A Critical Analysis on investigation methods Used in Artificially Roughened Solar Air Heaters system :(A Review)

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Abstract-Artificial roughness is useful on the absorber plate is the most common technique to get better thermal performance of solar air heaters. Experimental investigations related to distinct roughness geometries reveled that that the improvement in heat transfer is accompanied by significant rise in pumping power. Actually, a designer of roughness surface needs to carefully examine shape and compass reading of roughness elements in order to select the best fit roughness geometry for intended purpose. Furthermore it is essential to know how flow field is affected by particular roughness geometry so that direction of future researches could be conceived. So as to elucidate the useful findings an attempt has been made to review roughness geometries employed in solar air heaters. Some distinguished roughness geometries have been compared on the basis of heat transfer enhancements and thermo hydraulic performance to draw attention towards their usefulness for specific applications. Furthermore, light is frightened on different investigation method adopted for estimate of heat transfer and friction character of artificially roughened solar air heaters to identify features and limitations of each method. The method of Heat transfer by using artificially roughness are commonly used in various industries like process industries, heating and cooling in evaporators technique, thermal power station, air-conditioning apparatus, refrigerators, radiators, automobiles etc.It has been observed that roughened absorber plate results augmented heat transfer coefficient at the cost of frictional penalty. This paper addresses different artificial roughness geometry using in heat transfer.

Keywords- *Artificial roughness, extended surfaces, heat exchangers, heat transfer enhancement, free and forced convection. Solar air heater, Roughness geometry, Nusselt Number, Thermo hydraulic performance, Reynolds Number.*

1 Introduction

This is observed that thermal effectiveness of solar air heaters is found to be low due to low Heat transfer coefficient on the air side. Efforts have been done to improve 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. However the enhancement in heat transfer rate is accompanied by severe pressure drop penalty. In one more approach, heat transfer coefficient has been considerably enhanced by providing artificial roughness on absorber plate surface out in the open to air. In this approaching system, the turbulence is promoted by roughened surfaces just in the viscous sub layer region to get heat transfer improvement at the cost of moderate friction penalty. Many roughness geometries have been tested so far with the object to obtain utmost heat transfer enhancement with consumption of least pumping power. In another study, Hans et al. [1] stated that roughness element geometries working by various investigators to improve the thermal performance of solar air heaters. In view of finding optimal roughness pattern, 11 distinct roughness geometries have been compared on the basis of thermo hydraulic performance. Varun et al. [2] has stated in a review on roughness geometries use in solar air heaters in which they discussed the outcome of various studies about with heat transfer enhancement by the use of artificial roughness and showcased the correlations developed by various investigators for prediction of heat transfer and friction factor in roughened solar air heater ducts. An attempt has been made by Bhushan et al. [3] to categorize and review the roughness geometries used for creating artificial roughness in solar air heaters. Heat transfer coefficient and friction factor correlations developed by various investigators for roughened duct of solar air heaters have also been reported in this study.

2 Significance of artificial roughness

The role of energy becomes more and more important to fulfill requirements of current societies and to maintain fast economic and business growth global. Traditional power sources are depleting day by day and appear to be inadequate to fulfill large demand of energy in coming years. As one of long term option, the unconventional energy sources are having enough possible to occupy the place of conventional energy sources. Solar energy is one of the promising and easily convertible forms of renewable energy available in abundance on earth. 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

