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A Review on Roughness Geometry used in Solar Air Heaters

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Abstract—For the enhancement of rate of heat transfer of flowing air in the duct of a solar air heater, by applying an artificial roughness on its surface is one of the very effective technique of solar air heater absorber plate, till now numbers of geometries of roughness element has been investigated and their effect on enhancement of heat transfer has been carried out. This paper is an attempt has been made to classify and review various study of roughness geometries used for creating artificial roughness. On the basis of correlation obtained by different investigation for heat transfer coefficient and friction factor, enhancement of heat transfer coefficient is compared with standard data and experimental data. It is also an attempt to compare the thermo-hydraulic performance of different geometry of solar air heater duct have been reviewed and presented

Keywords- Solar air heater, Heat transfer enhancement ratio, V-shaped ribs, Reynolds number, Absorber plate

1. Introduction

Energy in different forms has played an important role in world wide for economic progress and industrialization. Since it is age of energy crises and conventional energy resources are limited, so more attention is paid to enhance and utilize the non-conventional energy resources. Sun is ultimate source of energy. The energy obtain by sun in form of sunlight that has heat energy solar can be use in various form such as solar drier, solar space heating etc. it is abundantly available and pollution free. So solar energy stands out a brightest long range resource for meeting continuously increasing demand of present and future generation.

The simplest and most efficient way to utilize solar energy is to convert it into thermal energy, for heating application by using solar air collector. Available solar air heaters, due to its inherent simplicity, cheap and most widely used for many applications at low and moderate range of temperature. When air flow over absorber plate, it creates laminar as well as turbulent layer over the surface, within turbulent layer near to plate surface, due to presence of laminar sub-layer is formed which decrease heat transfer rate. To overcome this problem and to enhance heat transfer coefficient, artificial roughened absorber plate is best suitable.

Regarding artificial roughened absorber plate, many experimental investigated have been reported in literature by various authors. Heat transfer coefficient and friction factor correlation developed by various investigator for roughened duct of solar air heater have been reviewed in this paper.

2. Concept of artificial roughness

Due to low value of convective heat transfer coefficient, efficiency of flat plate solar air heater is low. Low value of convective heat transfer coefficient is due to presence of laminar sub layer that has to broken by applying artificial roughness of different geometry and to create turbulence which results in increase in heat transfer rate. However artificial rough nesses result in high friction losses to more power require to flow the fluid. So turbulence has to create in a region very close to heat transferring surface. This is achieving by keeping height of roughness element small in comparison to duct dimension [2]. The important parameters that characterize roughness element are roughness element height (e) and pitch (p). These are expressed in terms of dimensionless parameters such as relative roughness pitch (p/e), relative roughness (e/D_h).

3. DEVELOPMENT OF ARTIFICIAL ROUGHNESS IN SOLAR AIR HEATER

3.1 TRANSVERSE RIBS

3.1.1 TRANSVERSE CONTINUOUS RIBS

In history of development of artificial roughness, PRASAD and MULLICK [3] were the first investigator to apply small diameter wire as roughness in solar air heater. The parameter used for study were relative roughness pitch as 12.7 and relative height as 0.019. The outcome of their result reported that application of protruding wires led to improvement of plate efficiency from 0.63 to 0.72.

PRASAD and SAINI [4] also used small diameter wire as roughness, parameter used for study were relative roughness pitch 10-20 and relative height 0.020-0.033. Maximum value of friction factor and Nusselt number were 4.25 and 2.38 respectively for relative roughness pitch of 10. The roughness used , shown in fig,1

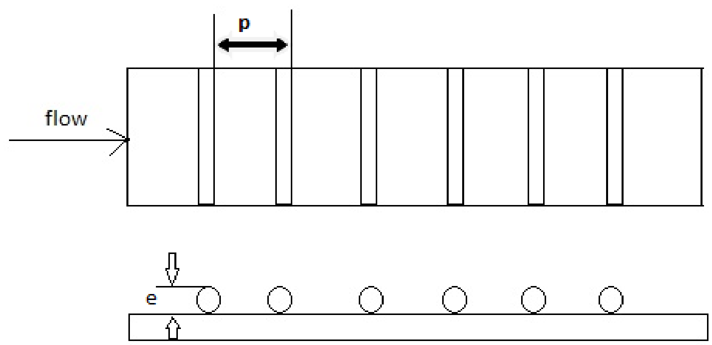

Fig 1 Transverse small diameter wire

Gupta et al [5] used transverse wires in solar air heater for transitional rough flow regime. Range of the parameter used were aspect ratio (W/H) as 6.8-11.5, relative height as 0.018-0.052, relative roughness pitch as 10 and Reynolds number range 3000-18000. They found that transitional rough flow regime Stanton number increases with increase in Reynolds number and Stanton number achieved maximum value for Reynolds number of 12,000.

