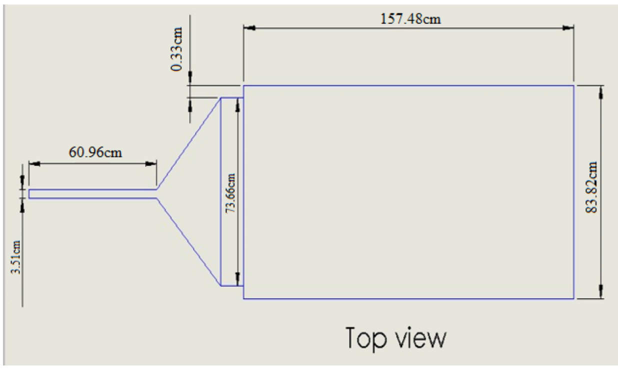
Where, A is the total opening space of the lower pass of the air heater and B is the volume of wooden box (lower pass) of the heater. A decrease in porosity increases the volumetric heat transfer coefficient. Top view and side view sketch drawing of double pass solar air heater are shown by Fig. 1.

2.3 Efficiency

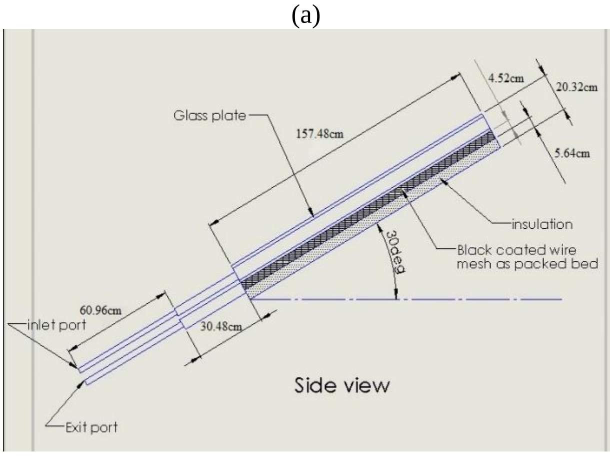
The solar collector efficiency can be calculated by using the following equation.

The efficiency of the collector, $\eta_c = \frac{\dot{m}c_p\Delta T}{IA_c}$ (3)

Where, ṁ is the mass flow rate (kg/sec), c_p is specific heat of air (kJ/kg °C), ΔT is temperature difference (°C), A_c is collector area (m^2) and I is the solar intensity (W/m^2).



(a)



(b)

Fig. 1: Sketch drawing of double pass solar air heater (a) top view; (b) side view.

3. EXPERIMENTAL METHODOLOGY

Firstly, a wooden box has been made which base was covered by wood of 1.343m². The box was sufficiently rigid to take the load of cover glass, collector sheet and other arrangements. Then a layer of glass wool has been given upon the wooden box as thick as half inch. A 1.27 cm (0.5 inch) thickness of foam is set upon the glass wool. For good insulating a 1.27cm (0.5 inch) cork sheet is adjusted upon the foam. Finally, a 6mm thickness of plywood is covered upon the cork sheet. After that 1mm black coated Galvanized Iron (GI) sheet used as absorbing pate was hardly adjusted upon the plywood through the wooden box. A packed bed wire mesh with black coated of 4.5 cm thickness was set upon the GI sheet which acts as a porous material. Then 2 pieces of 3.5 mm thickness of transparent glass plates are set as the distance between them was 21mm. Two passages has been connected by U turn made up of aluminum sheet and to avoid the heat losses to the surroundings. Sides of the solar collector are made up of 25 mm thick wood to reduce the heat losses to the surroundings. Two GI pipe of 3.5 cm diameter have been used as inlet and outlet portion. The photographic view of glass wool, foam, GI sheet and cork sheet have been shown by Fig. 2. A centrifugal blower has been used to draw the ambient air into the collector through the entrance section. Finally, the collector has been supported on a frame made up of M.S. iron angle. The complete experimental setup can be shown by Fig. 3.

