

Computational Investigation on Performance Analysis of Solar Air Heater

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Abstract

In this paper, the thermal efficiency of a solar air collector called unglazed transpired collector (UTC) has been studied using CFD. Experimental results were validated. The study was done to calculate efficiency of solar air heater under hot climatic conditions with two different mass flow rates of air. A commercial finite volume software (CFX) was used to model the heat transfer through the UTC. It was found that temperature rise decreases with increasing air mass flow rate and the efficiency increases with increasing air mass flow rate. Increasing the irradiation level seems to have a very limited effect on the collector efficiency for both mass flow rates. Still, the results show a small increase in efficiency as the irradiation intensity decreases for both mass flow rates.

Keywords: CFD, unglazed transpired solar air collector, thermal performance

1. Introduction

Energy consumption is on increase and the fossil fuels cannot last forever. Extensive fossil fuel consumption by human beings has led to some undesirable phenomena such as atmospheric and environmental pollutions. Consequently, global warming, greenhouse effect, climate change, ozone layer depletion and acid rain terminologies started to appear in the literature frequently. So, it has become the need of an hour to use the energy resource which is clean and eco friendly. Solar energy is one of the better options for clean energy. Solar air heating is a heating technology used to heat or condition air for buildings or process heat applications. It is typically the most cost-effective out of all the solar technologies, especially in commercial and industrial applications, and it addresses the largest usage of building energy in heating climates, which is space heating and industrial process heating.

Solar air collectors can be commonly divided into two categories:

- Unglazed Air Collectors or Transpired Solar Collector
- Glazed Solar Collectors

In this study we are going to focus on Unglazed Transpired Collectors. Unglazed transpired collectors (UTC's) are now a well-recognized solar air heater for heating outside air directly. They are key components in many engineering applications, such as in institutional and residential heating, industrial processes like sewage wastewater treatment, and food processing, crop drying. They differ from conventional solar air collectors in that their external wall is replaced by a black perforated sheet, that is unglazed, that allows the collection of solar irradiation.

After studying number of papers related with solar air heater it was observed that very less work has been carried out to study the performance of the device under hot climatic conditions like India. In this work the performance will be studied with CFD software in hot climatic conditions. Also the effect of different parameters such as air flow rate, ambient temperature, solar radiation intensity on the performance of the solar air heater system will be studied.

2. Principle of working

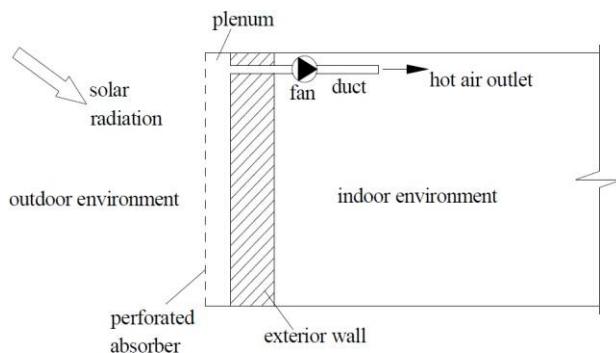


Figure.1 Basic principle of working of solar air heater

The basic principle of working of an Unglazed Transpired Solar Collector is as shown in figure 1. The unglazed transpired collector (UTC) has a dark

perforated surface through which air is drawn. Unlike typical solar air heaters, the UTC does not have a layer of glazing covering its front, and, unlike matrix collectors, it uses a single thin perforated sheet instead of a thick matrix for the solar absorber. The collector is typically mounted on the south side of the exterior of a building. Figure 1 shows irradiation heating the absorber surface through which air is heated as it is swept across the surface to the holes. The warmed air then moves up the plenum and is delivered to the building interior by a fan. A fan is necessary to overcome the pressure drop across the collector to drive the air through the absorber. The absorber surface is most commonly a thin perforated aluminum sheet, although other materials have been used such as fabric. The porosity of the collector surface is typically 0.5 to 2%. The space behind the absorber is called plenum. Figure 1 shows a cross-section of an unglazed transpired collector and building. The depth of the plenum varies from one collector design to another. Typical depths are between 5 and 30 cm. The back wall of the plenum is commonly the building's exterior surface.

After sunrise, as the radiant intensity increases, the temperature of the absorber increases, then the air in the plenum is heated by the absorber, when the air temperature reaches the set point, the temperature controller starts the blowing fan and forms negative pressure in the plenum, so outside air is sucked into the plenum and heated during the passage of air through the plenum, then hot air is delivered by air pipes to the place where heat is needed.