VERMA and PRASAD[6] did outdoor experiment using transverse wire roughness, parameter used were relative roughness pitch 10-40, relative height 0.01-0.03, roughness Reynolds number as 8-42 and Reynolds number varied from 5000-20,000. They found optimal efficiency of 71% corresponding to roughness Reynolds number of 24.

3.1.2 TRANSVERSE BROKEN RIBS

Sahu and Bhagoria [7] investigated transverse broken ribs as shown in fig.2. They found Reynolds number varied from 3000-12000, rib height as 1.5mm, roughness pitch as 10-30mm with aspect ratio 8. Maximum Nusselt number attained for pitch 20 mm. By these arrangement heat transfer coefficient increased by 1.25-1.4 times as compared to smooth duct operating under similar condition.

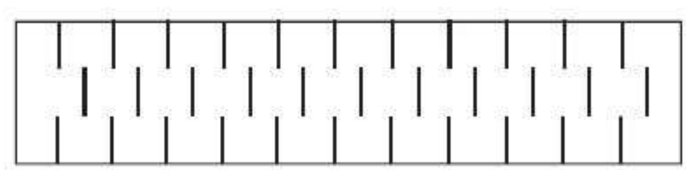

Fig. 2. Transverse broken ribs.

3.2 INCLINED RIBS

3.2.1 CONTINUOS INCLINED RIBS

Gupta et al [8] did experiment over transverse ribs with inclined rib. They used inclined circular ribs as artificial roughness for Reynolds number as 3000-18000, relative roughness height as 0.018-0.052 for relative roughness pitch of 10. They reported enhancement in thermal efficiency by 1.16-1.25 as compared to smooth plate in range of parameter investigated. Roughness used shown in fig.3

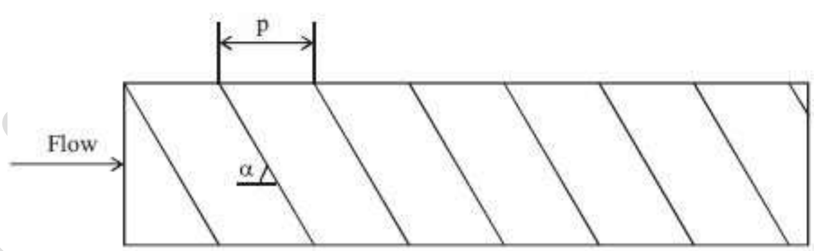

Fig. 3. Inclined continuous rib.

3.2.2 BROKEN INCLINED RIBS

AHARWAL et al [9] investigated inclined rib with a gap provision so as to allow release of secondary flow and main flow through the gap by creating local turbulence. Roughness used shown in fig.4, investigation found Reynolds number as 3000-18000, aspect ratio as 5.84, relative roughness pitch as 10, relative roughness height as 0.0377 and angle of attack as 60°. Gap position (d/w) and gap width (g/e) were in range of 0.1667-0.667 and 0.5-2. Maximum enhancement in Nusselt number and friction factor was reported as 2.59 and 2.87 times that of smooth plate respectively. The thermo hydraulic performance was reported to be maximum for relative gap width of 1.0 and relative gap position of 0.25.

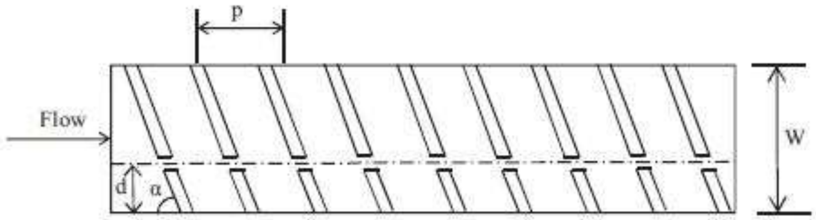

Fig. 4. Inclined ribs with gap.

