The Effect of Roughness Geometries on Heat Transfer Enhancement in Solar Air Heater - A Review

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Abstract: Artificial roughness applied on the absorber plate in the solar air heater is the most acclaimed method to improve thermal performance. Moreover it is required to understand how flow field is affected by particular roughness geometry with artificial roughness. This roughness creates turbulence in flowing air by disturbing laminar sub-layer as turbulence increases there in increament of heat transfer rate.Some distinguished roughness geometries have been compared on the basis of heat transfer enhancements, Nusselt number and friction factor correlations as function of system and operating parameters for predicting performance of the system having investigated type of roughness geometry.Artificial roughness in the form of ribs is a convenient method for enhancing thermal performance of solar air heaters.W shape rectangular ribs in discrete form with double passwill show the significant increase in heat transfer rate and friction loss over the smooth channel in the range of parameter of Renolds no 10000 to 12000, relative roughness height 0.043 to0.044, relative roughness pitch 10 to 12, angle of attack 60° to 70°.

***Keywords**: Solar air heater, artificial roughness, Thermo-hydraulic performance, Friction factor, angle of attack.*

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1. Introduction

In the ongoing era, when there is a continuous increasing demand of energy for the progress and industrialization, renewable energy sources are playing vital role. Everyone wants to design high performance heat transfer systems.Conventional energy sources are depleting day by day and seem to be insufficient to fulfill large demand of energy in coming years. As one of long term alternative, the renewable energy sources are having enough potential to occupy the place of conventional energy sources. Solar energy is one of the promising and easily convertible forms of renewable energy. Though it is location and time dependent and requires efficient collection and storage systems for economical utilization. Solar air heaters are one of the simplest and cost effective solar energy utilization systems, converts solar radiations into the useful thermal energy being absorbed by fluid medium which can be stored and utilized for various heating and drying applications. The thermal efficiency of solar air heaters is found to be low due to low heat transfer coefficient on the air side. Attempts have been made to enhance the heat transfer rate from the absorber plate to air by extending surfaces in the form of fins so that larger surface area could be available for convection to compensate the lower values of heat transfer coefficient. Designed devices using solar energy works on a principle of conversion of solar energy into thermal energy are heat exchangers and solar air heater that are considered as cost effective products based on solar energy. Schematic representation of the solar air heater is shown in Fig. 1.

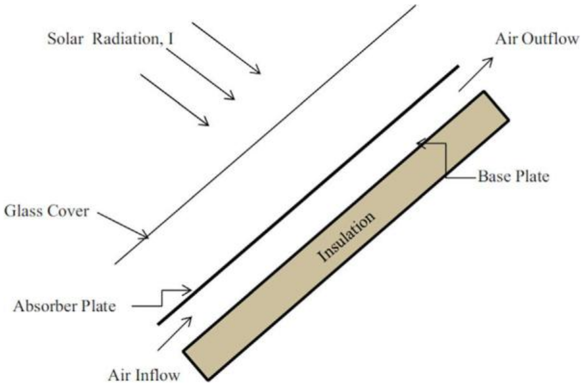

Fig. 1. Schematic diagram of conventional solar heater.

Solar air heaters are the devices which absorb the incoming solar radiations and convert it into thermal energy at the absorbing surface. The attempts to enhance the heat transfer includes provision of artificial roughness on the underside of absorber plate in the form of ribs, grooves, winglets, baffles, etc. Artificialroughness is a passive heat transfer enhancement technique which uses to improve thermo hydraulic performance of a solar heater . As the air flows through the duct of a solar air heater, a laminar sub layer is formed over the observer surface. Duct obstruct heat transfer to the flowing air, which adversely affecting the thermal performance of the solar air heater. Here we need higher heat transfer coefficient, so the flow at the heat transferring surface is made turbulent. Then energy for creating that turbulence has to come from fan, which increases the power requirement. So artificially roughened absorber plate is a good methodology to increase the heat transfer coefficient. This causes increase in friction loss in duct. It is desirable to create turbulence in the region very close to the heat transfer, in order to reduce the friction loss with the application of artificial roughness and power requirement may be lessened. This can be done by keeping the height of the roughness elements to be small in comparison with the duct dimension. The flow behavior in the viscous sublayer region due to presence of repeated roughness elements [10].