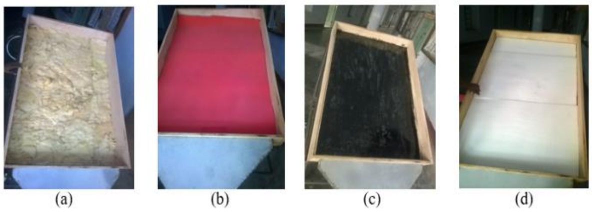


Fig. 2: (a) Photograph of glass wool 12.7 mm; (b) Photograph of foam 12.7 mm; (c) Photograph of black coated GI sheet 1 mm; (d) Photograph of cork sheet 12.7 mm.

Fig. 3: Photograph of experimental set up.

3.1 Working Principle

The working principle of double pass solar air heater is that, when sun light falls upon the upper glass plate, more amount of heat is transferred through glass plate to upper pass and makes the pass heated. At the same time, the trapped solar energy from the upper pass is transferred to the absorber plate at lower pass through middle glass plate. As a result, lower pass becomes more heated. When air is supplied to inlet port by blower, it expands in the upper pass and absorb heat. Then the partially heated air passes through the lower pass. While passing through the lower pass, maximum amount of heat is absorbed. Finally, the hot air is exhausted through exit port.

3.2 Temperature Measurement

The inlet and outlet temperature of air has been measured by a pyrometer which has high sensitivity. The temperature of different points such as 1st layer middle temperature, 2nd layer middle temperature, combination temperature of the two layers have been measured by the thermometer whose temperature range was zero to hundred and ten degrees centigrade.

3.3 Measurement of Mass Flow Rate

To measure the mass flow rate, the anemometer propeller was placed at the outlet of the blower. The velocity recorded by the anemometer was used in the following formula $m = \rho Av$ (where, ρ =density of air, A=cross sectional area, v=velocity of air). Here the density of air at the ambient condition and the cross sectional area of the inlet port were known. By this way we measured the mass flow rate. For a fixed mass flow rate, the velocity was different for the variation of temperature.

3.4 Data Collection

The data was recorded for different mass flow rate at a time interval of 30 minutes. For the fixed tilt angle the heater was not at normal position with the sun all time. The intensity of the sun in a day which was irregular in nature due to cloudy sky.

4. RESULTS AND DISCUSSION

The solar air heater with wire mesh as packed bed was investigated experimentally from dated 15-04-2016 to 25-05-2016 under weather condition of Rajshahi. The readings were taken at the bright sunshine day. The performance of a solar air heater was tested. The mass flow rate was varied from 0.0115 kg/s to 0.038 kg/s, where the intermediate mass flow rates were 0.021kg/s, 0.028kg/s and 0.0323 kg/s. The various performance curves of the solar air heater are given below:

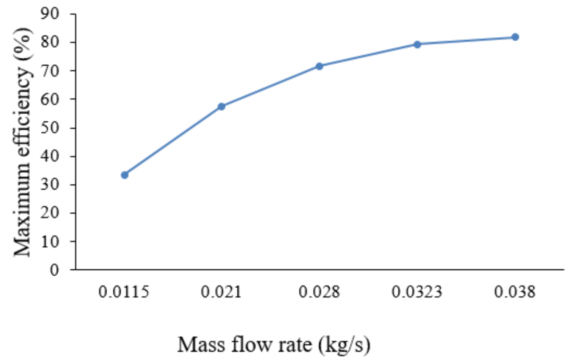


Fig. 4: Maximum collector efficiency Vs. Mass flow rate of air.

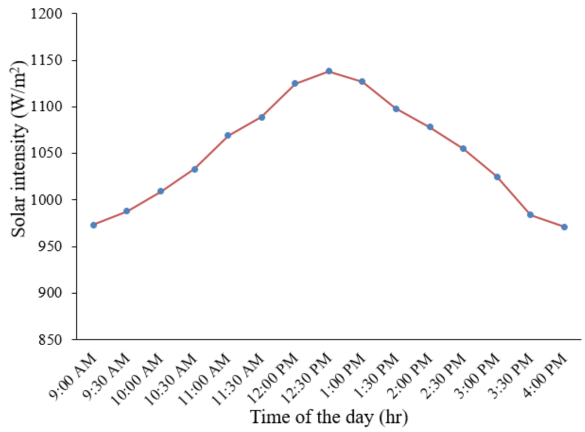


Fig. 5: Solar intensity Vs. Time of the day curve.

