Techniques for Performance Enhancement of Solar Air Heater: A Review

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Abstract

The improvement of thermal performance of solar air heater is required for increasing the heat transfer rate and minimizing the losses to reduce power consumption. This article includes a brief discussion on solar air heaters integrated artificial roughness which showed far more efficiency than the conventional solar air heater. Efficiency enhancement in all these studies is mainly based on increasing the heat transfer coefficient for increasing the heat transfer area for an effective heat transfer rate. Chamfered type of artificial roughness gives the best result among the other types of artificial roughness which about 2.77 times more value of Nusselt number (\(Nu=138.5\)) over the smooth duct for \(\phi=14.5^\circ\), \(\varepsilon/D_h=0.0278\), \(p/e=5.41\) and \(W/H=4.82\). Double pass solar air heater is more efficient than single pass solar air heater with the concept involved of doubling the heat transfer area based on increasing the heat transfer coefficient for increasing the heat transfer area for an effective heat transfer rate. In the given study it is also investigate the effect of geometric parameters like fin length, fin height, number of fin, selective coating, thermal storage and operating parameter like mass flow rate on solar air heater.

Keywords: Performance Optimization, Solar Air Heater, CFD Simulation, Artificial Roughness, Selective Coating

NOMENCLATURE

<table>
<thead>
<tr>
<th>(A)</th>
<th>Actual heat transfer surface ([m^2])</th>
<th>(p/e)</th>
<th>RELATIVE ROUGHNESS PITCH</th>
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<tr>
<td>(A_s)</td>
<td>SMOOTH PLATE HEAT TRANSFER AREA ([m^2])</td>
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<td>Prandtl number ([\mu C_p/k])</td>
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<tr>
<td>(C_e)</td>
<td>SPECIFIC HEAT ([J/kg \text{ }K])</td>
<td>(Q_u)</td>
<td>Heat transfer rate ([W])</td>
</tr>
<tr>
<td>(D_h)</td>
<td>Channel hydraulic diameter ([m])</td>
<td>(S_t)</td>
<td>STANTON NUMBER, (Nu/Re.Pr)</td>
</tr>
<tr>
<td>(e)</td>
<td>RIB HEIGHT ([m])</td>
<td>(T_i)</td>
<td>AIR TEMPERATURE ([K])</td>
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<tr>
<td>(e/D_h)</td>
<td>RELATIVE ROUGHNESS HEIGHT</td>
<td>(T_{in})</td>
<td>Bulk mean air temperature ((T_{in}+T_{out})/2) ([K])</td>
</tr>
<tr>
<td>(f)</td>
<td>FANNING FRICTION FACTOR</td>
<td>(T_{in})</td>
<td>AIR INLET TEMPERATURE ([K])</td>
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<tr>
<td>(H)</td>
<td>HEAT TRANSFER COEFFICIENT ([W/m^2 \text{ }K])</td>
<td>(T_{out})</td>
<td>AIR OUTLET TEMPERATURE ([K])</td>
</tr>
<tr>
<td>(H)</td>
<td>DUCT DEPTH ([m])</td>
<td>(T_{pm})</td>
<td>Mean plate temperature ([K])</td>
</tr>
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<td>(k)</td>
<td>THERMAL CONDUCTIVITY OF AIR ([W/m \text{ }K])</td>
<td>(w)</td>
<td>RIB WIDTH ([m])</td>
</tr>
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<td>(L)</td>
<td>Test section length ([m])</td>
<td>(W_e)</td>
<td>RIB WIDTH TO HEIGHT RATIO</td>
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<tr>
<td>(m)</td>
<td>Mass flow rate ([kg/s])</td>
<td>(W)</td>
<td>DUCT WIDTH ([m])</td>
</tr>
<tr>
<td>(Nu)</td>
<td>NUSSLETT NUMBER (\text{[1}HD_w/k)]</td>
<td>(W/H)</td>
<td>Channel aspect ratio</td>
</tr>
<tr>
<td>(p)</td>
<td>RIB PITCH ([m])</td>
<td>(X)</td>
<td>Length in axial direction ([m])</td>
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</tbody>
</table>