3.3 WIRE MESH

3.3.1 EXPENDED METAL MESH

Expended metal mesh as roughness geometry used by SAINI et al [10]. They investigated effect of mesh (s/e) on heat transfer long way length and friction factor. They found enhancement in heat transfer coefficient and friction factor of order 4 and 5 times over smooth duct corresponding to angle of attack of 61.9 and 72 ° respectively. Roughness used is shown in fig.5

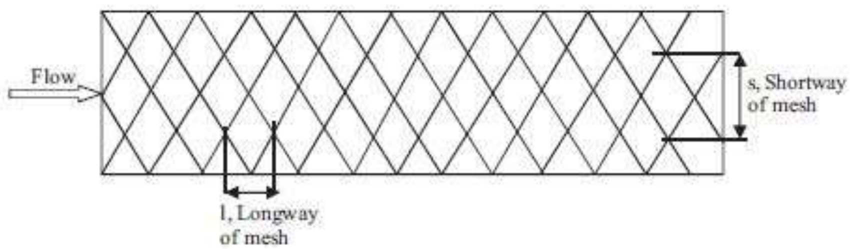

Fig. 5. Expanded metal mesh.

3.3.2 Discredited metal mesh

KARMARE and TIKEKAR [11] further discredited metal mesh, grit ribs as shown in fig .6, Range of parameter were Reynolds number as 4000-17000, (e/d) as 0.035-0.044, (p/e) as 12.5-36 and (l/s) as 1.72-01. They showed that plate with Roughness parameter (l/s) as 1.72, (p/e) as 17.5 had optimum performance.

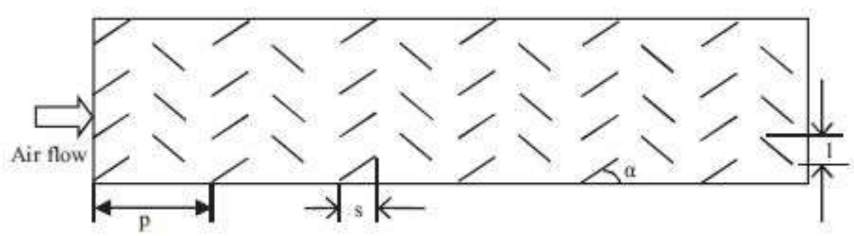

Fig. 6. Metal grit ribs.

3.4 chamfered ribs

KARWA et al [12] investigated effect of chamfered ribs as artificial roughness. These investigation covered rib chamber angle (φ) as-15 to 80°, Reynolds number as 3000-20,000, relative roughness pitch of 4.5-8.5, roughness height as 0.0141-0.0328. They reported two and three times increase in Stanton number and friction factor respectively. Highest value of both obtained at angle 15°.fig.7 shows chamfered ribs

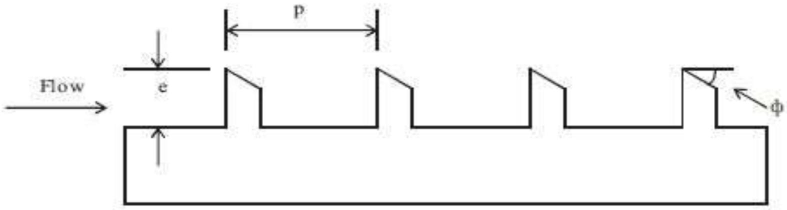

Fig. 7. Integral chamfered ribs.

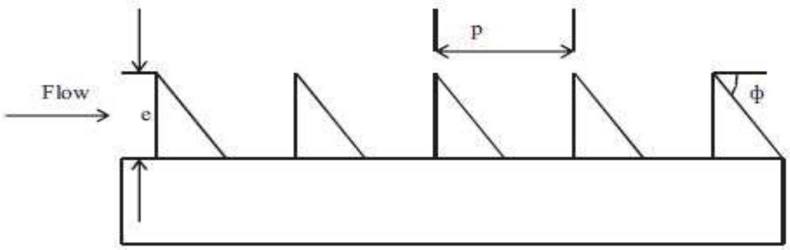

Fig. 8. Wedge shaped transverse integral ribs.