3. Fundamental of artificial roughness -

The fundamental of artificial roughness was first applied by Joule [4] to improve heat transfer coefficients for in tube condensation of steam and since then some experimental investigations were carried out on the use of artificial roughness in the areas of cooling of gas turbine blades, electronic equipments, nuclear reactors, and compact heat exchangers etc. Webb and Eckert [5] conducted experiential study of turbulent air flow in tubes roughened with rectangular repeated ribs and deduced heat transfer and friction factor correlations based on the law of wall similarity and application of the heat-momentum transfer analogy. They considered relative roughness height of 0.01- 0.04 at a relative roughness pitch of 10 - 40 and range of Prandtl number of 0.71- 37.6 for this study. Lewis [6] introduced new efficiency parameter for optimizing thermo hydraulic performance of roughened surfaces with reference to smooth surfaces.The experimental investigation performed by Han in seek of the effect of rib shape, pitch to height ratio angle of attack, and spacing in square duct with two opposite rib roughened wall revealed that the maximum value of heat transfer and friction factor occurs for the ribs oriented at 45^o angle with a relative roughness pitch of 10. Han et al. [7] investigated the effect of parallel and V-shaped broken rib orientation on the local heat transfer distribution and pressure drop in a square channel with two opposite ribbed walls and reported that 60° staggered discrete V-shaped ribs provide higher heat transfer than parallel discrete ribs. Han et al. [8] investigated the effect of angle of attack and apex orientation in case of V-shaped ribs and found that 45^o and 60^o V-shaped ribs facing upward show higher heat transfer rates compared to corresponding V-shaped ribs facing downward. They observed that V-shaped ribs facing upward forms two pairs of rotating cells along each divergent axis of rib, while in the case of V-shaped ribs facing downward, two pairs of counter rotating cells merge resulting in a higher pressure drop and lower heat transfer.

Liou and Hwang [9] perform experimental study on heat transfer and friction for turbulent flow through channel with two opposite walls roughened with semicircular, square and triangular shape ribs. They reported that among three types of ribs, the square rib yielded the maximum 1.9-2.7 fold increase in average Nusselt number while friction factor increased by 7-15 folds respectively.

Gao and Sunden [10] also find in his study that V-shaped ribs pointing downward perform better than the ribs pointing upward in rectangular ducts. . Lau et al. [11], Taslim et al. [12] and Olssom and Sunden [13] investigated the effect of V-shaped ribs in square channel and found fair enhancement in heat transfer as compared to inclined and transverse ribs. They observed that V-shaped ribs pointing downward have a much higher heat transfer coefficient because the warm air being pumped toward the rib leading region increases the apex region heat transfer coefficients as compared to that of the leading end region.

Zhang et al. and Kiml et al. 18, 19] made his study on thermal behavior of V-shaped ribs with 60^o angle of attack is better than that of 45^o angle for the same range of flow parameters. Lau et al. [14] find the substitute of continuous transverse ribs by inclined ribs in a square duct results in higher turbulence near the roughened wall due to interaction of the primary and secondary flows which goes in favor of better thermal performance. Lau et al. [15] investigated the heat transfer and friction behavior of fully developed flow in a square duct with transverse and inclined discrete ribs. They investigated that a five-piece discrete rib with 90^o angle of attack shows 10-15% higher heat-transfer coefficient as compared to the 90o continuous ribs, whereas inclined discrete ribs give 10-20% higher heat transfer than that of the 90^o isolated rib.

Burgess et al. [16] conducted an important experimental study to explore effect of dimple depth on heat transfer with aspect ratio of 8 and for Reynolds number range of 12000-70000 and reported that Nusselt number increases with increase in dimple depth. A study by Hu and Shen [17] presented the effect of inclined discrete ribs with and without groove and revealed that the performance of inclined discrete rib without groove has been found best arrangement. In a recent study, Cho et al. [18] investigated the effect of a gap in inclined ribs on heat transfer for a fluid flow through square duct and reported that a gap in the inclined rib accelerates the flow and enhances the local turbulence, which Moon et al. [19] investigated effect of channel height on heat transfer in a rectangular duct with a dimpled surface and observed enhancement in heat transfer by about 2.1 times regardless of channel height and friction factor of 1.6 - 2.0 times that of smooth channel. Manhood and Ligrani [20] measured local heat transfer on opposite walls with dimple type roughness with various temperature ratios having ratio of channel height to dimple print diameter of 0.5. They observed that the vortex structures augment local Nusselt number near downstream rim of each dimple.

