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An Experimental Study of Domestic Double Pass Solar Air Heating System Using V shaped rib

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Abstract:
Using rib on the absorber plate, an experimental study has been conducted to improve the efficiency of a solar air heater. The analysis of the thermal performance of a Solar Air Heater (SAH) with V rib with gaps, V rib without gaps and plain observer plate has been carried out in this researchfor varying mass flow rates on the SAH. To verify the performance enhancement, experimental outputs including outlet air temperature, and thermal efficiency were assessed. The maximum thermal efficiency of the V rib with gap absorber plate SAH were determined to be 78% at a mass flow rate of 0.045 kg/s, respectively 27.81% and 37.27% higher than the V continuous rib and without rib SAH. This study demonstrated that for the parameter under investigation, V-shaped ribs with gaps in a flow configuration offer superior thermal performance over continues ribs and smooth plate SAH.

Key Word*:Solar air heater, V shaped roughness**, energy***

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I. Introduction

One of the most significant solar energy systems for warming the surrounding air is the solar air heater (SAH). It is used for a variety of purposes, such as space heating, water desalination, building cooling, drying rural goods, dehydrating organic products, germination of seeds, flavoring wood, humidification, and dehumidification, and occasionally to produce electricity (Bakry et al.[1]). The absorber plates of the solar air heater are equipped with baffles and fins, which impede the free flow of air. As output, the rate of heat transfer is improved. The arrangement of baffles and pins in SAH causes a decrease in pressure and a rise in grating. The strong hot air movement and reduced friction loss are crucial phenomena to increase collector efficiency. The energy and exergy analyses on a single pass flat plate, double pass a roughened plate, double pass a finned plate, and double pass wire work SAHs have been published by Velmurugan and Kalaivanan[2]. They stated that as the mass flow rate increases, the exergy yield decreases and the pressure fall rises.

In order to determine the solar air heater's Nusselt number and friction factor, Luan and Phu[3] used inclined baffles. They investigated the effectiveness of the technique by altering the baffle angle between 0 and 180°. Consequently, they discovered that the highest collector efficiency of 0.7% was achieved while utilizing the baffles at 60° degrees. Bensaci et al[4] performed a numerical and experimental investigation on the placement of the baffles over the absorber plate to improve the thermal and hydraulic effectiveness of SAH. Finally, the 100% baffles put over the absorber layer contributed significantly to the system's excellent thermal efficiency. The energy and energyproduction of a solar air heater with w-shaped baffles were investigated by Nidhul et al.[5] They concluded that adding w form baffles improved the system's thermal and energetic performance by 40.7 and 95.4% while alsoimproving the nusselt number and Reynolds number. To test the effectiveness of the systems, Hassan et al.[6]added V-corrugated and corrugated-perforated baffles above the double-pass solar air heater absorber plate. Four distinct airflow rates were used for the experimental analysis. They concluded that during the experiment, corrugated perforated baffles, followed by a corrugated and finally a flat plate solar air heater, had the maximum efficiency. In order to improve heat transmission, friction factor, and thermo-hydraulic performance, Patel and Lanjewar[7] did an experimental investigation on a solar air heater with several discrete V-patterns paired with staggered rib as an artificial roughness. They concluded that the absorber plate's various discrete V-patterns and staggered ribs enhance heat transfer over a smooth plate. Additionally, they discovered that the friction factor varied depending on how far apart the ribs were from one another. Using rib configurations on the absorber plate, Sharma and Kalamkar[8] presented a computational and experimental investigation on the heat transfer and frictional loss characteristics of solar air heaters. The maximum friction factor value was reportedly attained in two continuous transverse ribs between the arrangement of truncated ribs, and they claimed that the friction factor rise with the Reynolds number. By altering the solar air heater's surface, Poongavanam et al.[9] examined the rate of heat transmission and friction properties. They discovered that the modified air heater outperformed the traditional solar air heater in terms of maximum Nusselt number and friction factor values. Additionally, they claimed that when the Reynolds number grows, the Nusselt number lowers and the friction factor increases. The improvement of heat transfer and friction factor of solar air heaters with S ribs was studied by Kumar et al.[10] They concluded that using the plate's artificial roughness allowed for an improvement in heat transfer and friction factor. An experimental investigation on heat transmission, friction factor, and thermal performance of a solar air heater with three artificially roughened sides was carried out by Behura et al.[11] In contrast to a single side roughened air heater, they discovered that a three-side roughened air heater had the highest heat transfer value. Broken arc ribs were used as an absorber plate roughness in an investigation by Hans et al.[12] into solar air heaters. When compared to broken arc ribs, they discovered that inclined ribs with gaps and v-ribs with gaps improved heat transfer the most. In order to increase the solar air heater's heat transfer coefficient, Maithani and Saini[13] studied it utilizing V-ribs with symmetrical gaps for generating turbulence. They concluded that, in comparison to the smooth plate, the Nusselt number and friction factor were rising. Additionally, they stated that the Nusselt number was increasing as the relative gap width increased. Saini and Verma[14]investigated how adding roughness to the underside of the collection plate could increase the heat transfer rate and friction factor of solar air heaters. They discovered that employing dimple shape roughness boosted the heat transfer rate and friction factor. Hassan and Abo-Elfadl[15]studied the impact of double pass SAH with varying airstream ratios for various absorber plates, including smooth, ribbed, and pin finned. For flat plate absorber and pin finned absorber plates, respectively, they reported that the maximal SAH efficacy was around 70 and 79% for 100% air streaming over the absorber plate. Singh and Singh[16] made a fictitiousconsideration on the functionality of curved SAH. When compared to a flat air heater, they discovereda little increase in the pressure fall on the curved air heater. In comparison to the smooth curved plate single-pass air heater, they also discovered an increase in the air outlet temperature for the curved V-corrugated plate. Lahori et al[17] concluded that the heat transfer characteristics of solar air heater with some modifications in design to increase air travel length. Performance of solar air dryer would be checked with and without air heater.

