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A Relative Study of Solar Air Heater Having Turbulators

Gyaneshwar Sanodiya

Abstract*: Due to the depletion of fossil fuel reserves, it is now more important than ever to explore and use alternate forms of energy. Solar energy is a promising long-term solution that can meet the world's energy needs. Due to the depletion of fossil fuel reserves, it is essential that we explore and use energy-related solutions as soon as possible. Solar energy is a promising long-term solution. Artificially roughened solar air heaters perform better than the smooth ones under the same operating conditions. However, artificial roughness leads to even more fluid pressure thereby increasing the pumping power. In this article a comparative study of thermo-hydraulic performance of two different types of artificial roughness geometries attached on the absorber plate of solar air heater has been performed in terms of thermo-hydraulic performance parameter.

***Keywords*: Solar Energy, Solar Air Heater, Artificial Roughness, Thermo-Hydraulic Performance.**

I. INTRODUCTION

Solar air heaters, because of their simplicity are cheap and most widely used collection devices of solar energy, has great potential for low temperature applications, particularly for drying of agricultural products. The thermal efficiency of a solar air heater is significantly low because of the low value of the convective heat transfer coefficient between the absorber plate and the air, leading to high absorber plate temperature and high heat losses to the surroundings. It has been 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. An artificial roughness on the heat transfer surface in the form of projections mainly creates turbulence near the wall or breaks the laminar sub-layer and thus enhances the heat transfer coefficient. However, the energy for creating such turbulence has to come from the fan or blower. It is therefore; the turbulence must be created only in the region very close to the heat transferring surface, i.e., in the laminar sub-layer only [1-17]. The artificial roughness has been used extensively for the enhancement of forced convective heat transfer, which further requires flow at the heat-transferring surface to be turbulent. However, the artificial roughness results in higher frictional losses leading to excessive power requirement for the fluid to flow through the duct. It is therefore, desirable that the turbulence must be created only very close to the surface that is in laminar sub layer only, where the heat exchange takes place and the core of the flow is not unduly disturbed to avoid excessive losses. This can be done by keeping the height of the roughness elements small in comparison to the duct dimensions [18-33]. A solar air heater is the most commonly used collector device due to its simplicity (Fig. 1). They are also the least expensive. Aside from solar power, solar air heaters are also used for various applications such as heating. Due to their simplicity, solar air heaters are commonly used for the heating of various areas They can also be used to provide heat to spaces with low temperatures.

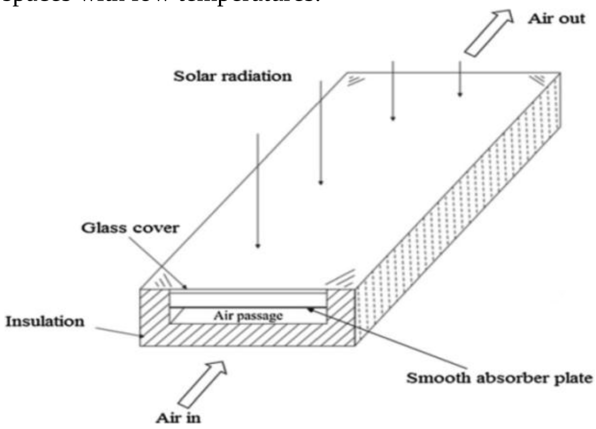

Fig. 1. SAH

To make solar air heaters more financially feasible in the long run, their thermal efficiency must be enhanced. This step involves increasing the air flow through the duct system and the plate to improve the thermal efficiency of the device. An increase in the HT between the air flow and the plate can help boost the device's thermal efficiency. HT coefficients can be divided into two categories. If solar radiation goes directly over the darkened protective surface of the highly absorbent, a large part of the vitality is absorbed and replaced in liquid tubes into the vehicle medium for capacity diversion or utilization. The underside of the safety board and both sides are covered from diminishing conduction Several investigators have attempted to design a roughness element, which can enhance convective heat transfer with minimum pumping losses [34-39]. Investigations of solar air heaters that form a system with only one roughened wall and three smooth walls have been carried out by various. The active force techniques that are commonly used involve an acoustic field, a surface vibration, or an electric field. The use of a fluid field to improve a HT system has been around for over 80 years. These techniques are known to improve a HT system by using a combination of factors, such as an acoustic field and an electric field.