Varun et al. [21] also reported different investigations on roughness geometries carried out in heat exchangers as well as in air heaters. Application of artificial roughness on one broad wall i.e. absorber plate of solar air heaters to improve thermal performance found its root from the above investigations. Sang et al. [22] investigated heat transfer with dimple/protrusion arrays in a rectangular duct with low Reynolds number range and observed heat transfer enhancement of 14 and 7 times for double protrusion wall and double dimpled wall at Reynolds number of 1000. However at high Reynolds number of 10000, enhancement level observed was from 2 to 3. Chang et al. [23] examined heat transfer characteristics for four sets of dimpled channels with Reynolds number ranging from 1500 to 11000 and determined effect of dimpled arrangement, fin length to channel hydraulic diameter ratio and Reynolds number on heat transfer over the dimpled fin channel..

4. Effect of artificial roughness on heat tranfer

The function of artificial roughness on the heated surface area induces local wall turbulence due to separation and reattachment of flow between two consecutive roughness elements. The turbulence promoted by roughness elements drastically enhances the heat extraction rates from the heated surface.This is also observed that If the roughness height is greater in comparison to thickness of laminar sub layer, the turbulence produced by roughened surface promotes disturbances in the turbulent core region and raises fluid friction which results in higher pumping power requirements. Figure 2 shows the flow characteristic in the viscous sub layer area due to presence of repeated roughness elements. As air flows over a heated surface, a thin layer called sub layer exists beneath the core turbulent flow region in which the flow remains predominantly laminar due to supremacy of viscous effects. Due to presence of this viscous sub layer over the heated surface, the heat transfer rates from surface to air is poor due to low values of heat transfer coefficient.

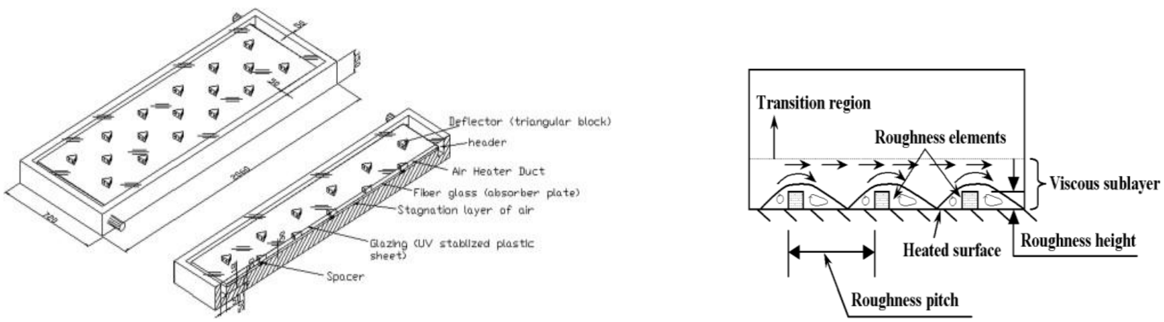

Fig. 1. Effect of roughness elements on flow field (source IJRE-12)

5. Solar air heaters with Roughened geometries of rib

5.1. Roughness with transverse ribs

An investigation has been made by Prasad et al [24} on effect of protrusions from underside of absorber surface in the form of small diameter wires on heat transfer and friction factor for fully developed turbulent flow in a solar air heater duct. The experiment were conducted for the relative roughness pitch of 10, 15, and 20 and relative roughness height of 0.020, 0.027 and 0.033 to predict the effect of height and pitch of the roughness elements on heat transfer and friction. Experimental study shows that Nusselt number as well as friction factor increase with increasing relative roughness height but the rate of heat transfer improvement diminishes with increase in relative roughness height while the rate of increase of friction factor was found to be nearly constant. The maximum value of Nusselt number and friction factor were recorded to be 2.38 and 4.25, respectively, at the pitch of 10. The study revealed that the reattachment of free shear layer is necessary between the consecutive ribs for heat transfer enhancement. This has been observed that for the relative roughness pitch less than 8, reattachment of free shear layer does not occur while the pitch beyond 10 produces lesser number of reattachment points, leads to poor heat transfer rates. It experimental study also suggests that the total advantage of artificial roughness possibly will be exploited until it disturbs the area up to transition limit without disturbing the turbulent core area. This study has concluded that the roughness height should be equal to or slightly higher than the laminar sub layer thickness to achieve the desired results.