I. INTRODUCTION

Solar energy is the origin of all forms of energy. This energy can be utilized in two ways the thermal route i.e. using heat for heating, drying, cooking or generation of electricity or through the photovoltaic route which converts solar energy into electricity. With its virtually inexhaustible supply, pollution free nature and global distribution- solar energy is a very attractive energy resource. India has a tremendous scope of generating solar energy. The geographical location of a country is a major advantage in the field of solar energy. On an average India receive 4-7 kWh of solar radiation per square meter which is equivalent to 2,300-3,200 sunshine hours per year.

Solar air heating systems are being used on a wide variety of commercial, residential and industrial applications. With increasing demand of solar air heating technology researchers have done numerous work to study and enhance the performance...
of solar air heater. The objective of the present study is to review different techniques used in the past for heat transfer augmentation in SAH. Important findings from various investigations have been discussed. The effect of different parameters on SAH thermal performance and its optimum effect has also been presented where possible.

II. ARTIFICIAL ROUGHNESS AND ITS EFFECT ON SAH

Artificial roughened surface is an effective technique to improve the rate of heat transfer to fluid flow in the duct of a SAH. Different geometries of roughness elements has been investigated on the heat transfer and friction characteristics of SAH ducts.

A. Chamfered Repeated Rib-Roughness

The maximum enhancement of Nusselt number occurs for chamfer angle of 18° but the friction factor increases monotonously with increase in chamfer angle. As compared to smooth surface the roughened surface can yield a maximum of about 2.6 times and 3.35 times increase in the Nusselt number and friction factor respectively. It is also found that as the value of chamfer angle increases, Nusselt number increases as well as friction factor also increases[4].

![Fig. 1: Chamfered repeated rib-roughness](image1)

B. Integral Inclined Discrete Ribs

The rib-roughened surface yields an increase of about 2.83 and 3.60 times in the Nusselt number and friction factor respectively as compared to the smooth surface for the given range of parameters. The maximum heat transfer enhancement occurs at the relative gap position of 0.25 with the relative gap width of 1.0 for the relative roughness pitch of 8.0, angle of attack of 60˚ and relative roughness height of 0.037. The value of friction factor increases with increase in the relative roughness pitch from 4.0 to 8.0, attains the maximum value at the pitch of 8.0 and then decreases with further increase in the relative roughness pitch.

![Fig. 2: Integral inclined discrete ribs](image2)

The variation of friction factor with Reynolds number for different values of relative roughness pitch is shown in Fig. 2 for the relative gap position (d/W) of 0.25, relative gap width (g/e) of 1.0, angle of attack of 60˚ and relative roughness height of 0.037[8].
C. V-Shaped Rib Roughness

![Fig. 3: V-Shaped Rib Roughness](image)

![Fig. 4: Discrete W-Shaped Rib Roughness](image)

The maximum enhancement of Nusselt number and friction factor for V-shaped artificial roughness is 2.30 and 2.83 times respectively that of smooth duct for an angle of attack of 60°. It is also observed that the same angle of attack (60°) corresponds to the maximum values of both Nusselt number and friction factor. The rate of increase of Nusselt number with an increase in Reynolds number is lower than the rate of increase of friction factor; this appears due to the fact that at relatively higher values of relative roughness height [14].

D. Discrete W-Down Rib Roughness

The maximum enhancement of Nusselt number and friction factor for discrete W-shaped artificial roughness has been found to be 2.16 and 2.75 times that of smooth duct for an angle of attack of 60°. It is investigated that the same angle of attack corresponds to the maximum values of both Nusselt number and friction factor. It appears that the flow separation and the secondary flow resulting from the presence of discrete W-shaped ribs and the movement of resulting vortices combine to yield an optimum value of angle of attack. The effect of Reynolds number on Nusselt number and friction factor is much stronger as compared to that of the angle of attack as represented by a relatively higher exponent of Reynolds number in both these cases [5].