The objective of the present paper is

(1) Classification of various types of roughness geometries so that for a specific purpose particular type of geometry can be selected as per the need.

(2) To discuss various types of roughness geometry.

(3) To discuss the variation of Nusselt and friction factor .

1.1.Analysis of solar air heater

Basic analysis of a solar heater helps us to make an efficient system. Thermal performance related with the heat transfer process within the collector and hydraulic performance deals with the pressure drop in the duct. A conventional solar air heater shown in Fig. 1 is considered for basic solar air heater.

Matte Black Interior – All surface which are situated at the inner part of solar air heater painted with deep black as that surface can absorb as much of the sun’s heat as possible.

Frame – It is generally made of wood or sometimes metal.

Air intake/outlet – Inlet is provided at the bottom through which cold air will pass and come in contact with heated inner surface, exits the top of air heater. This happens either through a natural process or thermostatically-controlled fan.

Insulation – Insulation is provided on the bottom and side walls to prevent the loss of heat from that walls.

Solar absorber – Solar absorber collects the heat which is coming from sun light and transferred to air traveling in the vicinity of that heated surfaces.

2. Literature Review

A variety of roughness geometries like ribs, protrusions, wire mesh and baffles have been investigated to examine that’s effect with respect to plane on the thermo-hydraulic performance of solar air heater. There are some detailed review of the roughness geometries used by researchers in the solar air heater have been presented in the recent past [1-4].

The following sections shows the effect of prominent roughness geometries and their parameters on the fluid flow and heat transfer and how efficient they are with comparison to others.

Maithani and Saini [5] investigated the effect of V-ribs with symmetrical gaps on heat transfer and pressure drop in a solar air heater.They found in his research that by incorporation of symmetrical gaps in repeated V-ribs, the Nusselt number can be enhanced up to 3.6 times and friction factor concurrently augmented to 3.67 times, in comparison to the smooth duct for the same range of parameters considered. On that roughness parameters he bring out maximum values of Nusselt number and friction factor are written as
N_g: 3, g/e: 4, p/e: 10 and α: 60°.

Deo et al. [6]experiment reported that the thermo-hydraulic performance has been lifted up to 2.45 by creation of multiple gaps in V-down rib roughness with staggered ribs while keeping the roughness pitch (p/e) of 12, roughness height (e/D_h) of 0.044 and angle of attack of 60° at Reynolds number of 12,000.

Kumar et al. [7] observed that both Nusselt number and friction factor attained maximum value at an angle of attack (α) of 55°. It was found that the V-pattern dimpled obstacles performed better than other dimple shaped obstacles and the optimum value of thermal hydraulic performance parameter was obtained as 3.26.

Thakur et al. [8] performed a 3D CFD simulation analysis on novel hyperbolic rib as roughness geometry with parabolic tip in the experiment showed the best performance with V-shaped configuration for rib height of 1 mm, rib pitch of 10 mm and angle of attack of 60° at the Reynolds number of 6000.

Jin et al. [9] investigated the effect of staggered multiple V-shaped ribs and concluded that the subsidiary vortex strength in the inter-rib region and redevelopment length in the leading end region are dependent on the stagger distance which greatly affects the heat transfer enhancement.

Anil et al. [11]In the experiment as the relative roughness width (W/w) is increased as a result of producing multiple v-ribs heat transfer further increases on account of formation of higher number of leading ends and secondary flow cells.

Kumar et al. [12] carried an experimental and get maximum heat transfer enhancement occurs for the relative roughness pitch of 12, relative gap position of 0.35 and relative roughness height of 0.0498

Singhet al. [13] experimentally investigated that the value of Nusselt number is found to be highest at angle of attack (α)¼ 60°. Also maximum value of Nusselt number is recorded at relative gap position (d/w) of 0.65.

