A Review on Roughness Geometry used in Solar Air Heater

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Abstract— CFD simulation on plain surface with the help of different geometry created over it is an important technique to enhance heat transfer rate of air flowing in solar air heater. In last few year different rib geometries have been designed to simulate over ansys for enhancing heat transfer and friction characteristics of solar air heater. In this paper an investigation is made to review different simulations over different rib geometries employed for creating artificial roughness.

Keywords: CFD, Single Flow Solar Air Heater, ARC Roughness

I. INTRODUCTION

Energy is required to sustain life. Broadly energy resources can be classified into conventional and nonconventional energy resources. The conventional energy resources are soon to deplete in near future. Hence, the quest of mankind is to find alternate energy resources. Non-conventional or alternate energy resources can be divided into renewable and non-renewable energy resources. Renewable sources take less time to renew. Although there are many forms of renewable energy resources available to us, solar energy is very user friendly and reaches most of the locations of the planet naturally. Solar energy is the most promising source of energy, available freely and omnipresent. It is indigenous source of energy that provides clean energy. The easiest methodology for making the proper use of solar energy is its conversion to thermal energy using solar collector. These solar collectors are the part of solar air heater and solar water heater which are used for heating air and water respectively. Crop drying and several industrial applications were done by solar air heater which regulate heated air from low to modrate temperature. All solar technologies available to us but only solar air heater is most effective. It's largely used in industrial and commercial domain. It addresses the largest usage of building energy in heating climates such as space heating. The thermal efficiency of solar air heater having smooth plate collector is very low due to low convective heat transfer coefficient between the absorber plate and the air flowing in the duct. The use of artificial roughness in underside of absorber plate surface is an effective way to enhance the heat transfer to the flowing air through the duct, at the expense of pressure drop. Several investigators have investigated that artificial roughness is provided by fixing wires, ribs, wire mesh or expanded metal mesh and by providing roughness in dimple shaped geometry. In a smooth plate solar air heater a thin viscous sub layer develops adjacent to the wall in turbulent boundary layers where the velocity is relatively low. In this region heat transfer is predominated by conduction and beyond this heat transfer process is dominated by convection. Which results to increase the heat transfer coefficient between the absorber plate and air flowing over the plate. Improvement in thermal efficiency is improved by providing roughness, but it would result in increased frictional losses. Therefore, greater power is required by fan or blower. In order to keep the frictional losses at minimum level, the turbulence must be created only in the region very close to the duct surface i.e. in laminar sub-layer.

II. A REVIEW OF INVESTIGATIONS

1) Lanjewar et al.[1] Concept of artificial roughness on plain surface is an important technique to enhance heat transfer rate of air flowing in solar air heater. Over the years different rib geometries have been designed to investigate heat transfer and friction characteristics of solar air heater. In this paper an attempt is made to review development of different rib geometries employed for creating artificial roughness. Heat transfer and friction factor correlations developed by various investigators are presented. Performance evaluation for different orientations of double arc rib roughness is presented.
2) Gabhane et al. [2]The Thermal and hydraulic performance of Double Flow Solar Air Heater (SAH) roughened with multiple C-shape rib was investigated experimentally. Three rib angles were used for different rib geometries with varying pitch distance, an angle of attack and Reynolds number. Multiple C-shaped ribs in double flow arrangement provides better heat transfer than other arrangements. Correlations were developed for Nusselt number, friction factor, Stanton number and Thermo hydraulic performance parameter to increase the usefulness of result.
3) Pandey et al.[3] In this present article an experimental study has been carried out on heat transfer and friction factor in rectangular channel which is having multiple-arc shaped with gaps as roughness element. The investigation encompassed Reynolds number (Re) ranges from 2100 to 21,000 (7 values), relative roughness height (e/D) ranges from 0.016 to 0.044 (4 values), relative roughness pitch (p/e) ranges from 4 to 16 (4 values), arc angle (a) values are 30–75_ (4 values), relative roughness width (W/w) ranges from 1 to 7 (5 values), relative gap distance (d/x) values are 0.25–0.85 (4 values) and relative gap width (g/e) ranges from 0.5 to 2.0 (4 values). The maximum increment in Nusselt number (Nu) and friction factor (f) is 5.85 and 4.96 times in comparison to the smooth duct. Utilizing these data, correlations were developed for Nu and f.
4) Aharwal et al.[4] Artificial roughness in the form of repeated ribs has been proposed as a convenient method for enhancement of thermal performance of solar air heaters. This paper presents the experimental investigation of heat transfer and friction factor characteristics of a rectangular duct roughened with repeated square cross-section split-rib with a gap, on one broad wall arranged at an inclination with respect to the flow direction. The duct has a width to height ratio (W/H) of 5.84, relative roughness pitch (P/e) of 10, relative roughness height `(e/Dh) of 0.0377, and angle of attack (a) of 601. The gap width (g/e) and gap position (d/W)