E. Transverse Wedge Shaped Rib Roughness

A maximum enhancement of heat transfer occurs at a wedge angle of about 10° while on either side of this wedge angle, Nusselt number decreases. The friction factor increases as the wedge angle increases. The maximum enhancement in Nu value is of the order of 2.4 times for using wedge shaped rib. The maximum enhancement in friction factor value is of the order of 5.3 times for using wedge shaped rib[10].

![Fig. 5: Transverse wedge shaped rib roughness](image)
F. **Dimple-Shaped Rib Roughness**

The maximum value of Nusselt number is found corresponds to relative roughness height (e/D) of 0.0379 and relative roughness pitch (p/e) of 10. The minimum value of friction factor is found corresponds to relative roughness height (e/D) of 0.0289 and relative roughness pitch(p/e) of 10 [7].

![Dimple-shaped rib roughness](image)

**Fig. 6: Dimple-shaped rib roughness**

<table>
<thead>
<tr>
<th>e/D</th>
<th>p/e</th>
</tr>
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<tbody>
<tr>
<td>0.0379</td>
<td>10</td>
</tr>
<tr>
<td>0.0289</td>
<td>10</td>
</tr>
</tbody>
</table>

G. **90° Broken Rib Roughness**

For 90° broken rib roughness Nusselt number increases for entire range of Reynolds number attains a maximum for roughness pitch of 20 mm (p/e = 13.33, e/D = 0.0338, W/H= 8) and decreases with an increase of roughness pitch. The maximum enhancement of heat transfer coefficient occurs at pitch of about 20 mm (p/e = 13.33, e/D = 0.0338, W/H= 8) and Roughened absorber plates increase the heat transfer coefficient 1.25–1.4 times as compared to smooth rectangular duct under similar operating conditions at higher Reynolds number [9].

![90° broken rib roughness](image)

**Fig. 7: 90° broken rib roughness**

III. **DOUBLE PASS SOLAR AIR HEATER**

The thermal Efficiency of a double pass Solar Air Heater is higher compared to single pass with the concept involved of doubling the heat transfer area. A number of studies have been carried out on the performance analysis of double pass solar air heater. Chamoli et al. [1] studied double pass solar air heater with parallel and counter flow arrangement. It was found that the maximum efficiency is obtained if the channel depths and mass flow rate is same in both the upper and lower duct. Double pass solar air heater integrated with porous media and extended surfaces can have efficiency improvement index from 70% to 130%. Dong Ho et al. [2] concluded from his experiments that increasing the reflux ratio and mass flow rate increases the thermal efficiency of double pass solar air heater. The results showed that the optimum value of reflux ratio is 0.5.

![Double pass Solar air heater](image)

**Fig. 8: Double pass Solar air heater**
IV. EFFECT OF GEOMETRIC AND OPERATING PARAMETERS ON SAH

The effect of different geometric and operating parameters on Solar Air Heater has been investigated through CFD simulation analysis. For the thermal performance study and analysis an experimental set-up of single pass fin type solar air heater (area 1.06 m$^2$) has been used. SAH (outer dimensions 1.27 m × 0.93 m × 8 cm) has a circular inlet and outlet pipe of 5 cm and 3.5 cm diameter respectively in the mid of collector width and an electric motor (0.372 kW) for circulation of air. The ordinary black painted cast iron absorber plate (1.21 m × 0.88 m) with transparent glass cover and four equally spaced fins (size 0.4 m × 0.04 m) of cast iron arranged in zigzag manner between the absorber plate and bottom plate made of wood with 2 cm air gap on the both sides of the fin are used in the air heater. The angle of inclination for solar air heater is kept 42° [i.e., latitude of Jaipur (27°) + 15°] [3].