II. Material And Methods

The primary goal of this study is to create a continuous V and V with gaps roughness to the absorber plate for a solar air heater to increase the rate of heat transfer and increase the effectiveness of the system.

2.1 Materials

The input, testing, and outlet of the solar air heater is 200 mm, 1200 mm and 200 mm respectively. GI sheet that was 1200 mm long and 1.5 mm thick used as an absorber plate made up the rectangular test portion. The rib in the absorber plate created artificial roughness or abstraction. A centrifugal blower provided the air for the duct, while a gate valve managed the air's entrance flow rate. The SAH support structure was built out of a wooden box and iron rods. Temperature measurements of the absorber plate, glass, input, and outflow were made using thermocouples (K-Type). The temperature measurements were shown by thermocouples that were fastened to the temperature indicator. During the experiment, solar radiations were monitored using a radiation meter. The system's pressure variations were measured using the manometer.

2.2 Experimental Setup

To evaluate the effectiveness of solar air heaters, an experimental setup was created. The proposed solar air heater design is contrasted with the flat (Smooth) plate solar air heater. To conduct a comparison investigation, three identical SAH were built, one with a smooth absorber plate and the second one is with 22 V-shaped continuous ribs that had rib height 35 mm and third one with 22 V shaped ribs with gaps that had rib height of 35 mm and 3 symmetrical gaps on each side of rib in the absorber plate. GI sheets were used to create the flat plate and the V shaped ribs fitted plate. Experimentations are carried out in the Department of Mechanical Engineering, Radha Raman Institute of Technology & Science Bhopal (23.26°N latitude, 77.41°E longitude), Madhya Pradesh, India. Figure 1 depicts the SAH with V with symmetrical gaps roughened design layout. Figure 2 and 3 depicts the real-time experimental setup for SAH using absorber plates that are and fitted with ribs and without ribs. To reduce side and bottom heat loss, the practical arrangements were well insulated using an insulating material. Air entered through the 51 mm-diameter intake port and left through the 51 mm-diameter output port. To reduce solar radiation reflection, 5 mm thick glass was used to cover the upper open surface. GI absorber plates have dimensions of 1200 mm

× 700 mm × 1.5mm. In order to absorb free solar energy, theabsorber plate was painted with high thermal conductivity black paint. Air in the three SAH were supplied by centrifugal blowers. All SAH experiments were conducted at the same location at the same time, with all of them positioned in a North-South orientation to receive the most of the sun's energy.