Bhushan et al. [14] carried maximum enhancement of Nusselt number and friction factor has been found 3.8 and 2.2 times respectively in comparison to smooth duct for the investigated range of parameters.

Lanjewar et al. [15] experimentally investigated that. The duct had a width to height ratio (W/H) of 8.0, relative roughness pitch (P/e) of 10, relative roughness height (e/D_h) of 0.03375 and angle of attack of flow (α) of 30°–75°.. Highest enhancement in thermo-hydraulic performance for W-down ribs was 1.98 while it was 1.81 for W-up ribs in the range of parameters investigated. The geometry has been shown in Fig. 2.

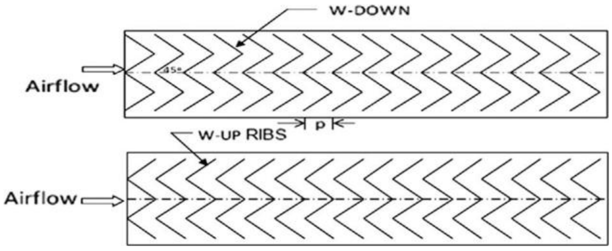

Fig .2. W-shaped rib[15].

Sriromrein et al. [16] studied heat transfer and friction char-acteristic of a rectangular duct roughened artificially with Z-shape ribs as shown in Fig.3. The enhancement in heat transfer rate and best thermal performance was reported for Z-rib inclined at 45°.

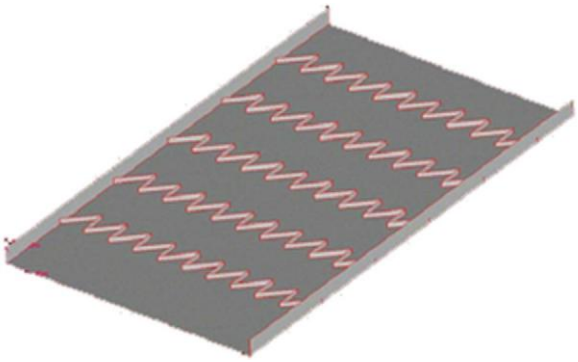

Fig.3. Z-shaped rib[16].

Promvonge [17]experimentaly confirmed that the V-baffle provides the drastic increase in Nusselt number, friction factor and thermal enhancement factor values over the smooth wall channel due to better flow mixing from the formation of secondary flows induced by vortex flows generated by the V-baffle. Significant increase in Nusselt number and friction factor values were found for the rise in blockage ratio and/or for the decrease in pitch ratio values. At lower Reynolds number, the use of V-baffle with e/H¼ 0.10 and PR¼ 1, reported the highest value of 1.87 for thermal enhancement factor.

Promvonge et al. [18] reported as 1.2–11 times for using the 30° baffle pair with BR¼ 0.1–0.3 and PR¼ 1, 1.5 and 2. Penalty of pressure loss in the range 2 to 54 times above the smooth channel was also reported by investigators. The maximum value of thermal enhancement factor was found to be 4.0 at highest Reynolds number and PR¼ 2. When effect of the baffle PR and BR values on heat transfer rate is examined, it was found that the maximum enhancement factor is about 4.0 for BR¼ 0.15, PR¼ 2.0 and Re¼ 2000

A numerical investigation had been carried out by Promvonge et al. [19]the heat transfer enhancement wasabout 100–1100% for using both the 45° baffles with BR¼ 0.05–0.3 and pressure loss ranging from 2 to 90 times above the smooth channel. Maximum value of thermal enhancement factor was reported as about 2.6–2.75 indicating higher thermal performance over smooth channel.

Promvonge et al. [20]numerical investigation reported that the P-vortex flow caused by the V-baffle induced impingement/attachment flows on the channel walls leading to drastic increase in the heat transfer rate and found to be about 1–21 times higher than the smooth channel with no baffle. However, this also results in friction loss ranging from about 1.1 to 225 times above the smooth channel.