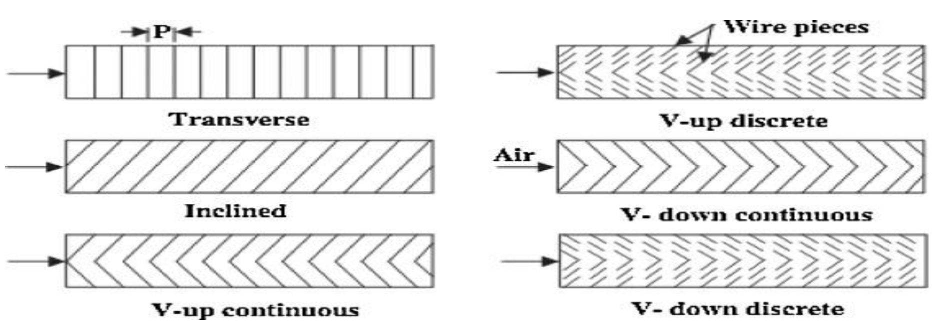

Fig. 2. Transverse ribs [32]

5.2 Roughness with inclined and transverse ribs

The effect of transverse and inclined wire roughness on fluid flow characteristics for solar air heater was investigated by Gupta et al. [26] .in his study They obtained maximum heat transfer coefficient at an angle of attack of $60^o$and pitch of 10. It has been observed that thermal efficiency of the system is enhanced by a factor of 1.16 -1.25. The study suggests that the system should be operated for Reynolds number ranges from 13000 to19000 in order to achieve healthier thermal performance.

It has been observed that the roughened surfaces with relative roughness height (e/D) of 0.033 corresponding to Reynolds number (Re) around 14,000 unveiled the best thermo hydraulic performance in the range of parameters investigated. This is stated that the useful performance increases as the insolation increases for the Reynolds number more than 10000. Maximum enhancement in heat transfer coefficient and friction factor in roughened duct was reported to be 1.8 and 2.7 times of smooth duct at an angle of attack of 600 and 700 respectively.

5.3. Roughness in the shape of extended metal lattice

The heat transfer rate and friction characteristics for flow inside a large aspect ratio rectangular duct with roughness in the form of expanded metal mesh geometry were invented by saini et al [27]. In their study They observed that the average Nusselt number attains higher value at the relative long way length of mesh (L/e) of 46.87 and relative short way length (S/e) of 25 at an angle of attack of 61.9^o. The higher friction occurs for an angle of attack of 72^o for relative long way length of 71.87 and relative short way length of 15.62. The maximum enhancement in Nusselt number and friction factor were found to be 5 and 6, respectively.