3.5 Wedge rib

Bhagoria et al [13] attempt to check possibility over chamfered integral rib. They proposed wedge shaped transverse integral ribs as shown in fig. 8. They reported enhancement Nusselt number as 2.4 times while of friction factor as 5.3 times as compared to smooth duct in range of parameter investigated. Heat transfer was the maximum for relative roughness pitch of 7.57. maximum enhancement in heat transfer was obtain at wedge angle of 10°

3.6 W-shape ribs

3.6.1. Continuous W-ribs

LANJEWAR et al [19] investigated by utilizing concept of increasing number of secondary cell of w-shaped rib. Range of the parameter was relative roughness height as 0.018-0.03375, relative roughness pitch 10, angle of attack 30-75°. They found W-down arrangement with angle of attack 60 ° gives optimum thermohydroulic performance. Maximum enhancement of Nusselt number and friction factor was 2.36 and 2.01 times that of smooth plate for a angle of attack 60°. Roughness geometry shown in fig.9

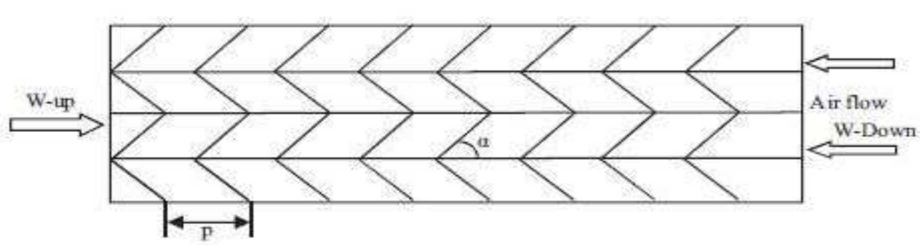

Fig.9 W – shaped rib roughness

3.6.2Discrete W-ribs

KUMAR et al [20] investigated discrete W-shaped rib. The investigation revealed Reynolds number from 3000-15,000, relative roughness height as 0.0168-0.0338, relative roughness pitch 10, angle of attack 30-75 degree. Maximum enhancement of Nusselt number and friction factor was 2.16 and 2.75 times that of smooth plate for a angle of attack 60°, relative roughness height 0.0338. Roughness geometry shown in fig.10

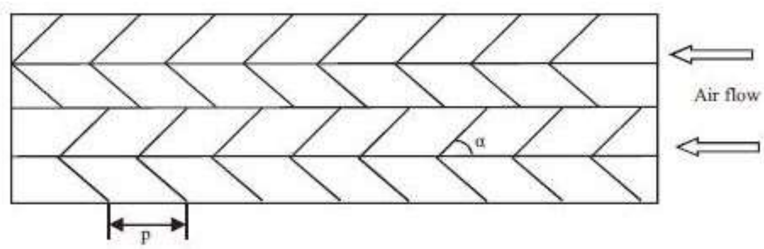

Fig.10 Discrete W-shaped rib

3.7 Roughness element combination

3.7.1 Transverse and inclined ribs combination

VARUNA et al [23] investigated by using concept combination roughness of transverse and inclined ribs. The found Reynolds number from 2000-14,000, relative roughness height as 0.030, relative roughness pitch 3-8, they also reported that roughened collector having roughness pitch of 8 gave best performance. Roughness geometry shown in fig.11

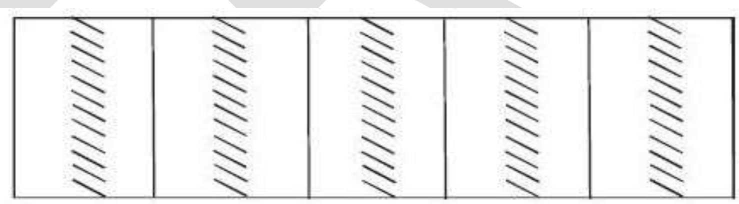

Fig.11 Transverse and inclined ribs

3.7.2 Transverse rib groove combination

JAURKER et al [24] investigated experiment for enhancement efficiency by performance of transverse rib roughness. Maximum heat transfer was achieved for relative roughness pitch of 6. Optimum heat transfer was reported for groove position to pitch ratio of 0.4. Roughness geometry shown in fig.12

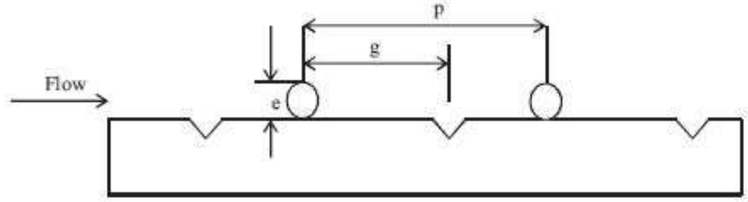

Fig.12 Rib groove roughness

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3.7.3 Chamfered rib groove combination