The efficiency of solar air heater can be calculated by using the equation 1

$$\eta = (m \cdot C_p \cdot \Delta T) / (I \cdot A) \quad (1)$$

η =Efficiency

m=mass flow rate of air (Kg/s)

Cp=Specific heat of air at constant pressure (KJ/Kgk)

ΔT =Difference between inlet and outlet temperatures of solar air heater ($^{\circ}$ C)
 I=Solar radiation intensity (W/m^2)
 A=Area of collector plate (m^2)

3. Solar air heater model specifications

The solar air heater mainly consists of UTC (Unglazed Transpired Collector) plate, plenum space and a suction duct at the back of the collector plate. We selected the different parameters of device as specified in paper Experimental study of solar air heating system based on unglazed transpired collector ,Proceedings of the ASME 2011 5th International Conference on Energy Sustainability ES2011 August 7-10, 2011, Washington, DC, USA by Lixin Gao ,Hua Bai, Xiumu Fang. The unglazed transpired collector is constructed from metal plate, which is perforated and covered with selective coating. The collector is mounted out 150 mm from the south exterior wall of a building to form an air cavity (also termed plenum).

The structure of UTC-based solar air heating system is shown in figure 2 and the system consists of two sub-systems, that is, solar energy collecting sub-system and heated air delivering sub-system. The solar energy collecting sub-system with an area of 2.5 m^2 was used for experiments. We also used the device with same dimensions for validation of the experimental results and CFD results.

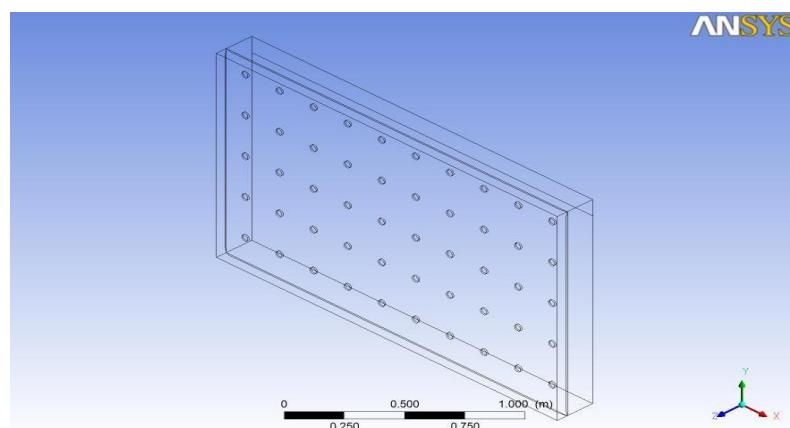


Figure .2 Actual model of solar air heater

4. Governing Equations

The governing equations of fluid flow represent mathematical statements of conservation laws of physics. These are the equations which must be solved subject to the boundary conditions of respective problems to get the solution of that problem.

Continuity equation

$$\frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0$$

Momentum equations

$$\begin{aligned}\frac{\partial}{\partial x}(\rho uu) + \frac{\partial}{\partial y}(\rho uv) + \frac{\partial}{\partial z}(\rho uw) &= -\frac{\partial p}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) \\ \frac{\partial}{\partial x}(\rho uv) + \frac{\partial}{\partial y}(\rho vv) + \frac{\partial}{\partial z}(\rho vw) &= -\frac{\partial p}{\partial y} + \mu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right) \\ \frac{\partial}{\partial x}(\rho uw) + \frac{\partial}{\partial y}(\rho vw) + \frac{\partial}{\partial z}(\rho ww) &= -\frac{\partial p}{\partial z} + \mu \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right)\end{aligned}$$

Energy equation

$$\frac{\partial}{\partial x}(\rho C_p u T) + \frac{\partial}{\partial y}(\rho C_p v T) + \frac{\partial}{\partial z}(\rho C_p w T) = k \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right)$$

5. Modeling and meshing

Modeling includes the generation of the geometry as per specifications as specified below

- Collector Area – 2.5 m²
- Plenum Length – 150 mm
- Collector Plate Dimensions- 2.00x1.25 m
- Perforation Diameter- 18 mm
- Number of perforations -50
- Perforations area- 2%

The AutoCAD 2008 was used for creation of the model of solar air heater. Ansys ICEM CFD (version 13.0) was used for the meshing. Ansys CFX was used as a solver.