were varied in the range of 0.5–2 and 0.1667–0.667, respectively. The heat transfer and friction characteristics of this roughened duct have been compared with those of the smooth duct under similar flow condition. The effect of gap position and gap width has been investigated for the range of flow Reynolds numbers from 3000 to 18,000. The maximum enhancement in Nusselt number and friction factor is observed to be 2.59 and 2.87 times of that of the smooth duct, respectively. The thermo-hydraulic performance parameter is found to be the maximum for the relative gap width of 1.0 and the relative gap position of 0.25.

5) Han et al. [4] experimentally investigated the effects of rib shape, angle of attack and pitch-to-rib height ratio on friction factor and heat transfer coefficient. Author reported that ribs with 45° inclinations produced better heat transfer performance than ribs with 90° orientations, when compared at the same friction power.
6) Han [5] investigated the developing heat transfer in rectangular channels with rib turbulators for rib angle varying from 90° to 30°. The combined effects of rib angle and channel aspect ratio on local heat transfer coefficient were studied. The results indicate that the best heat transfer in square channel was obtained with angled ribs at 30- 45° and was about 30% higher than the 90° transverse ribs for constant pumping power. However, for rectangular channel with aspect ratio of 2 and 4, the heat transfer enhancement using 30°-45° ribs was only 5% more than the 90° transverse rib. In general, it was noted that in square channel the heat transfer increased with decrease in rib angle whereas in rectangular channel the dependence of heat transfer on rib angle was negligible.
7) Verma and Prasad [6] developed the relations to calculate the average friction factor and Stanton number for artificial roughness of absorber plate by small diameter protrusion wire. They used these relations to compare the effect of height and pitch of roughness element on heat transfer and friction factor with already available experimental data. The friction factor for one side rough duct is determined by assuming that the total shear force in the one side rough duct is approximately equal to the combined shear force from three smooth walls in a four-sided smooth duct and the shear force from one rough wall in a four-sided rough duct. They used the friction similarity law and heat–momentum transfer analogy
8) Han et al. [7] studied a square channel with two ribbed walls for five different rib profiles. Their study illustrated that rib tabulators with greater number of sharp corners yield increasingly higher heat transfer coefficient as well as pressure drop.
9) Chandra et al. [8] carried out an experimental study of surface heat transfer and friction characteristics of a fully developed turbulent air flow in a square channel with transverse ribs on one, two, three, and four walls. Tests were performed for Reynolds numbers ranging from 10,000 to 80,000. The pitch to rib height ratio, P/e, was kept at 8 and rib height to channel hydraulic diameter ratio, e/D was kept at 0.0625. The channel length to hydraulic diameter ratio, L/D, was 20. The heat transfer coefficient and friction factor results were enhanced with the increase in the number of ribbed walls. The friction roughness function, R(e+), was almost constant over the entire range of tests performed and was within comparable limits of the previously published data. The heat transfer roughness function, G(e+), increased with roughness Reynolds number and compared well with previous work in this area. Both correlations could be used to predict the friction factor and heat transfer coefficient in a rectangular channel with varying number of ribbed walls. The results of could be used in various applications of turbulent internal channel flows involving different number of rib roughened walls.
10) Gupta et al. [9] carried out an experimental investigation on solar air heater with angled ribs with circular cross-section. They have investigated the effect of relative roughness height (e/D), inclination of rib with respect to flow direction and Reynolds number on fluid flow characteristics in transitionally rough flow region and evaluated the thermo hydraulic performance of solar air heaters.
11) Zhang et al. [10] observed that deploying of groove in between the ribs enhances the turbulences as well as reattaches the free shear layer nearer to the rib. They have reported that the addition of grooves in between adjacent square ribs enhances the heat transfer capability of the surface considerably with nearly same pressure drop penalty. It appears that it will be fruitful to investigate an artificially roughened surface with optimally chamfered rib combined with grooves present between two ribs in order to achieve further decrease in relative roughness pitch and enhancement of heat transfer rate from such a surface. In view of the above an experimental

