Performance analysis on Solar Air Heater with Discrete Arc Shaped Rib Element in Absorber Plate

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Abstract. Solar Air Heater (SAH) absorbs the irradiation and converts it into thermal energy, which is supplied to flowing fluid for the purpose of drying agricultural products, curing of industrial products, space heating applications and so on. An experimental examination has been conducted to assess the thermal performance of SAH having discrete arc shaped rib element in the absorber plate and analyzed against Flat Plate Solar Air Heater (FPSAH). Performance has been assessed by identifying the various parameters like useful heat gain, surface temperatures of collector plate, flow rate of working fluid, temperatures of air at inlet and exit. Investigation has been performed for flow rates of 0.028 kg/s and 0.045 kg/s. The results indicate that the absorber plate with artificial roughness element shows considerable increase in exit air temperature, heat transfer rate and thermal efficiency. Thermal efficiency of about 70% is obtained for 0.045 kg/s, which is 13.1% more than that of FPSAH.

Keywords: Flat plate, Thermal resistance, Roughness geometry, Discrete ribs, Heat gain

1. Introduction

Renewable energy sources become more promising alternative for fossil fuels since it reduces the greenhouse gas emissions. Among all the renewable energy, solar energy is voluminous, inexhaustible and clean energy source which has been used by humans for thousands of years to grow crops, dry farm products, to stay warm and so on[1-3]. Therefore, it is necessary and efficient to harness the solar energy for various industrial and agriculture applications. In recent days solar energy is used to generate electricity with the help of photovoltaic technology, heat water with the help of evacuated tubes, space heating with the help of air heaters.

SAH are the devices extensively utilized for low temperature operations due to its nature of heating the fluid to low and moderate temperatures. The development of viscous sub layer nearer to the plate lessens the heat transfer between collector plate and air, which leads to reduction in thermal gain of SAH [4]. The sub layer increases the thermal resistance, which can be eliminated by various techniques. Researchers investigated the thermal performance by providing various structures of protruded elements on collector plate [5]. The idea of providing dissimilar roughness geometries breaks the sub layer by creating disturbance in the flowing fluid nearer to the surface of the collector plate.

Various dissimilar structures and arrangements of roughness configurations helps in enhancing the heat transfer are transverse and inclined arrangements of broken and continuous ribs, chamfered ribs, wire mesh, dimple shaped protrusions, solid baffles, perforated baffles and so on[6-12]. Many researchers indicated that the usage of rib shaped roughness elements increase the performance of SAH than other forms of designs. In this work, the performance of SAH with newly designed rib element on the collector plate was examined for different mass flow rates and it was compared with Flat Plate Solar Air Heater (FPSAH).

2. Experimental arrangement
An experimental arrangement is constructed to test the thermal performance of newly designed absorber plate. The performance results obtained from new design is to be compared with the flat plate collector. The pictorial view of experimental arrangement is shown in Fig 1. It incorporates a collector box, absorber plate with ribs attached to it, plain glass cover at the top of collector box, centrifugal blower for forced convection, thermocouples for temperature measurement of air and absorber plate, anemometer for fluid flow measurement, collector frame to support the collector box and PVC pipe connections for fluid flow path. The dimensions of the collector box are 1600 mm x 600 mm x 50 mm and the length of test section is 1400 mm. Aluminium sheet of 1 mm thickness coated with black paint is adopted to fabricate the absorber plate. The aluminium material is chosen due to its high thermal conductivity compared to GI material. The height of the rib is 20 mm, the rib width is 40 mm, spacing between the ribs are 30 mm and the thickness of the rib is 2 mm.

![Photographic view of discrete arc shaped rib element in absorber plate](image1)

![Photographic view of experimental arrangement](image2)

**Fig.1.** (a) Photographic view of discrete arc shaped rib element in absorber plate, (b) Photographic view of experimental arrangement.

1 - Glass cover, 2 - Centrifugal blower, 3 – Wooden box, 4 – Digital temperature indicator, 5 – Absorber plate with arc shaped rib element

### 3. Thermal Performance Analysis

In the following section, the equations used for the analysis of SAH are discussed as below.

The useful gain in thermal energy absorbed by the working fluid ($Q_a$) when running across the collector plate is given by [13],

$$Q_a = m \cdot C_p \cdot (T_o - T_i)$$  \hspace{1cm} (1)

where $m$ is the mass flow rate of working fluid through the test section (kg/s), $T_o$ is the temperature of working fluid at outlet (K), $T_i$ is the temperature of working fluid at inlet (K) and $C_p$ is the specific heat capacity of working fluid (J/kg K). The working fluid employed for heat absorption is air.