5.1 Plate geometry

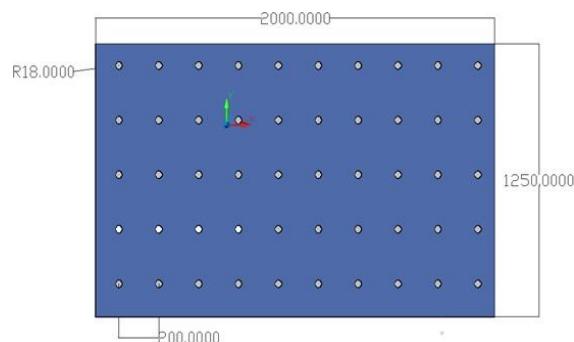


Figure.3 Collector plate geometry

The collector plate construction is as shown in figure 3. The area of the plate is 2.5m².The length of plate is 2m and breadth is 1.25m.The thickness of the plate is taken as 5mm.The perforations on the plate are 2% that is the 2% area out of total area is perforated.

Basically the hole diameter is between the range of 1.5-2.5mm.But we have selected diameter as 18mm because if we had selected the diameter as 2-2.5mm the total numbers of holes required becomes almost equal to 2500.It becomes quite difficult to create a model with so much number of holes. And for such models mesh size should be very much small which leads to such a high number of elements which requires high capacity computers. To overcome this problem we have selected the large hole diameter keeping the total percentage of perforated area constant that is equal to 2% of the total area.

5. Boundary conditions

The collector plate The boundary conditions mainly include solar radiation intensity, ambient temperature, mass flow rate of air at inlet and at outlet .As there is suction created by the suction fan at outlet the mass flow rate of air at outlet is more than that at inlet. For validation purpose the boundary conditions were taken from the reference paper [5]. After completing validation, the new boundary conditions were applied that is the boundary conditions for hot climatic conditions. The values for solar radiations were taken from the NREL (National Renewable Energy Laboratories) readings for different months.

6. Results

After A series of numerical simulations were performed to investigate the thermal performance of the UTC, under k-RNG model. The numerical results are presented below in terms of the collector efficiency. Two values mass flow rates of air were selected after studying number of papers. The two values are 0.04kg/s & 0.05 kg/s. The different surface temperatures obtained and respective outlet temperatures are presented in table 1 and 2. From the outlet temperature the efficiency of the solar air heater is calculated for respective values of solar irradiation and average ambient temperature in that month.

Table no 1 Results obtained with mass flow rate of 0.05 kg/s.

Month	Solar Irradiation(W/m ²)	Ambient Temp.(°C)	Mass Flow Rate(Kg/Sec)	Surface Temp.(°C)	Outlet Temp.(°C)	Efficiency %
Jan	527	20	0.04	53.25	49.86	73
Feb	610	22	0.04	55.64	51	71.65
Mar	658	27	0.04	61.84	57	69.65
Apr	690	32	0.04	68.27	63.5	69.76
May	697	35	0.04	70.33	66.8	69.68
Jun	573	30	0.04	61.68	56.18	69.84
Jul	519	25	0.04	53.54	48.73	69.81
Aug	512	25	0.04	52.74	48.4	69.95
Sep	551	22	0.04	51.04	47.18	70.58
Oct	546	30	0.04	58.37	54.95	71.25
Nov	531	22	0.04	52.87	48.54	72.4
Dec	511	20	0.04	48.44	43.36	68.56

Table no 2 Results obtained with mass flow rate of 0.05 kg/s.

Month	Solar Irradiation(W/m ²)	Ambient Temp.(°C)	Mass Flow Rate(Kg/Sec)	Surface Temp.(°C)	Outlet Temp.(°C)	Efficiency
Jan	527	20	0.05	42.78	39.02	74.02
Feb	610	22	0.05	48.29	43.98	72.42
Mar	658	27	0.05	56.46	50.73	72.48
Apr	690	32	0.05	61.24	56.86	72.41
May	697	35	0.05	65.83	60.11	72.41
Jun	573	30	0.05	56.75	50.67	72.5
Jul	519	25	0.05	47.95	43.73	72.53
Aug	512	25	0.05	47.68	43.48	72.54
Sep	551	22	0.05	46.4	41.88	72.52
Oct	546	30	0.05	54.18	49.7	72.52
Nov	531	22	0.05	45.52	41.16	72.52
Dec	511	20	0.05	42.64	38.45	72.57