Investigation has been planned to investigate the heat and fluid flow characteristics of artificially roughened surface with chamfered rib-grooved roughness.

12) Park et al. [11] presented the results of heat transfer and friction factor data measured in five short rectangular channels with turbulence promoters. Author investigated the combined effects of the channel aspect ratio, rib angle of attack, and flow Reynolds number on heat transfer and pressure drop in rectangular channels with two opposite ribbed walls. The channel aspect ratio (width to height, W/H, ribs on side W) varied from ¼ to ½ , to 1, 2 and 4, while the corresponding rib angles of attack were 90°, 60°, 45°, and 30°, respectively. The Reynolds number range was 10,000–60,000. The results suggested that the narrow aspect ratio channels (W/H < 1) gave much better heat transfer performance than the wide aspect ratio channels (W/H > 1). For the square channel (W/H = 1), the 60°/45°angled ribs provided the best heat transfer performance. For the narrow aspect ratio channel (W/H=1/4 or 1/2), the 45°/60°angled ribs were recommended while the 30°/45°angled ribs were better for wide aspect ratio channels (W/H = 4 or 2).

III. METHODS FOR PROVIDING ROUGHNESS

The surface roughness is produced by several methods, such as sand blasting, machining, casting, forming, welding ribs and by fixing thin circular wires along the surface(metal rib grits). Different types of wire, rib or wire mesh with different shapes, orientations and configurations on the surface are used to create required roughness. The easiest method used for the enhancement of heat transfer is to provide artificial roughness on the underside of plate. Hence, the chief domain of concern for investigators is to find appropriate geometry of roughness element that would enhance the heat transfer between the absorber plate and flowing fluid with lowering the friction factor.

A. Types of Roughness

Geometries Roughness elements play a vital role in increasing the heat transfer characteristics of absorber plate. Various shapes of artificial geometries are discussed below:

1) Multiple arc shaped elements

Fig. 1:

Singh et al.[2] investigated effects of artificial roughness on heat transfer and friction characteristics having multiple arc shaped roughness element on the absorber plate as shown in Figure 1. Figure 1: Multiple Arc shaped elements on absorber plate [2].

2) V-shaped Blockages

Alam et al. [2] investigated the effect of non-circulation perforation holes in terms of circularity of v-shaped blockages attached to one heated wall of rectangular duct. The V-shaped perforated blocks on absorber plate is as shown in Figure 2. Figure 2: V-Shaped perforated holes on absorber plate [2].

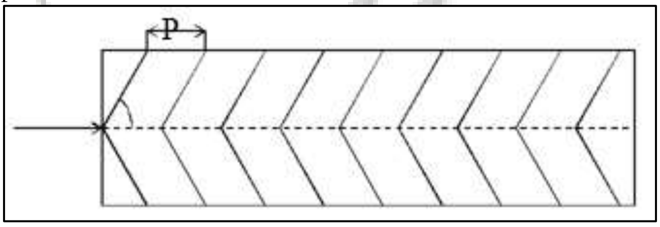

Fig. 2:

3) Small Diameters wires

Prasad et al. [3] carried out the fluid flow and heat transfer analysis for heat transfer enhancement in three sided artificially roughened solar air heater using small diameter wires on the top and side walls as depicted in investigation. Three sided roughened and one sided smooth rectangular duct [3]. Top side of absorber plate with small diameter wires [3].