Figure 4 reveals that collector efficiency increases with increasing mass flow rate and it continues up to mass flow rate 0.050 kg/sec. Maximum thermal efficiency is 81.88% for mass flow rate 0.038kg/sec at time 12:30 PM. Figure 5 describes that solar intensity increases gradually from the morning and maximum intensity is 1138 W/m^2 at 12:30 PM. The value of intensity decreases after 12:30 PM. There are some points in this graph which are irregular in nature due to cloudy weather.

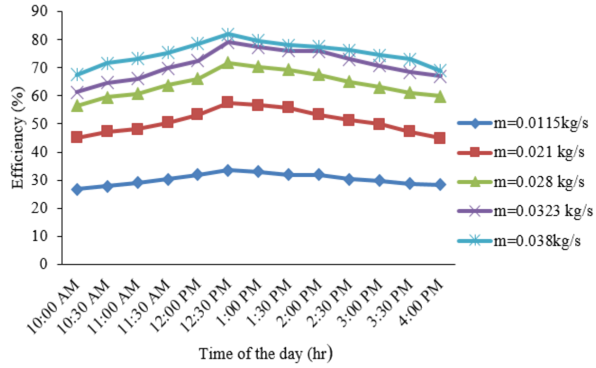


Fig. 6: Collector efficiency Vs. Time of the day curves.

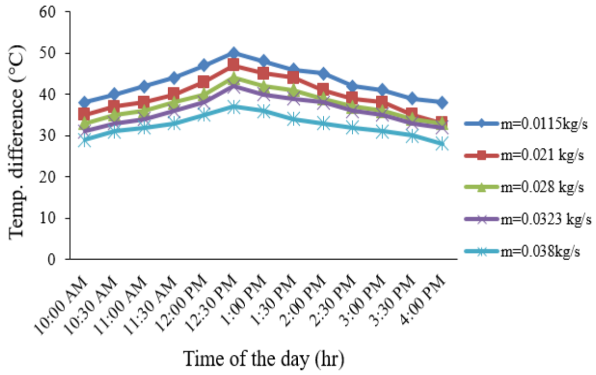


Fig. 7: Temperature difference Vs. Time of the day curves.

From Fig. 6, it is observed that efficiency is higher for higher mass flow rate and lower for lower mass flow rate for different time of the day. Figure 7 indicates that the temperature differences for lower mass flow rate are higher and lower for higher mass flow rate. This is due to fact that for lower mass flow rate, air gets more time to absorb heat and more time to withstand inside the heater.

Different efficiency Vs. time curves and temperature Vs. time curves are given for intermediate mass flow rate 0.021kg/sec, 0.028kg/sec, and 0.0323kg/sec. The data collection date of Fig. 8 and 9 was 28 April 2016.

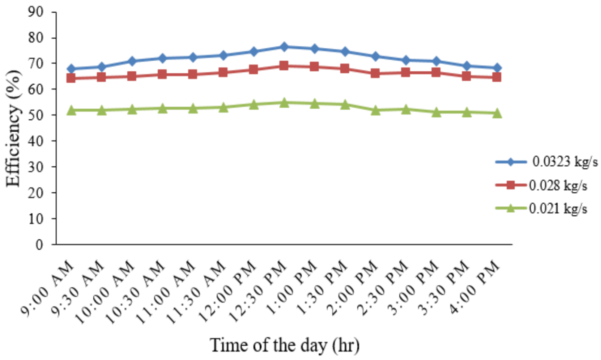


Fig. 8: Collector efficiency Vs. Time of the day curves.