2.3 Working Method

From the morning at 10:00 A.M. through the evening at 4:00 P.M., various parameters were measured and recorded for the experimental enquiry. For the experiment, June (2022) clear sky days were chosen, and the outside ambient temperature ranged from 31 to 31.5°C. Based on the incident radiation, inlet, and exit

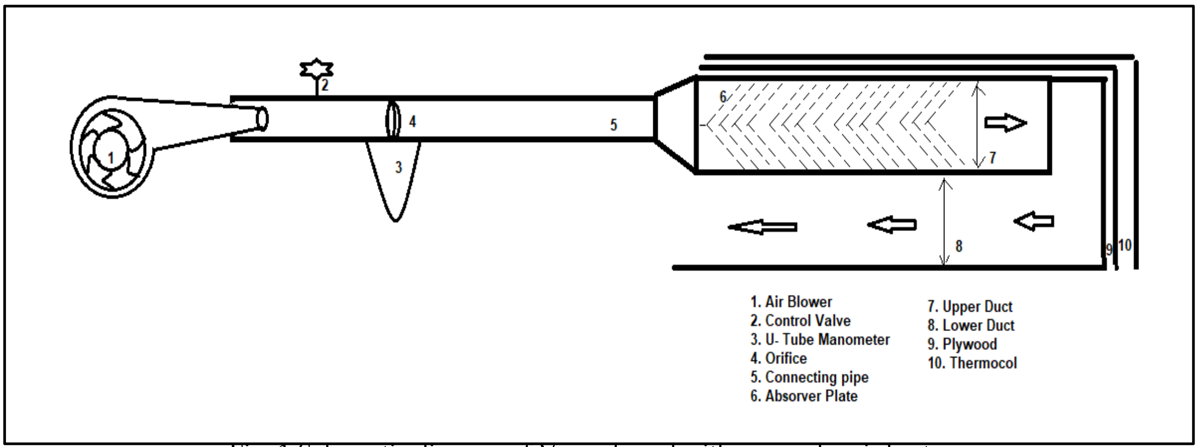


Fig. 1 Schematic diagram of V roughened with gaps solar air heater

Fig:2 Experimental Setup

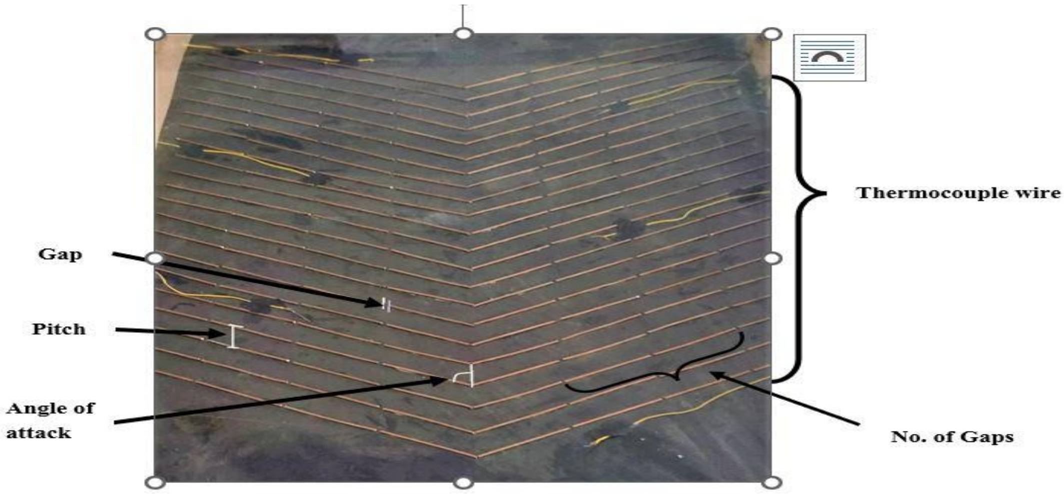


Fig: 3 Absorber Plate of V Roughened with Gaps Solar Air Heater

temperatures of SAH, the thermal performance of the V ribs with gap system was examined and contrasted with that of the V continuous rib and smooth plate air heater.During the experimental evaluation of three constructed SAH at the same site and time, various parameters were measured. Every hour, the temperatures of simple solar air heater (SSAH), V roughened solar air heater (VRSAH) and V roughened with gap solar air heater (VRGSAH) were measured and recorded using K type thermocouples linked to the temperature meter. The temperature of the ambient air, the temperature of the outlet port, the temperature of the absorber plate at six distinct positions, the temperature of the glass plate and other temperatures were estimated using thermocouples. For an interval of about 60 minutes, solar radiation measurements were also recorded. To determine the ideal values and efficiencies, the same experimentation method was carried out with three different air mass flow rates. Energy matrix analysis and a manufactured experimental setup were used to examine the economic and environmental behavior of the solar air heater system.