LAYEK et al [25] perform on chamfered rib roughness. The study was carried for Reynolds number from 2000-21,000, relative roughness height as 0.019-0.043, relative roughness pitch 4.5-10, chamfer angle as 5-30°, relative groove position as 0.3-0.6 and relative roughness height as 0.022-0.04. They reported Nusselt number and friction factor increased by 3.24-.78 times respectively as compared to smooth duct. Maximum enhancement of Nusselt number and friction factor were achieved for relative groove position of 0.4. Roughness geometry shown in fig.13

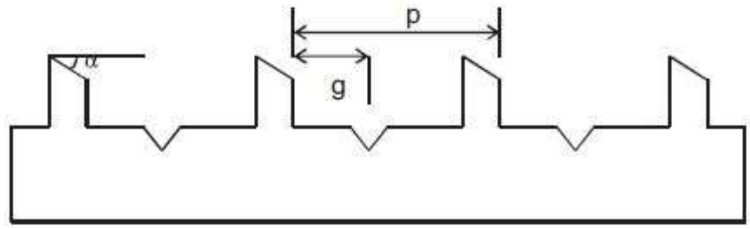

Fig.13 Integral transverse chamfered rib groove roughness

3.8 Arc shaped ribs

SAINI et al [26] utilize first Arc shaped ribs. Investigation encompassed duct aspect ratio 12, Reynolds number from 2000-17,000, relative roughness height as 0.0213-0.0422, relative, angle of attack 33-66°. They reported maximum enhancement in Nusselt number as 3.80 times corresponding relative arc angle (α/90) of 0.33 at relative roughness height of 0.0422. Corresponding increase in friction factor for this parameter was 1.75 times only. Roughness geometry shown in fig.14

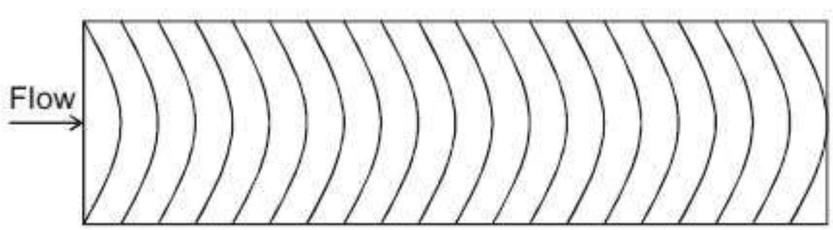

Fig.14 Arc shaped wire roughness

3.9 Dimpled surface

3.10.1 Transverse dimple roughness

SAINI et al [27] introduced new concept of dimple shaped artificial roughness. Investigation covered range of Reynolds number from 2000-12,000, relative roughness height as 0.018-0.037, relative roughness pitch 8-12. They found maximum value of relative roughness height of 0.0379 and relative roughness pitch of 10. Minimum value of friction factor corresponding to relative roughness height as 0.0289, relative roughness pitch of 10. Roughness geometry shown in fig.15

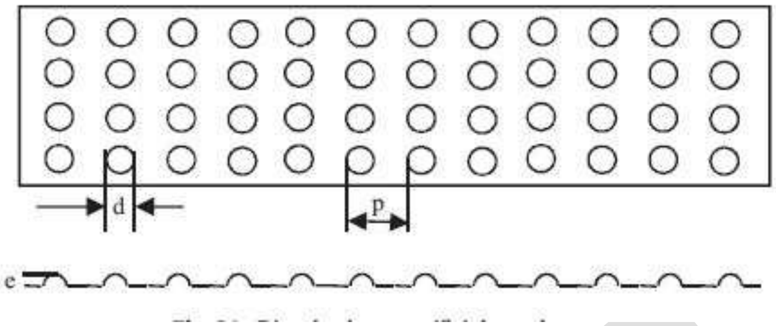

Fig.15 Dimple shaped artificial roughness

3.10.2 Staggered dimple roughness

BHUSHAN et al [28] investigated staggered dimple roughness in place of transverse dimple roughness. Range of parameter investigated were relative short way length (S/e) as 18.75-37.50, relative long way length (L/e) as 25.00-37.50, relative print diameter (d/D) as 0.147-0.367 , relative roughness height as 0.03, aspect ratio as 10 and Reynolds number from 4000-20,000. Under given condition maximum enhancement of Nusselt number and friction factor was 3.8 and 2.2 times respectively in comparison to smooth duct. Maximum enhancement in heat transfer coefficient was reported for relative short way length (S/e) of 31.25, relative long way length (L/e) of 31.25 and relative print diameter (d/D) of 0.294. Roughness geometry shown in fig.16

