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Study the solar air heater for drying purposes

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Abstract
The main objective in this paper is to analyze the heat exchange process inside the solar air heater and evaluate the energy efficiency. The analysis performed by using computational fluid dynamics (CFD) software. The result are also evaluated based on thermo graphic camera images.

Keywords: Computational fluid dynamics (CFD), solar air heater, technique, renewable energy

Introduction drying

A solar air heater absorbs incident solar radiations and transforms them into useful heat for heating the collector fluid such as water and air, the work presented in this paper aims to analyze the heat exchange process inside the solar air heater and evaluate the energy efficiency. The results of the analysis performed by using computational fluid dynamics (CFD) software. The main disadvantage of solar air heaters is possessing lower thermal efficiency in consequence of inherently low heat transfer capability between the absorber plate and air flowing in the duct (Kumar and Saini, 2009) [1].

On the other hand, the most important advantages for air-type solar heaters include: no freezing, boiling or pressure problems; generally lower weight and low construction cost. Computational fluid dynamics (CFD) is used as powerful simulation technique to observe the collector efficiency with less time and cost consuming in recent years. Many experimental studies have been carried out to evaluate performance of solar air heaters but very few attempts of CFD investigation have been made so far due to complexity of flow pattern and computational limitations (Yadav and Bhagoria, 2013; Wang *et al*., 2006) [3, 4]. With the development of computer, hardware and numerical methodology, applications of CFD are being used to carry out critical investigations in the field of solar air heaters.

Analysis

The solar energy collection as a renewable energy resource has been the primary interest of many engineers and researchers for the last two centuries due to its widespread applications. The schematic diagram of the solar air heater was shown in Figure 1.

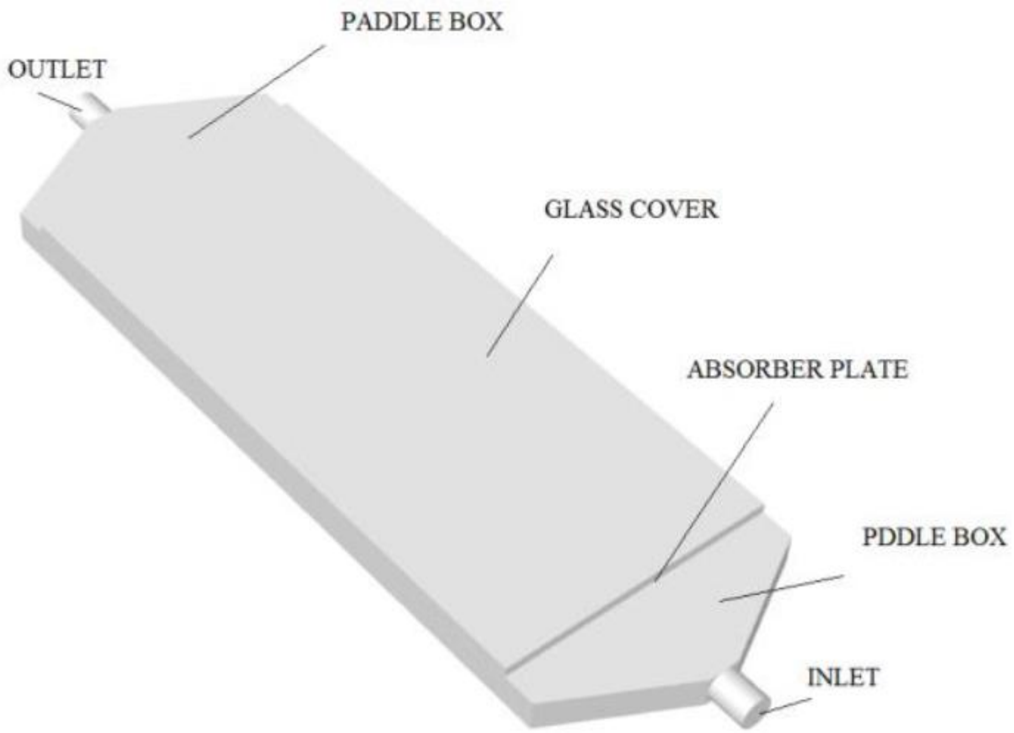

Fig 1: The solar air heater

In addition, the design parameters of the heater are summarized in Table 1.

