Effect on Nusselt Number and Friction Factor by Variation in Roughness Geometry-A Review

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Abstract - *To increase the heat transfer rate of the air which is flowing in the duct of the solar air heater, one of the effective technique of doing this is creating artificial roughness on the bottom of the solar air heater absorber plate, presently many different shapes and size of geometries of roughness element has been studied and their impact on the enhancement of the heat transfer rate on rough absorber plate has been studied. This paper has been focused on the classification and review of the different types of geometry on absorber plate. Based on the correlation that are obtained, by different studies for friction factor and heat transfer coefficient, and enhanced heat transfer coefficient, which is then compared with the experimental and standard data. This paper is an attempt for the comparison of thermo-hydraulic performance based on different geometry of solar air heater duct that have been reviewed and presented.*

***Key Words*: Solar air heater, Artificial roughness geometry, Nusselt number, Friction factor, Reynolds number, Heat transfer enhancement ratio.**

1.INTRODUCTION

Energy has played a vital role in the economic and industrialization progress for the world community. Since in this age we are facing energy crisis and our conventional form of energies are also getting depleted hence our main focus is on the enhancement and better utilization of the non-conventional form of energy. Sun is among one of the major source of non-conventional form of energy. Solar radiations which when received on the earth give solar energy, solar space heating etc and it is widely available and pollution free. Hence solar energy is one of cleanest and easily available source of energy to meet for increasing demand of energy.

One of the most simple and effective way to utilize solar energy is by converting it into thermal energy, so that it can be used for heating of solar air collector. Solar air heaters, due to its simple design, cheap cost and its wide application for low and medium temperature range. When the flow of air is over the absorber plate, it results in the formation of laminar as well as turbulent boundary layers, within the turbulent layer near the surface of the plate, but due to the formation of laminar sub-layer formed which result in the decrease of heat transfer rate. To tackle this problem and to increase the heat transfer coefficient, absorber plates having artificial roughness is most preferable.

There are number of experiments that have been performed to study the roughened absorber plate, many authors have submitted literature review on artificial roughness of plate. Heat transfer coefficient and friction factor correlations, have been observed by number of investigators in their research work in the field of solar air heater.

1.1 ARTIFICIAL ROUGHNESS

Because of poor value of convective heat transfer coefficient, efficiency of solar air heater is observed to be low. Due to the laminar sub layer the value of convective heat transfer coefficient is low, which is need to be resolved or changed by using concept of artificial roughness of various geometries and to generate turbulence which in return increase the heat transfer rate. However high friction losses, occurs due to artificial roughness which cause more consumption of power for flowing of fluid. The region where heat transferring surface is close turbulence should be created there. The parameters which are important to characterize the roughness element are the roughness element height (e) and pitch (p). They are considered in terms of dimensionless parameters such as relative roughness pitch (p/e), relative roughness height (e/D_h).

2. ARTIFICIAL ROUGHNESS IN SOLAR AIR HEATER

2.1 ARC SHAPED ROUGHNESS GEOMETRY

Saini et al experimentally investigated with Arc shaped roughness geometry in solar air heater. Parameters used for study were relative roughness height (p/e) from 0.0213-0.0422, relative angle of attack 33-66, aspect ratio (W/H) as 12 and Reynolds number varies from 2000 to 17,000. He investigated and reported maximum enhancement in Nusselt number (Nu) was 3.80 times corresponding relative arc angle (/90) of 0.33 at relative roughness height of 0.0422.

Corresponding increased in value of friction factor 1.75 times only. Arc shape roughness geometry are shown in the figure.