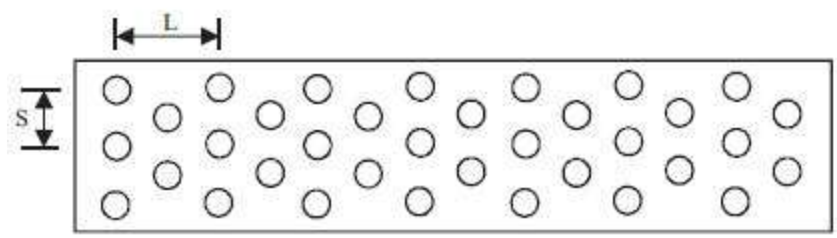

Fig.16 Staggered dimple roughness

3.10.3 Arc shaped dimple roughness 1

YADAV et al [28] employed Arc shaped dimple roughness. Experiment parameter were Reynolds number range from 3600-18,000, (p/e) as 12 to 24. (e/D) as 0.015-0.03 and arc angle of protrusion arrangement as 45-75°. Maximum enhancement of Nusselt number and friction factor was found to be 2.89 and 2.93 times respectively of smooth duct for range of parameter investigated. Maximum enhancement of heat transfer and friction factor occurred for relative roughness height of 0.03, relative roughness pitch of 12 and for arc angle value of 60°. Roughness geometry shown in fig.17

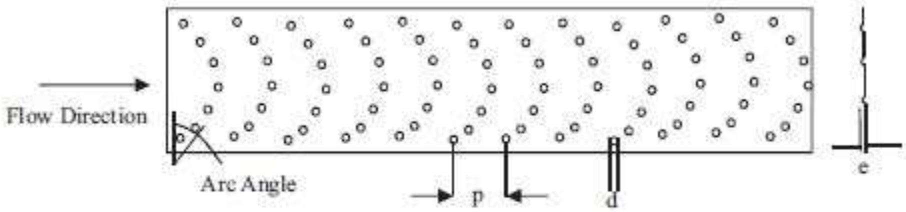

Fig.17 Dimple roughness in arc manner

3.10.4 Arc shaped dimple roughness 2

SETHI et al [30] investigated dimple shaped roughness but with different set of parameters. Investigation covered duct aspect ratio 11, Reynolds number from 3600-18,000, relative roughness height as 0.021-0.036, relative, angle of attack 47-75°. They reported maximum value of Nusselt number corresponding to relative roughness height of 0.036, relative roughness pitch of 10 and arc angle 60°.

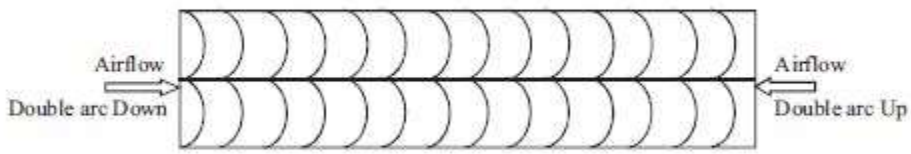

Fig.18 Double arc rib roughness with up and down orientation

3.11 V-shaped ribs

3.11.1 Continuous V-shape ribs

MOMIN et al [14] investigated inclined rib resulted in better performance than transverse ribs due to increase of secondary vortices. The number of secondary vortices was increased. They investigated V-shape rib roughness as shown in fig.19 and studied thermo hydraulic performance of solar air heater for Reynolds number as 2500-18,000, relative roughness height as 0.02-0.034, angle of attack as 30-90 °for fixed relative roughness pitch of 10. Nussselt number and friction factor was reported as 2.30 and 2.83 times of smooth duct plate for angle of attack 60° for maximum enhancement.

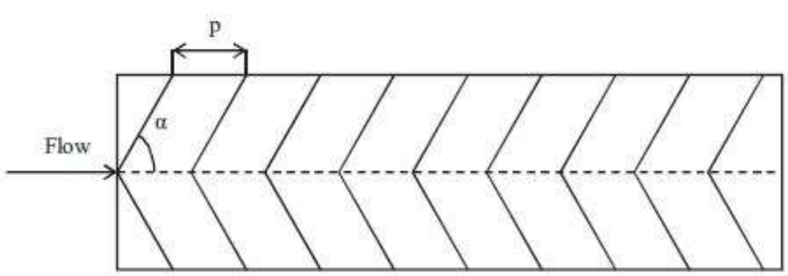

Fig.19 V-shaped ribs

3.11.2 Discrete V-ribs

MULUWORK et al [15] discredited V-shaped ribs, they compared thermal performance of staggered discrete V-apex up and V-down ribs with corresponding staggered discrete ribs. The roughness geometry shown in fig.20. They found Stanton number for V-down discrete ribs higher than corresponding V-up and transverse discrete ribs. Stanton number reported enhancement as 1.32-2.47 in range of parameters investigation.