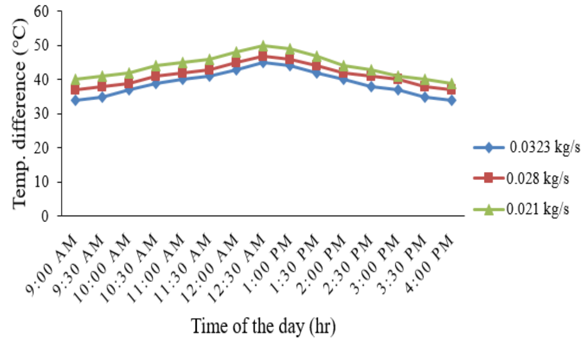


Fig. 9: Temperature difference Vs. Time of the day curves.

These two Fig. 8 and 9 show that maximum efficiency is 76.40% at 12:30 PM for mass flow rate 0.0323 kg/sec and minimum efficiency is 51.01% at 4:00 PM for mass flow rate 0.021kg/sec. Maximum and minimum temperature differences are 50^{0}C and 34^{0}C at times 12:30 PM and 4:00 PM for mass flow rates 0.021kg/sec and 0.0323kg/sec respectively.

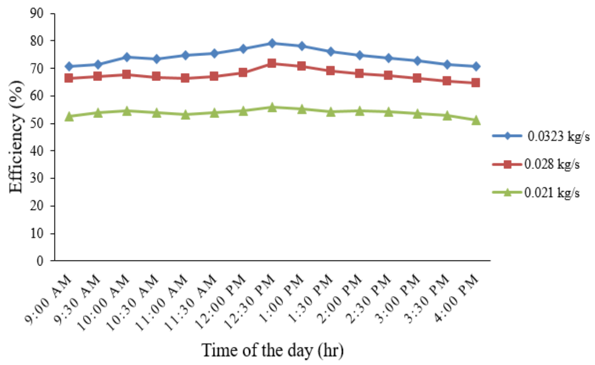


Fig. 10: Collector efficiency Vs. Time of the day curves.

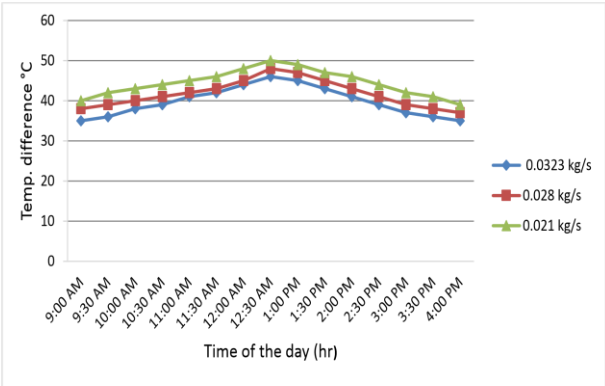


Fig. 11: Temperature difference Vs. Time of the day curves.

The data of Fig. 10 and 11 were collected at 30 April 2016. Graph 10 shows that efficiency is increasing from 9:00 AM to 10:00AM and suddenly decreasing at 10:30 AM. This is due to weather condition such as solar intensity does not radiate at increasing rate, cloudy sky. But temperature is increasing at slow rate which is shown by Fig. 11.

5. CONCLUDING REMARKS

The following conclusions are observed:

1. The thermal efficiency of Double Pass solar air heater using black coated wire mesh as packed bed 22 % higher than without using wire mesh as packed bed and 35% higher than single pass solar air heater also.
2. The maximum thermal efficiency of packed bed and without packed bed Double Pass solar air heater is 79.30% and 57.87% for same mass flow rate 0.0323 kg/sec respectively. The variation of efficiency is due to use of blacked coated wire mesh which acts as an absorbing media. Another causes for high thermal efficiency are air gets more time to heat, flow gets continuously turbulence and so on.
3. The thermal efficiency increases gradually if the mass flow rate increases up to 0.05kg/sec. When the mass flow rate exceeds this value then the product of mass flow rate and temperature difference decreases which gives lower thermal efficiency.
4. Porosity measured in this experiment is 0.83. A decrease in porosity increases the volumetric heat transfer coefficient.
5. Though it was insulated properly, some heat was lost due to some reasons such as radiation, convection, conduction, inlet and exit ports etc.

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