A numerical investigation had been carried out by Promvonge et al. [21] the enhancement was in the order of 150–850% for using both the 45° baffles with BR¼ 0.05–0.3. On the other hand, the heat transfer augmentation is associated with enlarged pressure loss ranging from 2 to 70 times above the smooth channel. They investigated that for the 45° baffles, the heat transfer enhancement was around 100–200% higher than that for the 90° baffle whereas the friction loss can be reduced at about 10–150%.

Kwankao-meng et al. [22] numerically investigated the order of enhancement is about 100–650% for using the angled baffles with BR¼ 0.1–0.3. The heat transfer augmentation was associated with enlarged pressure loss ranging from 1 to 17 times above the smooth channel.Thermal enhancement factors for the inclined baffles at BR¼ 0.15 was found to be highest about 2.9.

Chii-Dong et al. [23] performed a solar air heater featured with double-pass as well as fins and baffles. The best possible reflux ratio for the fined plus baffled double-pass design was investigated about 0.5 while considering both the collector efficiency and the pumping power requirement.

Sriromreun et al. [24] investigated experimentally and numerically the Effects of the Z-baffle height and pitch spacing length were examined to find the optimum thermal performance for the Reynolds number from 4400 to 20,400. The Z-baffles inclined to 45° relative to the main flow direction were characterized at three baffle to channel-heightratios (e/H¼ 0.1, 0.2 and 0.3) and baffle pitch ratios (P/H¼ 1.5, 2 and 3).

Min et al. [25] Study shows that the modified rectangular wing pairs (MRWPs) have better flow and heat transfer characteristics than those of rectangularwing pair (RWP). It was found that at z¼740 mm from the centerline of the heater plate, the local heat transfer is enhanced due to the strong longitudinal vortices generated by the presence of the LVGs.

Kotcioglu et al. [26] analysedand found that at the low Reynolds number, the entropy generation number was influenced by the heat transfer while at the high Reynolds number, it was influenced by the pressure drop. Another conclusion reported that, the present vortex generator (CDLVG) shows an increase in the heat transfer enhancement from 15% to 30% and also an increase in the pressure-loss penalty from 20% to 30%, in a comparison with and without vortex generators, respectively.

Champookham et al. [27] investigated. The test channel had an aspect ratio, AR¼ 10 and height, H¼ 30 mm with a rib height, e/H¼ 0.2 and rib pitch, P/H¼ 1.33 with the Reynolds number range of 5000–22,000. Investigations reported that the use of the wedge rib turbulators with e/H¼ 0.2 causes a high pressure drop increase, specially for the in-line wedge pointing downstream and also provides considerable heat transfer augmentations, Nu/Nu_0¼ 2.9–3.5 for use with the WVGs.

Promvonge et al. [28] experimentally studied the effects of Rectangular channel with aspect ratio, AR¼ 10, height, H¼ 30 mm with Reynolds number in the range of 5000–22,000 was used. They reported that combined rib and the DW provides considerable heat transfer augmentations, Nu/Nu_0¼ 2.3–2.6 and also causes a moderate pressure drop increase, f/f_0¼ 4.7–10.1, depending on the attack angle and Re values. Another conclusion is that, the use of combined rib and PD-DW at lower angle of attack provides higher heat transfer of about 40–65% and better thermal performance than the rib/the DW alone, leading to more compact heat exchan-ger.