Table.1 Parameters taken in present work

S.No.	**Parameters**	**Value(s)**
Operating parameters		
1.	Mass flow rate (ṁ)	0.026-0.045 Kg/s
Roughness Parameter		
2	Relative roughness (P/e)	10.76
3	Relative roughness height (e/D_h)	0.0255
4.	Rib height (e)	3.25 mm
5.	Angle of attack (α)	60° C

III. Data Reduction

The heat transfer coefficient, Nusselt number, Average surface temperature, Average air temperature, Mass flow rates and friction factor have all been calculated using the data that was gathered. Below are relevant equations for the computation of the parameters as well as a few intermediate parameters;

Temperature of Air and Plate

The average of all the heated plate's temperatures is the plate's mean temperature. ($\boldsymbol{T_p}$)

$$\boldsymbol{T_p = \frac{T_{p1}+T_{p2}+T_{p3}+T_{p4}+T_{p5}+T_{p6}}{6}} \quad \dots (1)$$

Average air temperature (T_f)is given by

$$\boldsymbol{T_f = \frac{T_i+T_o}{2}} \quad \dots (2)$$

Mass Flow Rate Measurement (ṁ)

The following formula was used to calculate the mass flow rate of air fromthe pressure drop data via the orificemeter.

$$\dot{m} = C_d \times A_0 \sqrt{\frac{2\rho(\triangle P_0)}{1-\beta^4}} \quad \dots (3)$$

Velocity of the air (V)

$$V = \frac{\dot{m}}{\rho \times W \times H} \quad \dots (4)$$

IV. Result and Discussion

For the hot and humid climate of the Bhopal region in MP, India, the SAH performance was examined with and without ribs. The result is presented in three subsections, first one incident solar radiation, second one temperature distribution, and the third one SAH's thermal efficiency. Losses from auxiliary devices like blowers and valves are disregarded.

4.1 Solar Radiation

Depending on the solar radiation that was incident, the SAH's performance changed. Figure 4 depicts the incident solar radiation fluctuation throughout the course of the experiment days, which grew from 10.00 A.M. until it reached a maximum value between 12:00 P.M. and 1.00 P.M. After that, it began to fall until the end of the day. Additionally, it was evident that there was little variation in the ambient factors over the course of the experiment's three days. Between the three days, there was a maximum radiation difference of roughly 115 W/m^2. It meant that the output values from different days did not significantly differ; Figure 4 also shows the Variation in the solar Figure 4 also shows the Variation in the solar radiation on anhourly basis during the test days. Variation in maximum values (i.e., at 01 PM) of second and third day is approx. 8%.