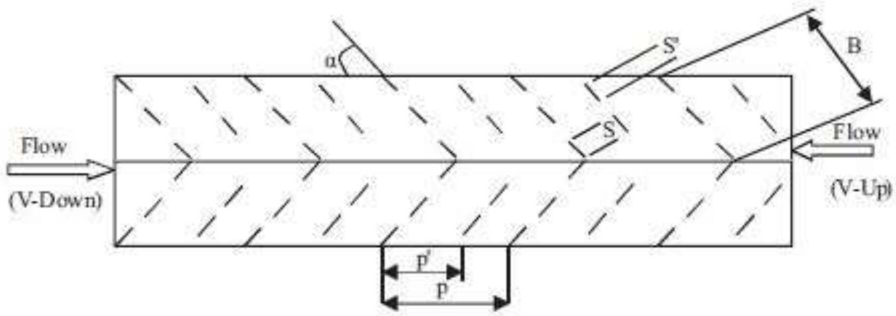

Fig.20 Discredited V-ribs

KARWA et al [16] perform experimental study using v-discrete and v discontinuous ribs. Parameter range was relative roughness pitch as 10.62, relative roughness length (B/S) as 3 and 6, angle of attack as 45 and 60 °and Reynolds number as 2850-15,500. They found that discrete ribs perform better then discontinuous ribs and 60 °rib perform better than 45 °ribs. Roughness geometry shown in fig.21

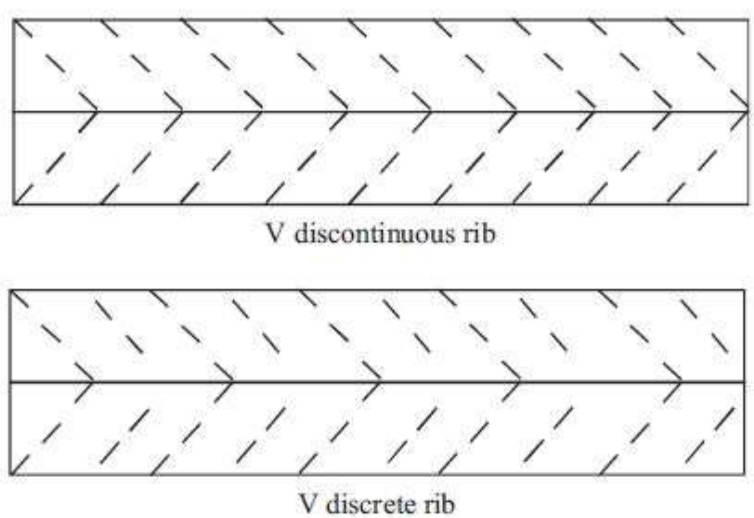

Fig.21 V-shape rib of different configuration

KARWA et al [17] investigated comparison of transverse inclined, v-down continuous, v-up continuous, V-down discrete and V-up discrete. He reported that based on equal pumping criteria discrete V-down arrangement gives best heat transfer performance.

SINGH et al [18] perform on discrete V-down ribs. Experiment was carried for Reynolds number 3000-15,000 with relative gap width (g/e) and relative gap position (d/w) in range of 0.5-2.0 and 0.20-0.80 respectively, relative roughness height as 0.015-0.045, relative roughness pitch as 4-12, angle of attack 30-75°. Roughness geometry shown in fig.22. , maximum increase in Nusselt number and friction factor over smooth duct was 3.04 and 3.11 times respectively. Rib parameter corresponding to increase in Nusselt number and friction factor were d/w=0.65, g/e=1.0, p/e=10, angle of attack 60 °and e/D=0.043