4) Using G.I. Thin wires

B.N. Prasad [9] carried out the thermal performance of artificially roughened solar air heaters by using thin G.I. wires in twin flow air heaters, in comparison with single flow air heater [9].

5) Dimple shape geometry rectangular fashion Saini and Verma [22]

Investigated the effect of roughness geometry and operating parameters on heat transfer in a roughened duct provided with dimple shape roughness geometry. The geometry investigated is as shown in Dimpled Ribs on absorber plate [22].

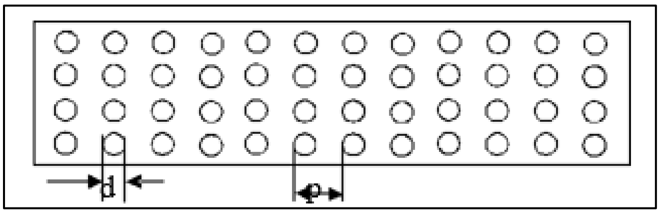

Fig. 3:

6) Rib grit roughness element

Karmare and Tikekar[16,19]investigated lower side of absorber plate by roughening it with metal ribs of circular, square and triangular cross sections, having 60° inclination to the air flow and it's analysis is done by using CFD. The grit rib elements are fixed on surface in staggered manner. Rib grit roughness element on collector plate [16.19].

7) Transverse and inclined ribs geometry

Varun et al. [18] carried out an experimental study on heat transfer and friction characteristics by using a combination of inclined and transverse ribs on the heated plate of a solar air heater duct. For relative roughness pitch value of 8 and relative roughness height value of 0.030 the best thermal performance was reported. The investigated geometry has been shown in Figure 6. Figure 6: Inclined and transverse ribs on absorber plate [18].

B. Arc shaped ribs

Kumar and Saini [20] investigated the performance of a solar air heater duct provided with roughness geometry in form of thin circular wire in arc shaped geometry as shown in Figure 10. It‟s analysis is done by using CFD. Figure 10: Arc shaped elements on underside of plate [20]. Saini and Saini[21] studied the effect of arc shaped ribs on the heat transfer coefficient and friction factor of rectangular solar air heater ducts. The investigated geometry is as shown in Figure 7.

1) Gap in an inclined Continuous Rib arrangement

Aharwal et al. [23] carried out an experimental investigation on heat transfer characteristics using artificial roughness in the form of repeated ribs of square section split rib with gap, inclined with respect to flow direction. The arrangement is as shown in Figure 4. Figure 4 Inclined ribs with Gap [].

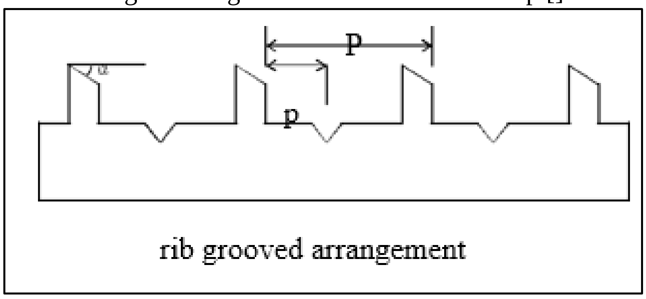

Fig. 4:

2) Rib- grooved arrangement

Jaurker et al. [] performed experimental investigation on heat transfer and frictional characteristics of ribgrooved artificial roughness on one board heated wall of rectangular duct. The arrangement of groove pattern is as depicted in Figure 13. Figure 13: Rib groove arrangement on absorber plate [].

3) W- shaped rib roughness

Lanjewar et al. [13] carried out an experimental investigation of heat transfer and friction factor characteristics of rectangular duct roughened with W shaped ribs arranged with an inclination to the flow direction. W ribs have been tested for both pointing in downstream W-down (Figure 5) and upstream W-up (Figure 5) to the flow: W- down roughness geometry [13]. Figure 5: W- up roughness geometry [13].