Table 1: Main properties solar air heater

Parameters	Value
Absorber material	Aluminum
Plate thickness	2 mm
Absorber coating	Dull black paint
Glazing	Single glass (thickness 4 mm)
Working fluid in flow ducts	Air
Width of the duct, W	0.82 m
Collector side wall height, h_e	0.1 m
Air flow duct height, D	43 mm
Length of the collector, L	1.9 m
Emissivity of the glass cover, ε_g	0.85
Emissivity of the absorber plate, ε_p	0.95
Emissivity of the bottom plate, ε_b	0.95
Tilt angle, β	35^0
Insulation thicknesses, t_b, t_e	50 mm
Thermal conductivity of insulation, λ	0.043 W/m.K
Heat transfer coefficient of aluminum, λ_{Al}	210 W/m.K
Heat capacity of aluminum, $c_{p,Al}$	0.90 J/g.^{0}C

A single glazing was chosen in order to maximize the radiation impact on the absorber and reduce convective losses. Dimensions of the air heater are 1.92×0.82×0.10 m, in length, width and height, respectively.

The heater has an insulation thickness of 0.05 m on the bottom and lateral surfaces. The gap between the absorber plate and bottom of the heater is 0.043 m. The thickness of the absorber plate is 2 mm and its surface is painted matt black. In this study, inlet and outlet air temperatures of solar air heater, ambient temperature, airflow rate, solar radiation, pressure drop and wind velocity was measured and all of data were recorded by a data logger. A radial fan with a capacity of 0.41 m^3/s was used for solar air heater to provide the airflow. A controller unit was used to adjust the fan speed and airflow rate.

Inlet and outlet air temperature, absorber plate surface and ambient temperature were measured by using K-type thermocouples. Wind speed was measured using a cup anemometer (Delta-T A100 R, accuracy: 1% ±0.1 m/s). Anemometer was placed about 1 m above the solar air heater. A flow meter [Testo 405, accuracy: (±0.1 m/s ±5% of M.V.) at 0-2 m/s and (±0.3 m/s ±5% of M.V.) at 2.01-10 m/s] was used to measure the inlet air velocity for the solar air heater. The amount of global incident solar radiation on the heater was measured using a solar sensor (Delta-T ES2, accuracy: ±3% at 20^{0}C). The solar sensor was placed on the glass cover of the heater. All of sensors were connected to a data logger (Delta-T, DL2e) and the measurements were recorded 5 min interval.

Results and Discussion

Figure 2 presents a typical day for solar radiation, inlet and outlet air temperatures between 09.00 am and 04.00 pm.

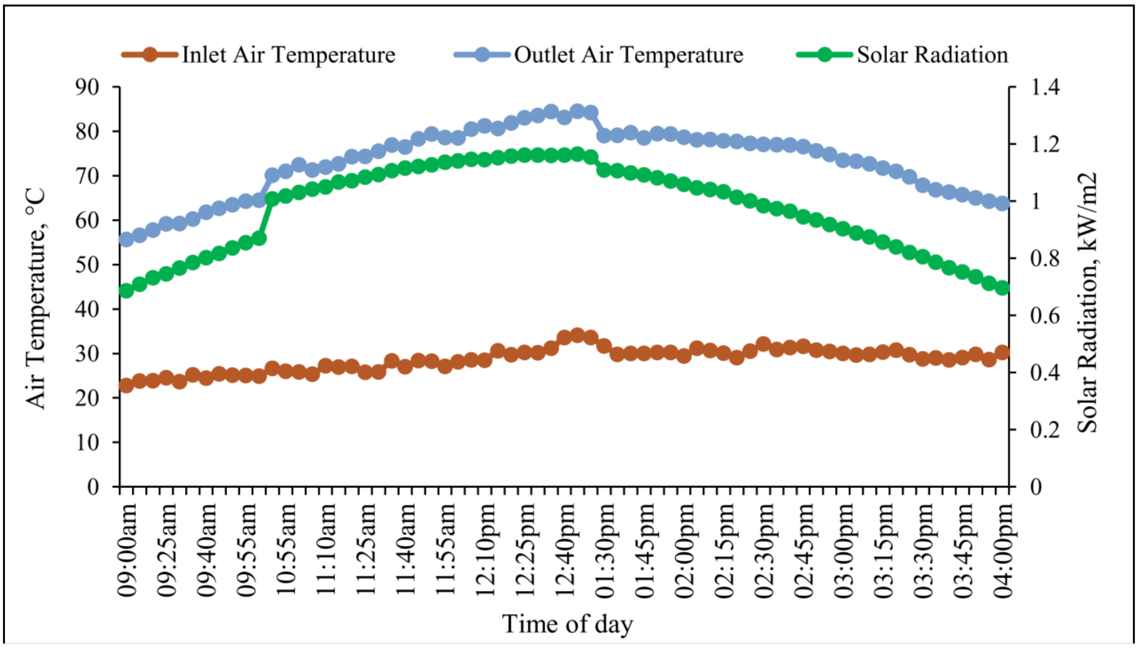

Fig 2: Data for Solar heater

The ambient temperature was considered to be the same as the inlet air temperature. It seems that inlet, outlet air temperatures increase with increasing solar radiation and the highest values were observed at midday.