A. Effect of number of Fins

Two, four and six fins were considered with optimum air flow rate of 0.024 kg/s and solar radiation and ambient air temperature were kept same as in the experimental observation. Maximum heat gain and outlet temperature of air is obtained with the use of six fins but the effect of six fins in terms of thermal performance improvement is not significant because of the higher air outlet velocity and lower turbulence intensity as compared to four number of fins. The motion of the air through solar air heater and its thermal performance is dependent on the number, length and height of fins attached apart from other parameters. The performance is optimum with four fins as there is no significant difference in the thermal performance between four and six fins [3].

B. Effect of fin length

Four fin lengths from 40 cm to 70 cm are considered in the simulation with optimum air flow rate of 0.024 kg/s, four number of fins and keeping other parameters same as in experimental observation. When fin length increased from 40 cm to 50 cm the performance of SAH in terms of useful heat gain improves significantly for both fin height of 4 cm and 6 cm, but further increase in the fin length to 60 cm and 70 cm does not bring further improvement in the performance of solar air heater. Thus 50 cm is the optimum fin length. Performance of solar air heater with 6 cm fin height is better in comparison to 4 cm fin height for 50 cm fin length because with 4 cm fin height there is 2 cm air gap above and below the fin through which large amount of air gets by passed[3].

C. Effect of fin height

Fin height of 4 cm, 6 cm and 8 cm have been considered with fin length 40 cm, 4 number of fin and 0.024 kg/s air flow rate while other parameters like solar radiation and ambient temperature are kept same as the experimental observation. The reason behind higher outlet velocity and lower turbulence intensity is that with 8 cm fin height there is no space above and below the fins so the whirled air gets trapped. Hence, fresh air instead of going into the whirl gets by-passed through central gap between fins [3].

D. Effect of mass flow rate

Solar air heater different flow rates ranging from 0.01 to 0.05 kg/s have been considered during the simulation and other parameters such as solar radiation and ambient air temperature were taken same as in the experimental observation. As the air flow rate increases, the useful heat gain also increases but outlet air temperature decreases and outlet air temperature from heater decreases. An optimum point at air flow rate of 0.024 kg/s where the solar air heater performance in terms of air outlet temperature and heat gain is optimum [3].

V. EFFECT OF SELECTIVE COATING

To improve the solar air heater performance, effect of using absorber plates coated with various selective coating materials on the solar air heater performance can also be considered. The best performance was achieved using nickel–tin as a selective coating material with a daily average of the instantaneous efficiency of 0.46 due to the decreased rate of heat losses and the increased rate of useful energy.
For Ni–Sn as a selective material, the total rate of energy losses was found to decrease by 30%, however, the rate of useful energy was increased by 30.95% compared to those for the black painted absorber and it was also noted that the annual average of $\eta$ with the Ni–Sn selectively coated absorber is higher than that with a black painted absorber by 29.23%. The conventional flat plate solar air heaters with Ni–Sn or CoO as selective coating materials can be used as a heat source for high temperature agricultural drying and some industrial applications require temperatures around 80 °C.[6]

VI. CONCLUSION

It was found that Integral discrete inclined rib gives the best result among the other types of artificial roughness which gives about 2.83 times more the value of Nusselt number over the smooth duct for $\alpha=60^\circ$, $e/D=0.037$, $p/e=8$ and $d/H=0.25$. Chamfered type of artificial roughness also gives good result among the other types of artificial roughness which about 2.6 times more the value of Nusselt number ($Nu=138.5$) over the smooth duct for $\phi=14.5^\circ$, $e/D=0.0278$, $p/e = 5.41$ and $W/H=4.82$. It is also observed that friction factor tends to decreases as the Reynolds number increases. The effect of selective coating of Ni-Sn gives the best result that heat losses is decreased about 30%. It was observed that the performance is optimum with four fins as compare to six fin because of the higher air outlet velocity (6.26m/s) and lower turbulence intensity (10.11%). Optimum fin length is 50 cm because with six fin it gives maximum heat gain about 481.63W at air flow rate of 0.024 kg/s.

REFERENCES