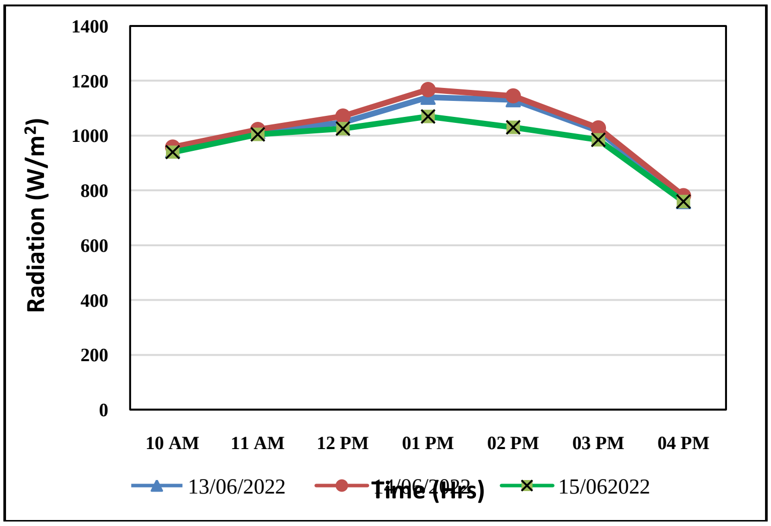


Fig. 4 Variation in the solar radiation on an hourly basis during the test days

4.2 Distribution of temperatures

Figure 5 illustrates how the temperature of the air heater varied for several mass flow rates of 0.026 kg/s, 0.034 kg/s, and 0.045 kg/s. Temperature distribution graphs show that the absorber platetemperature is higher than the glass temperature because black body radiation causes the absorber plate to heat up more than the glass, Because the roughened absorber plate has a larger surface area in contact with the air than the flat plate SAH, thetemperature distribution of the roughened absorber plate is higher. The duration of air retention in theSAH greatly increased, causing the air to gain the temperature. The temperature at the SAH outflow increased as a result of additional heat being produced by the absorber plate and incident sun energy. In contrast to the other two greater mass flow rates, Figure 5 demonstrates that a lower mass flow rate provides a useful improvement in the air heaters temperature.

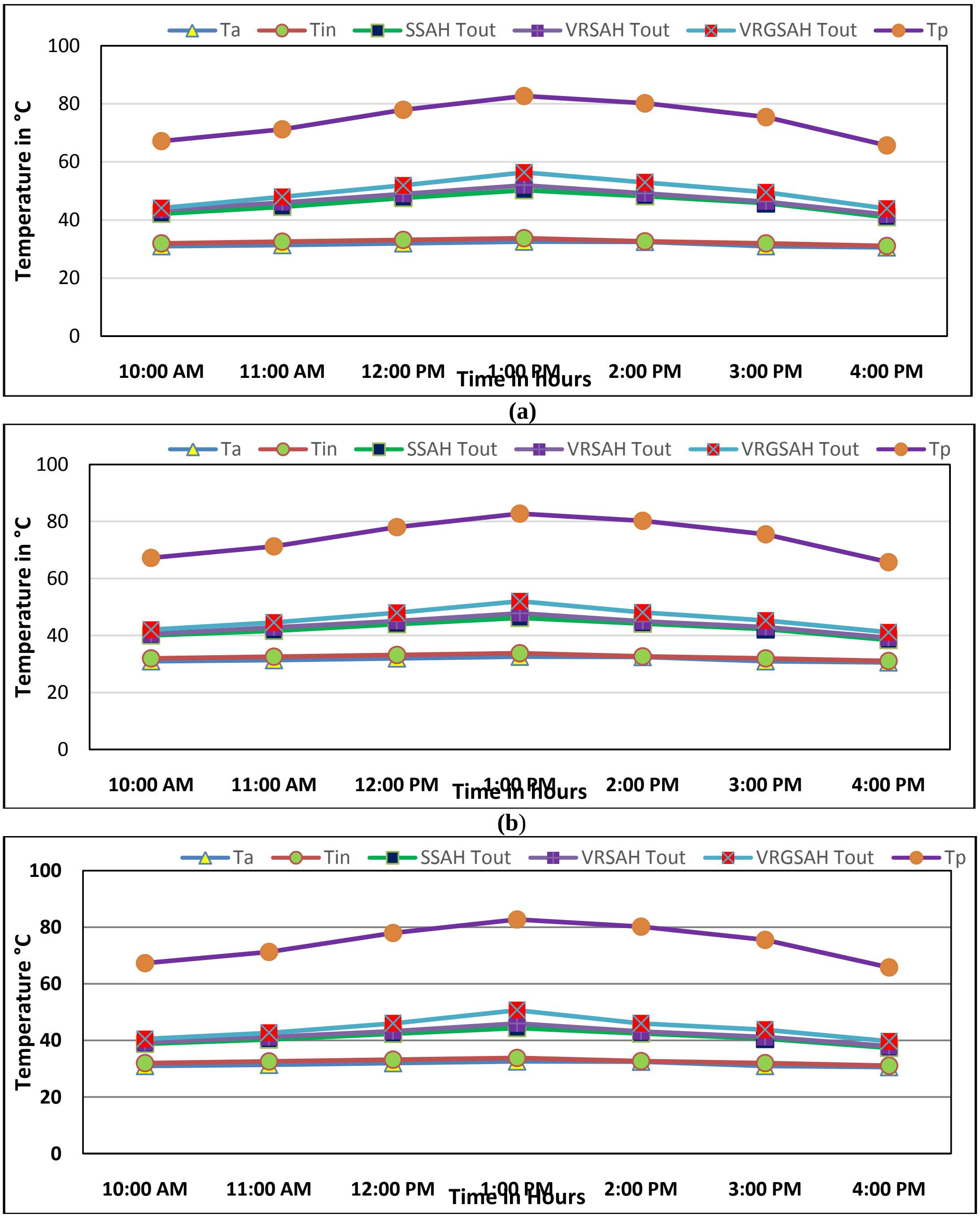
distribution with V ribs with gaps. With a mass flow rate of 0.026 kg/s, the air heater's absorber and outlet air reached maximum temperatures of 87 °C, and 56.4 °C, respectively. On visualizing figure for mass flow rate of 0.045 kg/s, the corresponding temperatures are 87 °C, and 50.7 °C, respectively, outlet temperature10.10% lower than the earlier value.