The energy efficiency of the solar air heater was calculated using Equation 1:

$\eta = \dot{m}c_p\,(T_{out}-T_{in})/(G_T A_c)$ (1)

Where $\dot{m}$ is mass flow rate (kg/s), c_p is specific heat of air (J/kg. K), T_{in} is inlet temperature (^{0}C), T_{out} is outlet temperature (^{0}C), G_T is solar radiation intensity (W/m^2) and A_c is collector surface area (m^2). Figure 3 shows energy efficiency for solar air heater. According to Equation 1, energy efficiency calculated and it was found approximately η=0.25.

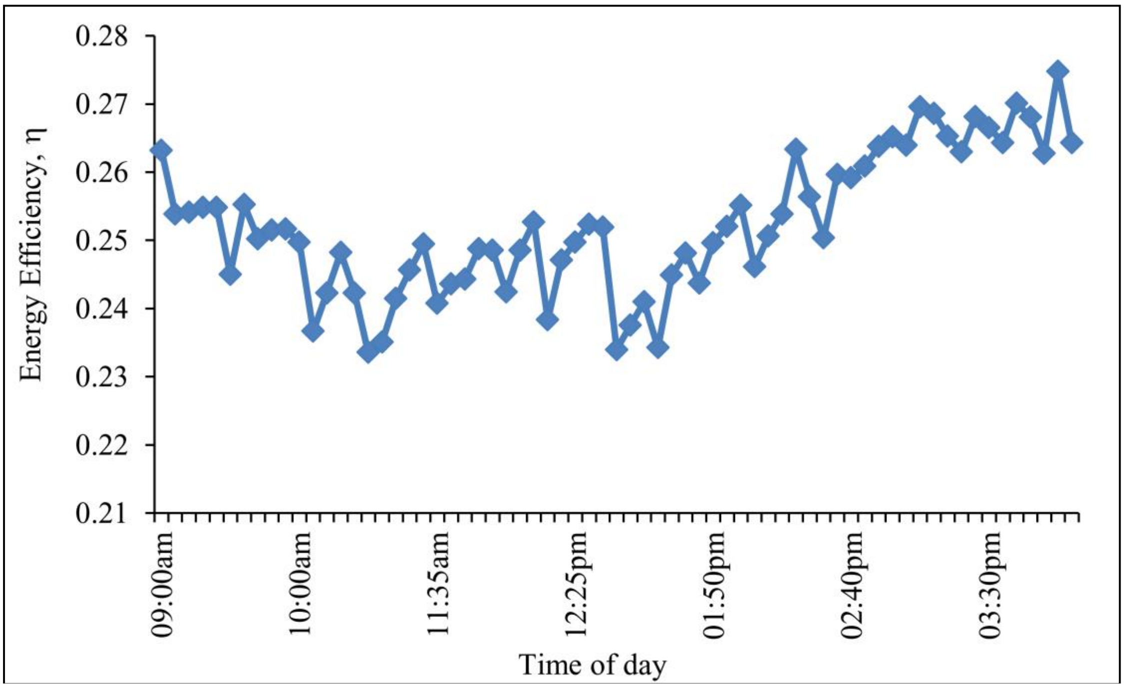

Fig 3: The Energy Efficiency of the solar air heater

CFD simulation

15.0 software was used for CFD simulations. To gain simulation results using CFD software, a simulation procedure has to be followed. The procedure requires setting the boundary and volume conditions of the simulated module. Assuming that the collector is a simple flat plate solar air heater, boundaries should have both convection and radiation heat transfer mechanisms.

In our system two different convection mechanisms takes place. While natural convection occurs in the region between glass and absorber plate there is a mixed convection between absorber and bottom plate. Streamlines in the solar air heater for three different inlet air velocities are shown in Figure 4.