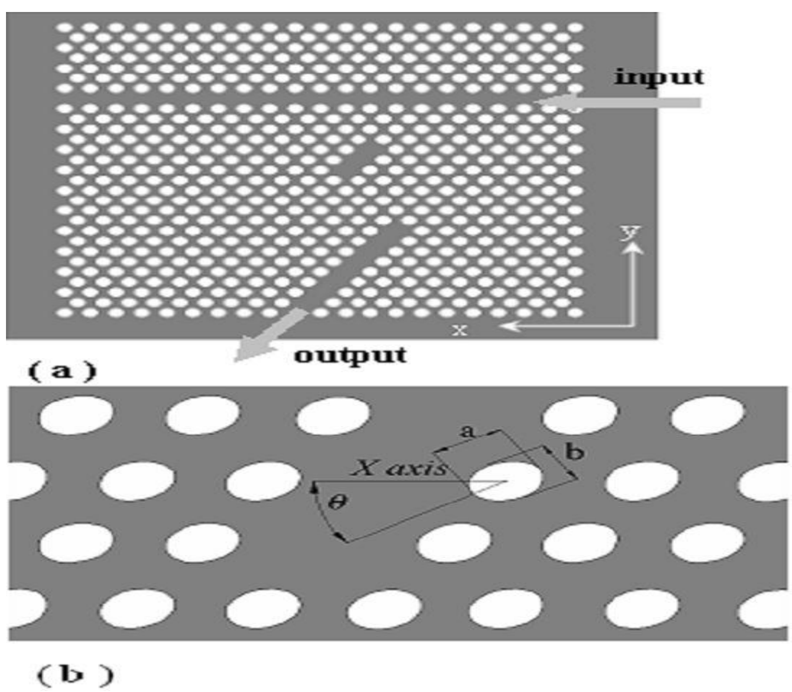

Fig. 3. Wire mesh roughness [34]

5.4. Repeated chamfered rib roughness

Karwa et al. [28] conducted experimental study to predict the thermo-hydraulic performance of solar air heater duct roughened with chamfered rib roughness applied in transverse direction with respect to the flow of air. The chamfered ribs on one broad wall yields up to about two-fold and three-fold increase in the Stanton number and the friction factor, respectively, for the range of Reynolds number (3000-20000), chamfer angle (-15o-+18o), relative roughness height (0.014-0.033), relative roughness pitch (4.6-8.5) and duct aspect ratio (4.65-12). Square ribs with 15o chamfer angle observe maximum heat transfer rates and highest friction.

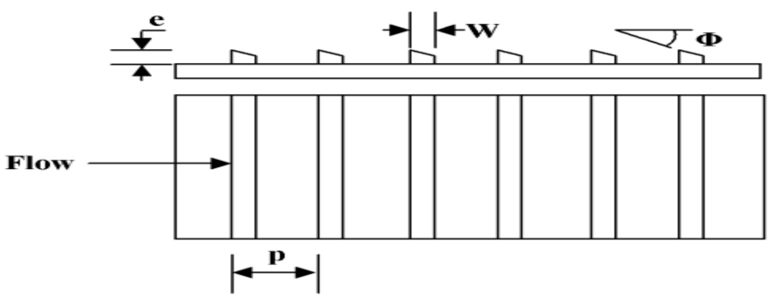

Fig. 4. Chamfered ribs [35]

It is seen that Stanton number and friction factor values increase with increase in the chamfer angle from -15 to +15o and beyond +15o chamfer angle, the rate of change of Stanton number and friction factor decrease. The heat transfer function increases with the increase in the aspect ratio from 4.65-9.66 and the roughness function decreases with the increase in the aspect ratio from 4.65-7.75 and thereafter both the functions attain nearly a constant value. It has been pointed out that positive chamfer encourages frequent shedding of vortices causing greater heat removal from the surface and higher frictional losses while in case of negative chamfer, the Stanton number and friction factor decreases due to suppression of the shedding of vortices as a result of skimmed flow over the ribs.

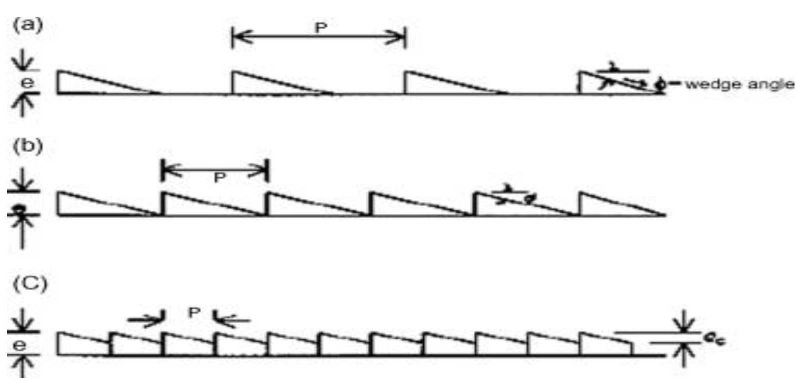

Figure 5. Wedge shape ribs [36]