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***** Correspondence Author
Gyaneshwar Sanodiya*, Department of Mechanical Engineering, Oriental College of Technology, Bhopal (MP), India. Email: gyan.sanodiya1@gmail.com

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The use of a fluid field and electric field to achieve this goal has been the subject of extensive research. Aside from physical surfaces, the techniques used for swirling flow involve adding fluid additives and using a variety of devices such as twisted tap inserts. To produce a swirling flow, the active methods need to have specific surface geometries. For over 140 years, researchers have been studying the various techniques that were used to improve a HT system. Studies carried out by these researchers have shown that the geometry of rib, namely shape, pitch, angle of attack and height, affects significantly the heat transfer and friction characteristics of the duct. It has been found that discrete inclined or V-shaped rib arrangement yields better performance as compared to continuous rib arrangement [40-52]. In this article a comparative study of thermo-hydraulic performance of two different types of artificial roughness geometries attached on the absorber plate of solar air heater has been performed in terms of thermo-hydraulic performance parameter.

II. METHODOLOGY

Thermal performance

Thermal performance of solar air heater can be expressed as:

$$Q_u = A_p\ F_R\ [\ I(\tau\alpha)_e - U_L\ (T_i - T_a)] \quad (1)$$

or

$$q_u = \frac{Q_u}{A_p} = F_R\ [\ I(\tau\alpha)_e - U_L\ (T_i - T_a)] \quad (2)$$

The rate of valuable energy gain by flowing air in the course of duct of a solar air heater can be intended as follows equation;

$$Q_u = m\ c_p\ (T_o - T_i) = hA_p\ (T_{pm} - T_{am}) \quad (3)$$

The value of heat transfer coefficient (h) can be increased by various active and passive augmentation techniques. It can be represented in non-dimensional form of Nusselt number (Nu).

$$Nu = hL/k \quad (4)$$

Further, thermal efficiency of a solar air heater can be expressed by the following equation;

$$\eta_{th} = \frac{q_u}{I} = F_R\ [(\tau\alpha)_e - U_L\ (T_i - T_a)/I\ ] \quad (5)$$

Hydraulic performance

Pressure drop can be represented in non-dimensional form by using the following relationship of fanning friction factor (f).

$$f = \Delta PD/2\rho L v^2 \quad (6)$$

Thermo-hydraulic performance

An important thermo-hydraulic performance evaluation parameter which is used to compare the heat transfer of artificially roughened duct to that of a smooth duct under constant pumping power constraints as defined by Webb and Eckert (1972):

$$\text{Thermo} - \text{hydraulic performance parameter} = \frac{\left(Nu_r/Nu_s\right)}{\left(f_r/f_s\right)^{\frac{1}{3}}} \quad (7)$$

A value of this parameter higher than unity ensures the effectiveness of using an enhancement device and can be used to compare the performance of number of arrangements to decide the best among these.

III. RESULT AND DISCUSSION

An artificial roughness enhancement can be commonly used in forced convection HT to improve the turbulence near the HT surface. However, this method requires too much electricity to effectively move the air through the duct. In most cases, the use of artificial roughness has been widely adopted to improve the turbulence near the HT surface. However, this method usually consumes a high amount of electricity and requires a low power consumption to get done.

Table 1 Fixed value of geometrical and operating parameters.