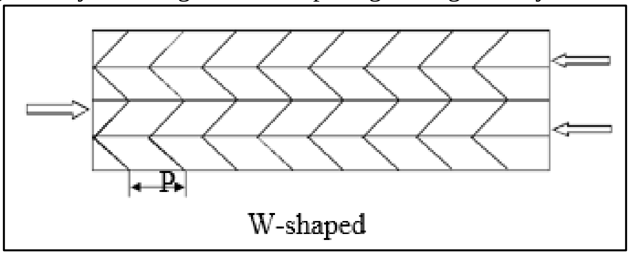

Fig. 5:

4) Circular transverse wire rib roughness

Yadav and Bhagoria [10] carried out flow analysis of artificially roughened solar air heater provided with circular transverse wire rib roughness on the absorber plate. The arrangement of roughness elements is as shown in Figure. Figure: Roughened plate with continuous transverse wire ribs [10].

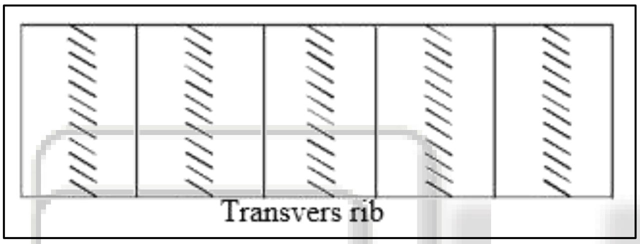

Fig. 6:

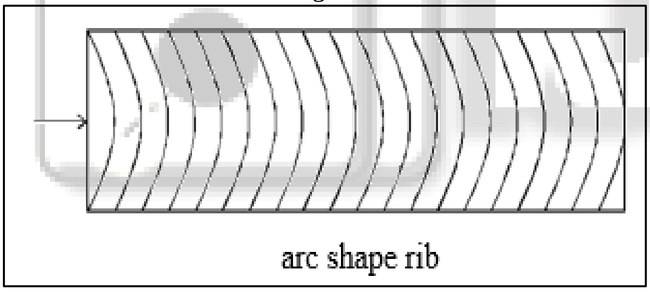

Fig. 7:

5) Multiple V-shaped with gap rib

Kumar et al. [11] carried out an experimental investigation of heat transfer and friction in the flow of air in rectangular ducts having multiple V- shaped rib, as shown in Figure 9. Figure: Multiple V-shaped ribs with gap [11].

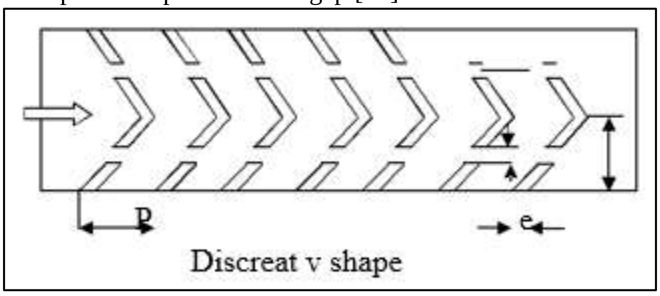

Fig. 8:

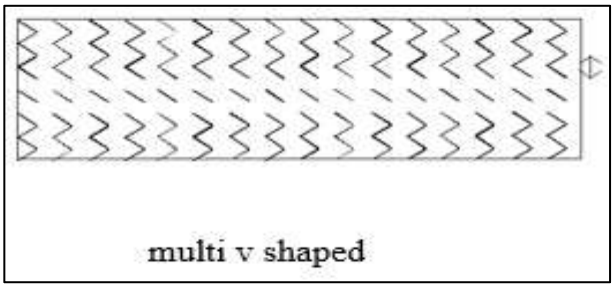

Fig. 9:

6) Square sectioned transverse ribs

Yadav and Bhagoria [8] carried out numerical investigation on the heat transfer and fluid flow characteristics of fully developed turbulent flow having repeated transverse square sectioned rib roughness on the absorber plate. Roughened plate with square transverse ribs [8].