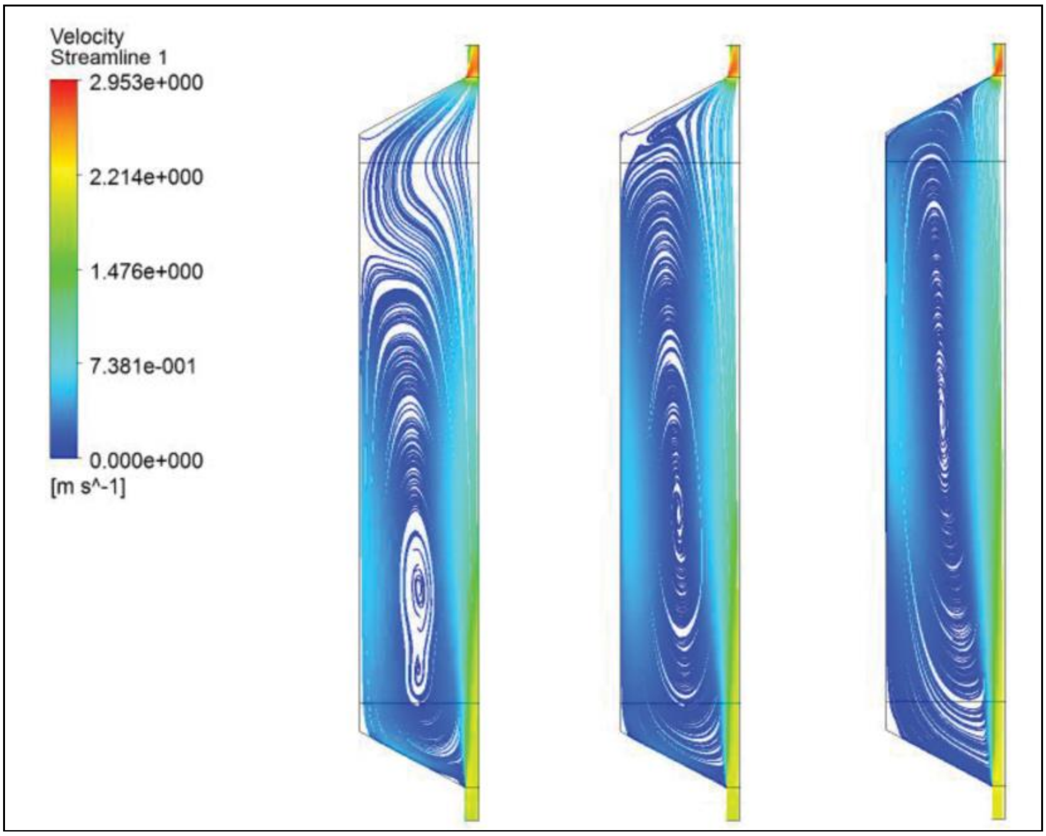

Fig 4: The Streamlines of air in the solar heat

It seems that, a circulation zone occurs near the sidewall of the collector and the zone grows with increasing the inlet velocity of air.

The effect of inlet air temperature on the outlet temperature were investigated and compared with the experimental data. The comparative data is given on Table 2.

Table 2: Comparison of the experimental and predicted data in terms of outlet air temperature

Case	Inlet Air Temperature	Solar Radiation	Experimental Data Outlet Air Temperature	Predicted Data Outlet Air Temperature	Deviation
(#)	(°C)	(kW/m^2)	(°C)	(°C)	(%)
#1	23.9	0.7312	57.6	55.17	-4.45
#2	26.6	1.0182	70.1	69.72	-0.5
#3	30.2	1.1294	75.6	78.19	3.1

Increasing the inlet air temperature causes an increase on the outlet air temperature as shown in figure 5. Table 2 also shows the maximum deviation between the predicted and measured outlet temperature is less than 5%, which means that the accuracy of the numerical analysis is quite acceptable for parametric survey.

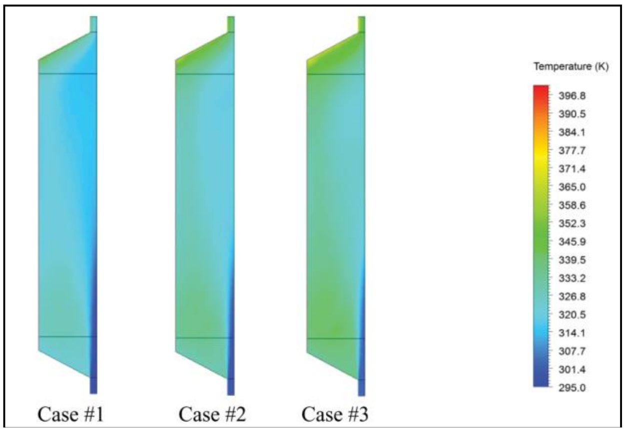

Fig 5: The temperature distribution solar air heater

Temperature distributions of air depending on the airflow rate are consistent with the streamlines. Solar air collectors can heat up the air much more at the lower air rates, because the air have more time to get hot inside the heater. As the air velocity increases, the air movement at the edge of the paddle box also increases and the hot air cannot accumulate here. These results also decrease the outlet temperature. In the location of the thermocouples for experiments and the results of the thermal images were given. Temperature values of the defined locations on the absorber plate were also measured from the thermal images.

Conclusion

A Solar air heater absorbs incident solar radiations and transforms them into useful heat for heating the collector fluid such as water and air. It's find several applications in space heating, seasoning of timber and crop drying. It has been also found that the main thermal resistance to the heat transfer is due to the formation of a laminar sub-layer on the absorber plate heat-transferring surface.

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