5.5 Roughness in rib with Wedge form transverse

Bhagoria et al. [29] applied wedge shaped transverse repeated rib roughness on one broad heated wall of solar air heater duct and generated data pertinent to friction and heat transfer. They reported that the presence of wedge shape ribs yield maximum enhancement in Nusselt number and friction factorby about 2.4 and 5.3 times as compared to smooth duct. The maximum Nusselt number was obtained at a relative roughness pitch of about 7.57 and decreases further with increasing values of the relative roughness pitch from 7.57 to 12.12, while the friction factor continuously decreases as relative roughness pitch increases from 5.67 to 12.12. The Nusselt number increases and attains maximum value at a wedge angle of about 10° and then sharply decreases with increasing wedge angle beyond 10° while the friction factor increases as the wedge angle increases.

5.6 Roughness in rib with V shaped

Momin et al. [30] performed experimentations on flow through duct roughened with V-shape ribs attached to the underside of one broad wall of the duct, to collect data on heat transfer and fluid flow characteristics. They observed that the Nusselt number increases whereas the friction factor decreases with an increase of Reynolds number. It was found that for relative roughness height of 0.034 and for angle of attack of 60°, the V-shaped ribs enhance the values of Nusselt number by 1.14 and 2.30 times over inclined ribs and smooth plate case at Reynolds number of 17034. The rate of increase of Nusselt number with an increase in Reynolds number is lower than the rate of increase of friction factor as the re-attachment of free shear layer might not occur at higher Reynolds number. The thermo-hydraulic performance parameter increases with increasing the angle of attack of flow and the maxima occurs at an angle of attack of 60°. Study shows that besides flow separations and reattachments, the secondary flow moving along the two limbs of V-rib roughness contributes much in obtaining higher values of Nusselt number and friction factor.

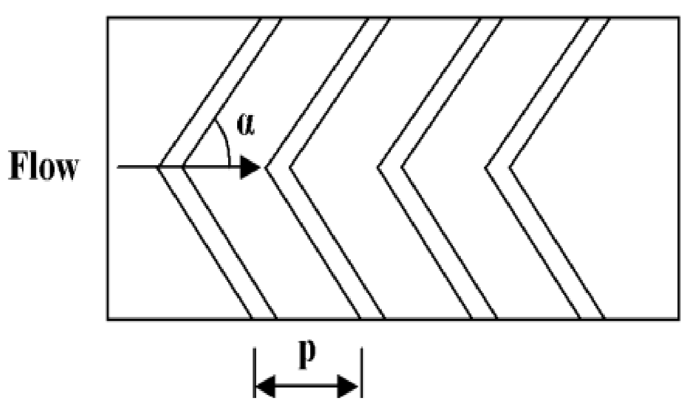

Fig. 6. V shape ribs

5.7 V-continuous and V-discrete ribs

An experimental study conducted by Karwa [31] on heat transfer and friction in a high aspect ratio duct with transverse, inclined, V-up continuous, and V-down continuous, V-up discrete ribs, and V-down discrete ribs shows that the enhancement in Stanton number over smooth duct was found to be 65-90%, 87-112%, 102-137%, 110-147%, 93-134%, 102-142% respectively. Study revealed that the V-down discrete rib roughness secured the best thermal performance for the same power consumption.

It has been reported that in V-up continuous rib pattern, the divided secondary flow directed towards the side walls which allows higher heat extraction rates in the central region while in case of V-up continuous rib pattern, the secondary flow is towards the central axis where it interacts with the axial flow creating additional turbulence leading to higher heat transfer rates. The study also emphasized that discrete rib arrangements have lower friction losses as compared to continuous ribs due to change in flow behavior as result of modified secondary flow field.