Figures 5,6,7 show the variation of the different result parameters with respect to time .It has two curves one represents the results for the mass flow rate of 0.04

kg/s and the other for 0.05 kg/s. From graph it is clearly visible that the temperature values for simulations with 0.04 kg/s are higher as compared to

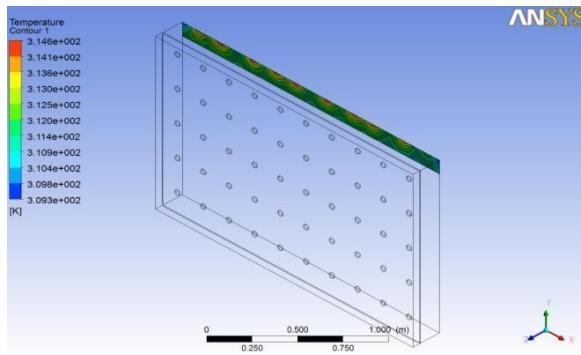


Figure.4 Temperature profile obtained in one of the simulation

that of 0.05 kg/s. The reason for that is exposure time. Air is in contact with collector surface for more time for lower flow rate. Figure 4 shows the temperature profile obtained in one of the simulation

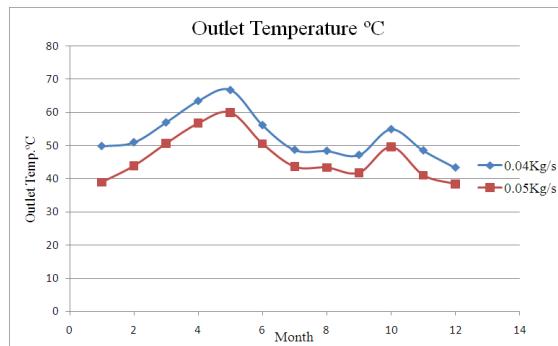


Figure.5 Variation of outlet temperature for different mass flow rates

Figure 5 shows the variation of outlet temperature for different months. It shows two curves. One curve shows the variation of outlet temperature for air mass flow rate of 0.04 kg/s and other for 0.05 kg/s

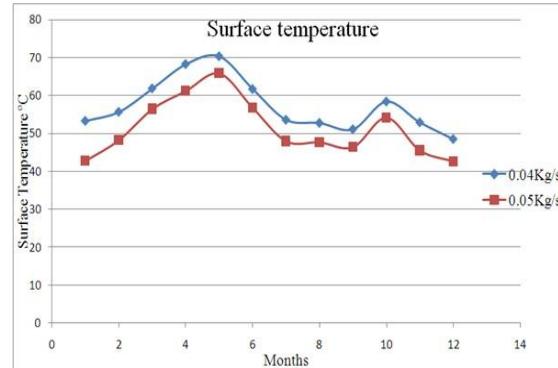


Figure.6 Variation of collector surface temperature for different mass flow rates

Figure 6 shows the variation of collector surface temperature for different months. It shows two curves. One curve shows the variation of collector surface

temperature for air mass flow rate of 0.04 kg/s and other for 0.05 kg/s.



Figure.7 Variation of efficiency of solar air heater for different mass flow rates

Figure 7 shows the variation of efficiency of solar air heater for different months. It shows two curves. One curve shows the variation for air mass flow rate of 0.04 kg/s and other shows variation for 0.05 kg/s.

7. Conclusion

The performance of solar air heating system based on unglazed transpired collector has been discussed. The efficiency of an UTC has been investigated numerically. After studying the results obtained the conclusions can be stated as:

- Results show that temperature rise decreases with increasing air flow rate, while collector efficiency increases with increasing air flow rate.
- The efficiency increases with increasing air mass flow rate. This is because the heat transfer capacity depends directly on the mass flow rate, which induces higher velocities through the perforations and more heat transfer from the plate to the air.
- Increasing the irradiation level seems to have a very limited effect on the collector efficiency for both mass flow rates. Still, the results show a small increase in efficiency as the irradiation intensity decreases for both mass flow rates. Nevertheless, this small effect may be due to the reduction of the absorber plate temperature, resulting in lower losses from the collector at low irradiation.

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