The heat energy harnessed by the collector plate due to irradiation incident on the projected area of collector plate is given by,

$$Q_a = I \cdot A_p$$  \hspace{1cm} (2)

where $I$ is the amount of radiation intensity incident upon the absorber plate (W/m²) and $A_p$ is the projected area of collector plate in test section (m²).

The value of convective heat transfer coefficient between the collector plate and working fluid flowing over it ($h$) can be calculated by,

$$h = \frac{Q_a}{A_p \cdot (T_p - T_f)}$$  \hspace{1cm} (3)

where $T_p$ is the mean temperature of collector plate (K), $T_f$ is the mean air temperature flowing across the absorber plate (K) and $h$ is in the unit of W/m² K.

The value of $T_p$ is calculated by taking mean value of temperatures at nine points of the absorber plate and it is given by,
The value of $T_v$ can be calculated by

$$T_v = (T_o + T_i)/2$$  \hspace{1cm} (5)

4. Results and discussion

The thermal behavior of newly designed SAH having discontinuous pattern of arc shaped rib element in absorber plate is investigated. The mass flow rates are chosen as 0.028 kg/s and 0.045 kg/s for better comparison with previous studies. The functioning of SAH with discrete rib elements have been studied and compared with the FPSAH. The experiment was tested in daytime during March 2020.

The amount of radiation falling on the absorber plate was captured with the aid of solar power meter. During start of the day, the irradiation was found to be 507 W/m² and then it gradually increases until noon followed by reduction in irradiation when the sun moving towards west. The maximum value of irradiation incident upon the upper layer of the collector plate was found to be 960 W/m². Thermocouples were utilized to determine the temperature of working fluid at entry and exit. Variance in temperature on hourly basis between the outlet and inlet air is seen in Fig.2. It is evidently understood that maximum temperature variance is noted between 12:00 to 14:00 hr. Maximum temperature difference identified for 0.028 kg/s is 18 K whereas 20 K for 0.045 kg/s. Many researchers identified that the maximum temperature difference observed in flat plate collectors are not more than 15 K. Therefore, it is observed that more than 5 K of temperature difference is obtained with rib shaped element on collector plate with higher flow rate. The temperature variance is low for lower flow rate, increases in flow rate increases the difference. The ribs provided on the surface of aluminium plate help air to collect more heat due to increase in surface area.

![Fig. 2. Comparison of temperature difference for different flow rates](image)

Fig. 3 manifests hourly variation of useful heat gained by the absorber plate for chosen mass flow rates. At lower rate of flow, the maximum thermal energy acquired by the air when passing across the collector plate is 506 W. Similarly at higher mass flow rate the maximum energy acquired by the air is 534 W. From above observations, it is evidently understood that increase in flow rate facilitates air to absorb more heat. In FPSAH, maximum useful thermal energy acquired by the air is found to be 420 W. Compared to flat plate collectors, more amount of heat is absorbed by newly designed air heater at higher mass flow rate.
The variation of thermal efficiency obtained by newly designed SAH for dissimilar flow rates is shown in Fig. 4. The thermal efficiency gradually increases from morning to the afternoon session and then gradually decreases. The thermal efficiency of highest value is obtained for 0.028 kg/s flow rate is 66% whereas the maximum efficiency obtained for 0.045 kg/s is 70%. Therefore, it is evidently understood that increase in efficiency is witnessed for higher mass flow rate than the FPSAH, since many researchers identified that the maximum efficiency identified by FPSAH was 45%.

The value of $h$ between air and collector plate is calculated by convective heat transfer equation. The variation in value of $h$ for dissimilar fluid flow rates is shown in Fig. 5. The value of $h$ can be calculated for supply of air at 0.028 kg/s and 0.045 kg/s.
Convective heat transfer coefficient of absorber plate with rib shaped roughness element has higher value, when it is evaluated against FPSAH. The maximum value is found to be 20 W/m²K for 0.045 kg/s obtained at the time of 14:00 hr., whereas the value of h is 18 W/m²K for the supply of air at 0.028 kg/s. The increase in value of h is due to increase of heat gain at higher mass flow rate.

5. Conclusion

Experimental examination has been executed to observe the heat exchange rate and thermal gain of SAH with roughness geometry on the surface of absorber plate. The thermal efficiency has been investigated for flow rates of 0.028 kg/s and 0.045 kg/s. Outlet temperature of air for arc shaped rib element is more for higher flow rate than lower flow rate. The maximum thermal efficiency obtained for 0.045 kg/s is 70% whereas 66% for 0.028 kg/s. From the above results, it is concluded that usage of roughness element increases the turbulence, thereby increases the value of h. Also increase in flow rate increases the thermal efficiency of the SAH. Therefore, it is suggested to use SAH with artificial roughness geometries on the surface of absorber plate with higher mass flow rate to have better thermal performance.

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