Geometrical and operating parameters	Fixed value
Length of duct, *L* (mm)	1000
Height of duct, *H* (mm)	20
Width of duct, *W* (mm)	300
Duct aspect ratio, *W/H*	15
Reynolds number, *Re*	3800-18000
Angle of attack of flow, α (deg)	60°
Intensity of solar radiation, *I* (W/m^2)	800
Chamfer angle, φ (deg)	10°
Relative roughness pitch, *P/e*	10
Relative roughness height, *e/D*	0.02
Density of air, ρ (kg/m^3)	1.105
Specific heat of air, C_p (J/kg-k)	1008
Thermal conductivity of air, *k* (J/kg-m-k)	0.026
Viscosity of air, μ (kg/s-m)	1.865×10^{-5}

The key dimensionless geometrical parameters that are used to characterize artificial roughness are: Relative roughness pitch (P/e): Relative roughness pitch (P/e) is defined as the ratio of distance between two consecutive ribs and height of the rib. Relative roughness height (e/D): Relative roughness height (e/D) is the ratio of rib height to equivalent diameter of the air passage. Angle of attack (α): Angle of attack is inclination of rib with direction of air flow in duct. Aspect ratio: It is ratio of duct width to duct height. This factor also plays a very crucial role in investigating thermo-hydraulic performance. In this article two different shapes (circular and square shaped) of roughness elements are considered for comparative analysis. The fixed values of parameters considered under the present investigation are given in Table 1. Fig. 2 shows the variation of thermo-hydraulic performance parameter with Reynolds number for circular and wedge shape rib roughness geometries used in solar air heaters duct. The thermo-hydraulic performance parameter initially tends to increase with the rise of Reynolds number and then decreases with the further rise of Reynolds number. Hence there is an optimum value of relative roughness height, relative roughness pitch and Reynolds number which give the maximum thermo-hydraulic performance parameter.

This comparative analysis has proved that square shaped rib roughness geometry has the highest thermo-hydraulic performance parameter as compared to circular rib roughness geometry.

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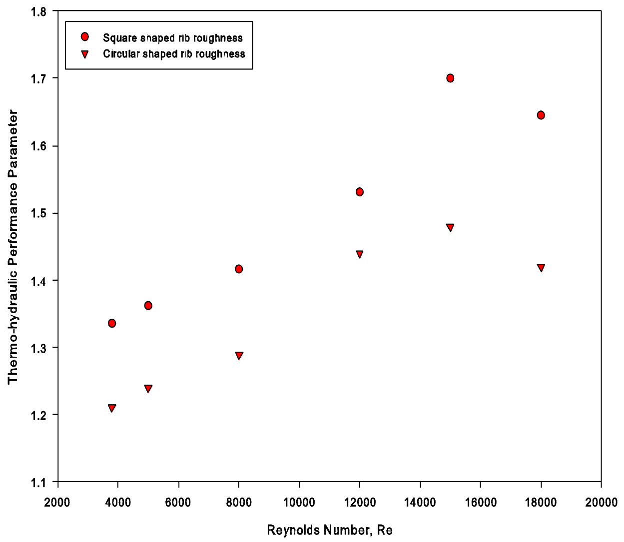

Fig. 2. The variation of THPP with Re

IV. CONCLUSION

The major conclusion drawn from the investigations are as follows:

1. Use of artificial roughness brings about a substantial improvement in the performance of the solar air heater resulting in size reduction or maximization of heat transfer rate. Thereby, conserving energy along with savings in material cost.
2. Rib Roughness strongly affects the flow pattern and hence the performance of the duct.
3. Solar air heaters with roughened absorbers perform better as compared to smooth heaters.
4. It was observed that 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, the reattachment of free shear layer might not occur and the rate of heat transfer enhancement will not be proportional to that of friction factor.
5. Square shaped rib roughness geometry has the highest thermo-hydraulic performance parameter as compared to circular rib roughness geometry.

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AUTHORS PROFILE

Gyaneshwar Sanodiya, pursuing M. Tech. (Thermal Engineering) in the Department of Mechanical Engineering at Oriental College of Technology, Bhopal (MP). He received his Diploma in Production Engineering from S V Polytechnic College Bhopal (MP). He received his Bachelor's Degree in Mechanical Engineering from Trinity Institute of Technology & Research, Bhopal (MP).

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