IV. EFFECT OF ROUGHNESS PARAMETERS

In solar air heaters air gets heated when it passes over the absorber plate. But the heat transfer to the air flowing over the plate is too low. It is due to the viscous sub-layer formed in the turbulence zone. This viscous sub-layer formed is adhered to the absorber plate and thus it acts as the thermal barrier between absorber plate and the air flowing above it. Hence, to break this viscous sub layer artificial roughness is provided in this zone. It enhances the heat transfer characteristics and resulting into the heat transfer enhancement but with the penalty of increase in friction factor. The roughness geometries are generally evaluated on basis of few roughness parameters such as relative roughness pitch (P/e), relative roughness height (e/D) and angle of attack (α) on heat and fluid flow characteristics. The values of above parameters used by various investigators are as follows: Values for various roughness parameters

1) Singh et al. [1] Arc shaped 4-16 0.018-0.045 30-75°
2) Prasad et al. [3] Small dia. wires 10-20 0.020-0.033 –
3) Alam et al. [4] V-shaped blockages 4-12 - 30-75°
4) Bekele et al. [5] Mounted obstacles - - 30-90°
5) Yadav and Bhagoria [6] Triangular sectioned rib 7.14-35.7 0.021-0.042 –
6) Alam et al. [7] V-shaped blockages 4-12 - 60°
7) Yadav and Bhagoria [8] Square sectioned transverse ribs 7.14-35.7 0.021-0.042 –
8) casePrasad [9] Thin G.I. wires 10-40 0.0092-0.027 –
9) Yadav and Bhagoria [10] Circular transverse wires 7.14-35.7 0.021-0.042 –
10) Kumar et al. [11] V-shaped with gap 6-12 0.022-0.043 30-75°

V. CASE STUDY

A. CFD analysis of smooth plate solar air heater 3D Modeling of smooth absorber plate is done in PRO-E Wildfire. Further this model was converted into step format before importing it into ICEM CFD. ICEM was used as preprocessor for the purpose of volumetric meshing. Plate material type was set as aluminum. Quality of the mesh was checked and it was found in acceptable limit. Figure 19. 3D model of duct. The boundaries and continuum as inlet, outlet, heated wall, insulated wall and the fluid zones all were defined as per the experimental conditions. The geometry as shown in Figure

1.was exported so that it is accessible in Fluent. Fluent is used as a processor for the analysis to be done. It uses four equations including continuity equation and three momentum equations by default to solve the problem. For solveing the temperature variation, Energy equation must be kept on. For turbulent flow, k–e model was selected as turbulent model for further analysis of the problem. Energy equation was also kept ON for a heat transfer model. Air was selected as working fluid. The different boundary conditions for the geometries were selected as: air inlet velocity = 0.66 m/s to 3.26 m/s, Both Inlet and Outlet pressure was kept as zero gauge pressure. As the absorber plate was being heated from one side, the boundary condition for the wall was having uniform temperature of 300 K. All the other walls were considered to be completely insulated with zero heat flux. all the walls are slip feree.

A. Computational analysis

Pre-processor ICEM-CFD Solver Fluent Post-processor CFD-Post Domain 3D Solver Pressure-Based Time Steady Model Energy and RNG k–ε model Solution method SIMPLE Fluid Air Near wall treatment Standard wall function Density Ideal gas Plate material Aluminum After setting all necessary input conditions the problem was iterated for 1000 iterations within which it gives well converged solution so that accurate results were displayed. The contours were displayed by using post processor.

VI. SUMMARY

The thermal performance of conventional solar air heater is lower as compared to that of artificially roughened solar air heaters. This artificial roughness elements includes various types of geometries such as Transverse and inclined ribs, Chamfered ribs, Expanded mesh metal, Wedge shaped rib, Multi v-shaped rib, Dimpled surfaces, Arc shaped ribs, W-shaped rib etc. The use of artificial roughness in different forms and shapes is an effective and economic way of improving the performance of solar air heaters. A table is presented which gives values of different roughness parameters for various roughness geometries. The maximum Nusselt Number (Nu) enhancement occurs at particular relative gap width (g/e), relative roughness pitch (P/e) and angle of attack (α). The value of Nusselt number (Nu) is more for multi v-shaped with gap rib than that for continuous multi v-shaped rib. As for regular purpose the use of metal grit rib is more efficient and fabrication is also simple. Many research is going on various artificial geometries and improvement in heat transfer and fluid flow characteristics is the main objective of all the research on artificial roughness geometries.

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