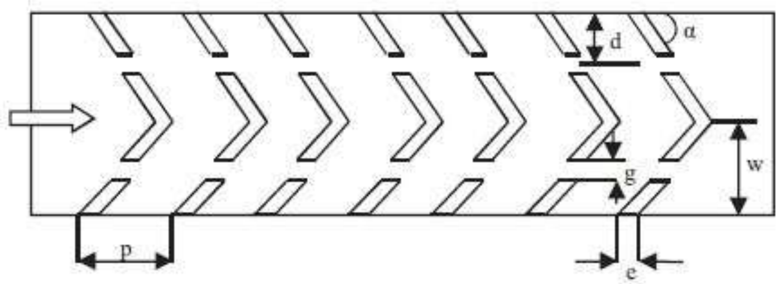

Fig.22 Discrete V-down ribs

3.12Multiple V-ribs

3.12.1 Multiple continuous V-ribs

HANS et al [21] investigated multiple continuous V- ribs by using concept of increasing number of secondary flow cells. The experiment encompassed Reynolds number from 2000-20,000, relative roughness height as 0.019-0.043, relative roughness pitch 6-12, angle of attack 30-75 °and relative roughness width (W/w) range as 1-10. Maximum heat transfer occurred for relative roughness width (W/w) of 6 while friction factor attained maximum value for relative roughness width (W/w) of 10. Both Nusselt number and friction factor 6 and 5 times respectively in comparison to smooth duct of parameter investigated. Roughness geometry shown in fig.23

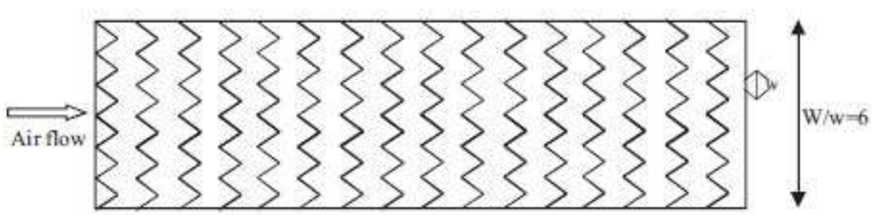

Fig.23 Multiple V-ribs

3.12.2 Multiple V-ribs with gap

KUMAR et al [22] utilized concept of turbulence and acceleration of flow by providing gap.Range of parameter encompasses, Reynolds number from 2000-20,000, relative width ratio as 6, relative gap distance ratio as 0.24-0.8, relative gap width as 0.5-1.5, relative roughness height as 0.043, relative, angle of attack 60°. They reported maximum enhancement in Nusselt number and friction factor as 6.32 and 6.12 times of smooth plate respectively. Roughness geometry shown in fig.24

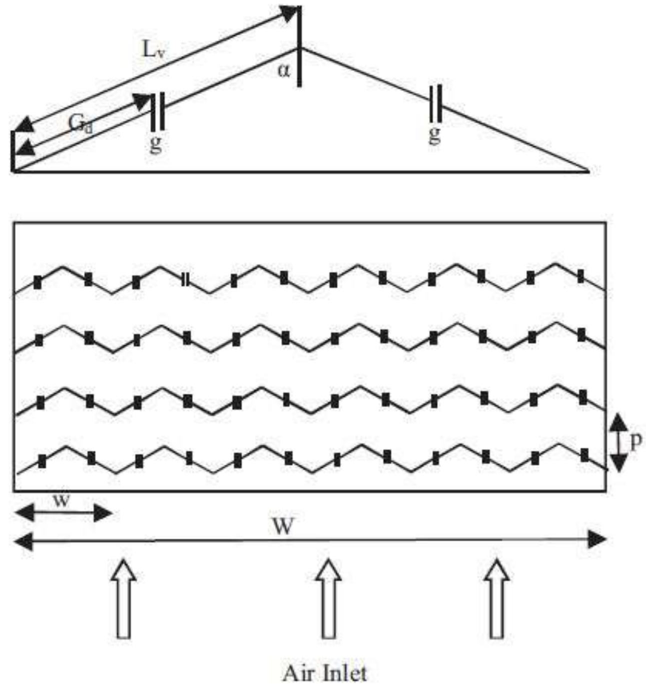

Fig.24 Multi V-shaped ribs with gap

4. Conclusion

The present review paper concluded that lots of work for heat transfer enhancement of solar air heater by using artificial of different shapes and size is carried out with compromising with slightly more consumption of blower power.

So far various correlations for heat transfer and friction factor for solar air heater duct having artificial roughness of different geometry has been investigated. This derived correlation can be used to predict the thermo-hydraulic as well as thermal performance of solar air heater having roughened duct.

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