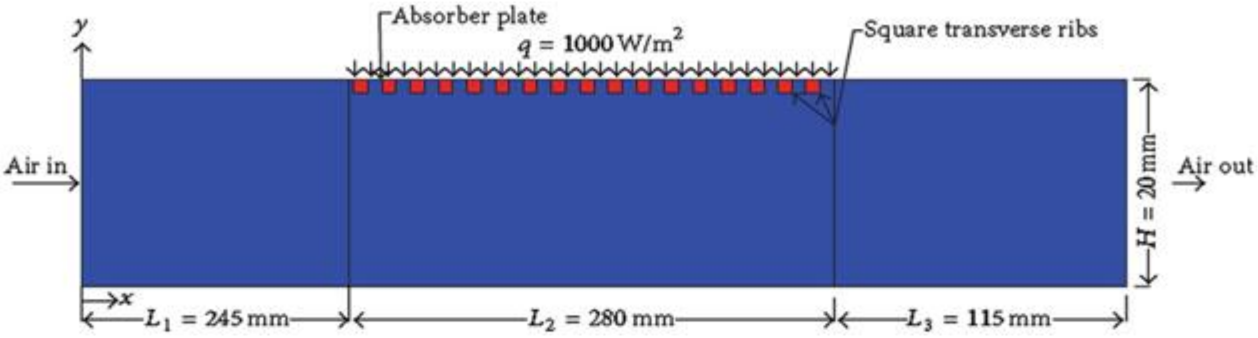

Fig.4. Geometry of two dimensional domain[32].

Zhou and Ye [29]studied that Delta Winglet Pair (DWP) is the best in laminar and transitional flow region, while Curved Trapezoidal Winglet Pair (CTWP) has the best thermo hydraulic performance in fully turbulent region due to the streamlined configuration and then the low pressure drop, which indicates the advantages of using this kind of vortex generators for heat transfer enhancement. Small attack angle of CTWP, such as β¼ 01 and 151, have better thermo hydraulic performance of R than larger attack angles. Particularly, when Re is larger than 18,000, β¼ 01 presents the best thermo hydraulic performance with R as high as 1.6.

Tanda [30]study the effect of rib spacing on the thermal performance of the ribbed channel, the parallel ribs have been installed either onto one wall of the channel (1RW case) or, in-line, onto two opposite walls (2RW case) with a rib pitch-to-height ratio ranging from 6.66 to 20.0. Heat transfer augmentations, relative to the smooth channel with the same mass flow rate, decrease with Re, as typically occurs in rib-roughened channels, and range from 1.6 to 2.25 for the 1 RW case and from 1.85 to 2.55 for the 2RW case.

Chauhan et al. [31] experimentally investigated to study heat transfer and friction factor characteristics using impinging jets in solar air heater duct. The study shows that there is considerable enhancement in heat transfer and friction factor by 2.67 and 3.5 times respectively.

Yadav et al. [32] carried literature survey in the field of artificially roughened solar airheater. A CFD based investigation of turbulent flow through a solar air heater with square sectioned transverse rib roughness as shown in Fig.4. .Using four different configurations of rib roughness keeping relative roughness pitch constant at P/e14.29 and six different values of Reynolds number, ranging from 3800 to 18,000, reveals that the relative roughness height is a vital factor and mainly affects the rate of heat transfer and the increase in flow friction. In this analysis, the maximum value of thermo hydraulic performance parameter (THPP) has been found to be 1.8 for the range of parameters investigated

Sharma et al. [33] showed the combined effect of swirling motion, detachment and reattach-ment of the fluid were responsible for the increase of heat transfer rate during CFD analysis. Nusselt number increases and friction factor decreases with increase in Reynolds number for all combination of relative roughness height (e/D) and relative roughness pitch (P/e). An average percentage deviation predicted between CFD and exact solution was found less than 73%. V-shaped rib roughness found to give high rate of heat transfer.

3.Concusions:

Various researchers reported that there is a heat transfer enhancement because of the inclusion of the roughness geometry inthe path of the air flow. But this heat transfer enhancement is also leads to increased pumping power penalty due to correspond-ing increase in friction factor. So it is essential to determine the geometry that will results in the maximum enhancement in heat transfer and minimum increase in friction factor

Correlations of heat transfer and friction factor for different roughness geometries in double pass solar air heater are used to derive thermo hydraulic performance. Therefore relative roughness pitch (P/e) value as 10 and relative roughness heigh range 0.043-0.044 with discrete W-shape roughness at renolds number range of 10000-12000 will give better perfomane at an angle of 50° to 70°.

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