In a solar air heater with V continuous rib, a mass flow rate of 0.026 kg/s results in maximum temperatures for the absorber plate and air outlet of 87°C and 52 °C, respectively, while a mass flow rate of

0.037 kg/s results in outlet air temperature is 8.07% lower than the former. For mass flow rate of 0.045 kg/s,Outlet air temperature is 46 °C, A similar pattern is formed; however, it is 11.53% smaller than the first one.

In a solar air heater without roughness, a mass flow rate of 0.026 kg/s results in maximum temperatures for the absorber plate and air outlet of 87°C and 50.3°C, respectively, while a mass flow rate of 0.037 kg/s results in outlet temperature is 8.15% lower than the former. For mass flow rate of 0.045 kg/s temperature of outlet airis 44.4°C, A similar pattern is formed; however, it is 11.72% smaller than the first one.

Results show that a V rib with gap with a mass flow rate of 0.026 kg/s produces a maximum exit temperature for the SAH of 56.4°C



(a)

(b)

(c)

Fig. 5 The solar air heater's temperature fluctuation hourly in simple solar air heater (SSAH), V Roughened solar air heater (VRSAH) and V Roughened with gaps solar air heater (VRGSAH) for different mass flow rates (a) 0.026Kg/s. (b) 0.037 Kg/s (c) 0.045 Kg/s

4.3 Thermal Efficiency

The air heater's thermal efficiency is an important performance indicator that may also be used to improve the effectiveness of next research. To forecast energy losses and determine the SAH's energy production percentage, thermal efficiency of SAH. The amount of heat absorbed by the air from the absorber plate can also be determined. The percentage conversion of incident energy into useable energy gained at an outlet is also expressed using this term. According to equation, it is dependent on the mass flow rate, inlet & outlet temperatures, solar radiation, and collector area. The current work used V rib roughness addition at a varied mass flow rate and incident solar energy variation to improve the performance of the solar air heater for the chosen site. Without modifying the absorber plate area, the wire ribs added to the absorber plate improves convective heat transfer tothe air. As aresult, SAH with a rib with gaps performs better than SAH with continuous rib and smooth absorber plate.

According toFigure6, efficiency starts to rise with time. Due to variations in solar radiation and the daily average temperature, it peaks at noon and begins to decline in the late afternoon. The retention period of air going through SAH with V rib with gapis noticeably longer than SAH with V Continuous and smooth plate. This improves heat transfer between the air and the absorber plate.