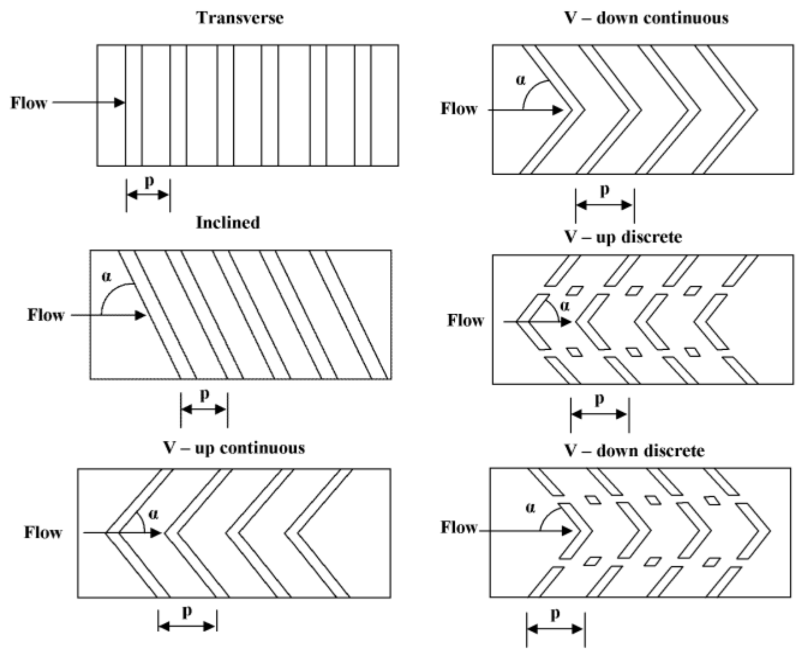

Fig. 7. Roughness geometries investigated by Karwa

higher heat transfer rates. The study also emphasized that discrete rib arrangements have lower friction losses as compared to continuous ribs due to change in flow behavior as result of modified secondary flow field.

5.8 Grooved in rib with roughness

Jaurker et al. [32] experimentally generated the friction and heat transfer data for turbulent flow through a rectangular duct with rib-grooved transverse repeated rib roughness produced on one broad heated wall. The application of rib grooved artificial roughness enhances Nusselt number up to 2.7 times while the friction factor rises up to 3.6 times as compared to smooth surface in the range of parameters investigated. The maximum heat transfer and friction factor were observed at relative roughness pitch of about 6 and relative groove position of 0.4.

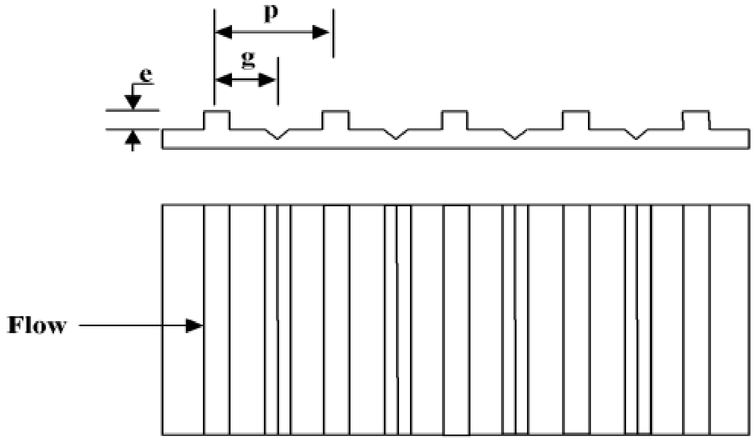

Fig. 8. Rib grooved roughness

5.9 Roughness in rib with broken transverse

Sahu and Bhagoria [33] varied the pitch for 90^{o} broken transverse rib roughness and examined its effect on thermal performance of solar air heater. Experiments were conducted for the range of Reynolds number 3000–12000, pitch of ribs from 10–30 mm, roughness height 1.5 mm and aspect ratio of eight. They observed that the Nusselt number increases sharply at low Reynolds number and remain constant for higher values of Reynolds number. The maximum enhancement in heat transfer was reported at the pitch of 20 mm. It has been highlighted that smooth duct performs better than the roughened duct at low Reynolds number (below 5000). Experimental results revealed that roughened absorber plates increase the heat transfer coefficient 1.25–1.4 times as compared to smooth rectangular duct and maximum thermal efficiency of roughened solar air heater lying in the range of 51–83.5%, depending upon the flow conditions.

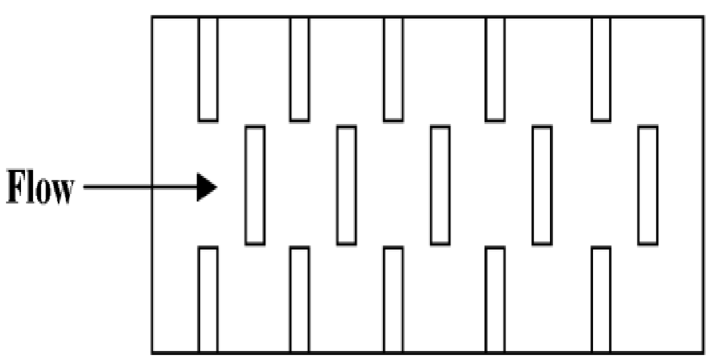

Fig 9. Broken transverse ribs [39]

5.10. Ribs with metal grit

Karmare et al. [34] experimentally determined the thermal performance of a rectangular duct with metal grit rib roughness employed on heated wall of solar air heater duct. The enhancement in the Nusselt number and friction factor in case of roughened duct was observed nearly 200 and 300%, respectively, in comparison to smooth duct. The maximum heat transfer rate was reported for the set of roughness parameters (l/s = 1.72, e/Dh = 0.044, p/e = 17.5), and highest friction factor was observed for the set of roughness parameters (l/s = 1.72, e/Dh = 0.044, p/e = 12.5). For the roughened surface, rate of increase in Nusselt number with the Reynolds number was registered more than that of smooth surface. At low Reynolds number, roughened and smooth both surfaces have similar values of Nusselt number while at higher Reynolds number, the roughened surfaces owned higher Nusselt number as compared to smooth surface.
It has been stated that at lower Reynolds number the laminar sublayer region is comparatively thick and therefore contribution of roughness elements is insignificant. The laminar sublayer thickness is reduced at higher Reynolds number which improves the effectiveness of roughened surface in promoting higher disturbances in viscous zone leads to higher heat transfer rates.

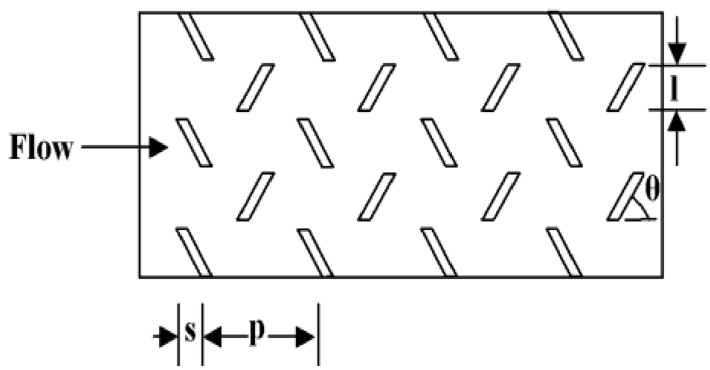

Fig 10. Metal grit ribs [41]

6. Conclusion

Artificial Roughness in the different shape of ribs like wire matrix, and dimples has been suggested by different investigators to get improved thermal performance. This is concluded that among all, artificial rib roughness was found the tremendous performer for thermal efficiency. This paper is very useful for researchers in carrying out the experimental and numerical investigations to find out and optimize the new element geometries for the maximum enhancement of heat transfer.

7. Scope for Future work

This is interesting to see for further work that how Correlations can be developed for heat transfer and Friction factor for solar air heater ducts having artificial roughness of different geometries for different investigators. These correlations can be used to predict the thermal efficiency, effective efficiency and then hydraulic performance of artificial roughened solar air heater ducts

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