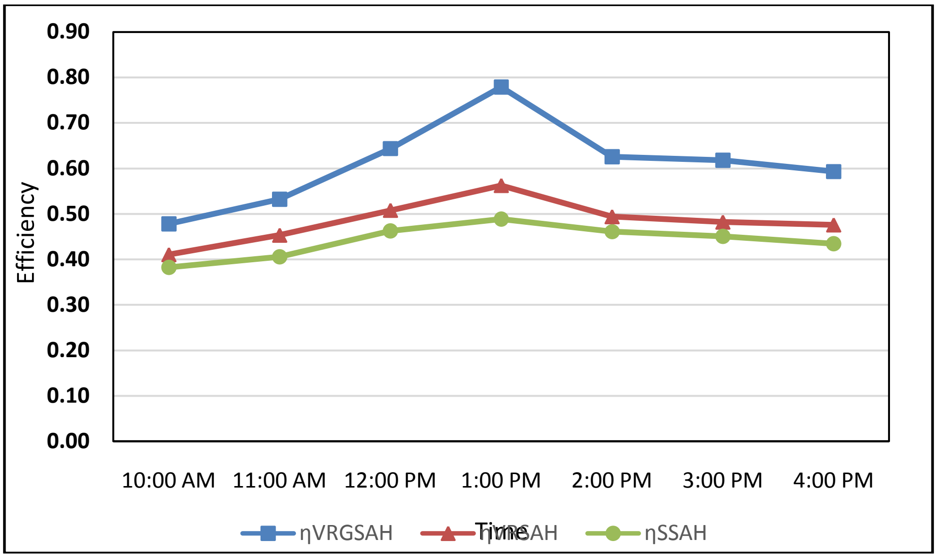


Fig. 6Hourly Variation in efficiencies at mass flow rate 0.045 kg/s

Due to the existence of V-shaped ribs inside the SAH, the creation of the laminar sub-layer in the absorber plate is minimized. SAH with V roughened with gaps performs more thermally efficiently than SAH with smooth plates and Continuous V roughness. Additionally, it demonstrates that the maximum SAH efficiency with a V shaped rib with gaps is around 77.9% at a mass flowrate of 0.045 kg/s is 27.81% and 37.27% greater than V continuous rib and without roughness respectively.

V. Conclusion

The work on "V rib with gap," "V continuous," and "without rib."has been done to compare the performance of the three rib geometries for solar air heaters. From the current investigation the following results can be drawn:

(i) Efficiency of V roughened with gaps solar air heater at mass flow rate 0.045 is 27.81% and 37.27% more as compared to V roughened solar air heater, Simple solar air heater respectively.

(ii) At a mass flow rate of 0.037, the efficiency of the V roughened with gaps solar air heater is 23.07% and 31.86% higher than that of the V roughened solar air heater and the Simple solar air heater, respectively.

(iii) At a mass flow rate of 0.026, the efficiency of the V roughened with gaps solar air heater is 19.46% and 26.99% higher than that of the V roughened solar air heater and the Simple solar air heater, respectively.

(iv) Outlet air temperature is inversely proportional to mass flow rate for all the three solar air heaters. Retentiontime can be the reason for the same.

(v) Thermal efficiency increases as mass flow rate does. From m1 to m2, the efficiency of a V roughened with gaps solar air heater is found to grow by 14.60%, and from m1 to m3, it increases by 29.42%,

(vi) For V Roughened solar air heater air heaters efficiency increased by 9.46% - 16.01%. and for simple solar air heater efficiency increased by6.94%-11.18%.

(vii) V roughened with gaps solar air heater with a mass flow rate of 0.026 kg/s produces a maximum exit temperature for the Solar air heater of 56.4 °C. which is 12.12% and 8.46% more as compared to Simplesolar air heater and V roughened solar air heater.

Nomenclature

A_p	Smooth and roughened absorber plate area, m^2	T_o	Mean temperature of air at outlet, °C
A_o	Area of orifice plate, m^2	T_p	Mean temperature of absorber, °C
D_h	Hydraulic diameter of duct, m	*e/Dh*	Ratio of rib height to hydraulic diameter, Dimensionless
e	Rib element height, m		
g	Gap width, m	*g/e*	Ratio of gap width to rib height, dimensionless
$\dot{m}$	Mass flow rate, Kg/s	*Nu*	Nusselt number, Dimensionless
G	Heat transfer function	*p/e*	Ratio of rib pitch to height, dimensionless
H	Depth of duct, m	*Re*	Reynolds number, dimensionless,
h	Heat transfer coefficient, W/m2 -K	*SAH*	Solar air heater
k	Air thermal conductivity, W/m-K	*VRSAH*	V Roughened Solar air heater
L	Smooth and roughened surface length, m	*VRGSAH*	V Roughened with gaps Solar air heater
Ng	Number of gaps (Ng)	*Greek Symbols*	
Qu	Heat transfer, W	α	angle of attack (Degree)
T_a	Ambient temperature, °C	β	ratio of orifice diameter to pipe diameter
T_f	Average air temperature, °C	Δpo	Pressure drop across the orifice (Pa)
T_i	Temperature of air at inlet, °C	ρ	Density of air (kg/m^3)
		η	Efficiency

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