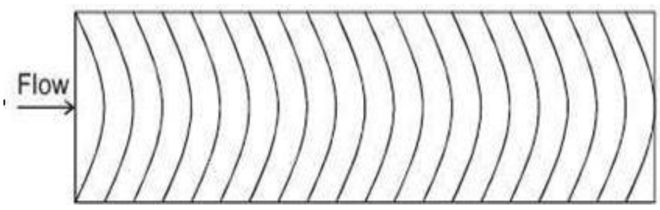

Fig.1 Arc shape roughness geometry

2.2 DIMPLED SURFACE

2.2.1 TRANSVERSE DIMPLE ROUGHNESS GEOMETRY

Saini et al experimentally investigated with dimple roughness geometry in solar air heater. Parameters used for study were relative roughness pitch (p/e) 8 to 12, relative roughness height (e/D_h) 0.018-0.037 and Reynolds number varies from 2000 to 12,000. He got maximum value of relative roughness pitch 10 and relative roughness height of 0.037.Friction factor minimum value corresponding to relative roughness pitch of 10, and relative roughness height as 0.0289. Transverse dimpled shape roughness geometry are shown in the figure.

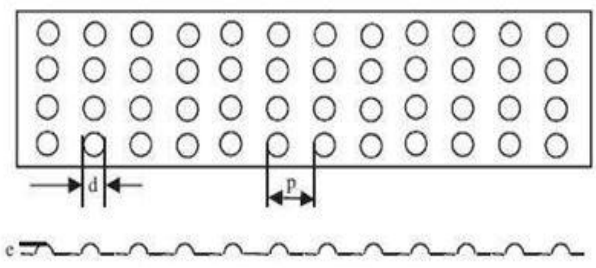

Fig.2 Transverse dimpled shape roughness geometry

2.2.2 ARC SHAPED DIMPLE ROUGHNESS GEOMETRY

Yadav et al experimentally investigated Arc shaped dimple roughness geometry in solar air heater. Parameters used for study were relative roughness height (e/D_h) as 0.015 to 0.03, relative roughness pitch (p/e) of 12 to 24, arc angle of protrusion arrangement as 45-75, and Reynolds number varies from 3600 to 18,000. Maximum increase in friction factor and Nusselt number was found to be 2.93 and 2.89 times in comparison with smooth plate for range of parameter investigated. Maximum increase in heat transfer and friction factor occurred for relative roughness pitch of 12, relative roughness height of 0.03 at an arc angle

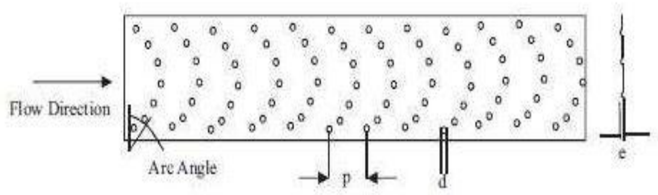

Fig.3 Arc shaped dimple roughness geometry

2.2.3 ARC SHAPED DIMPLE ROUGHNESS GEOMETRY

Sethi et al experimentally investigated on dimple shaped roughness geometry but set of parameters are different. Parameters used for study were relative roughness height (e/D_h) as 0.021-0.036, relative roughness pitch (p/e) of 10, relative, angle of attack 47-75, aspect ratio (W/H) as 11 and Reynolds number varies from 3600 to 18,000. He reported maximum enhancement of Nusselt number corresponding to relative roughness pitch of 10, relative roughness height of 0.036 at an arc angle 60^{o}.

2.3 TRANSVERSE RIBS ROUGHNESS GEOMETRY

2.3.1 CONTINUOUS TRANSVERSE ROUGHNESS GEOMETRY

The development of artificial roughness in history, PRASAD and MULLICK were the first investigator who used small diameter size of wire as roughness element in solar air heater. Relative roughness height (e/D_h) as 0.019 and Relative roughness pitch (p/e) as 12.7 were the parameters used for study. In the experimental investigation outcome obtained that enhancement in efficiency from 0.63 to 0.72.

Prasad and Saini also experimentally investigated on small size wire diameter as roughness element. Relative roughness height (e/D_h) as 0.020-0.033 and relative roughness pitch (p/e) as 10 -20 were the parameters used for the study. Nusselt number and friction factor maximum value was obtained 2.38 and 4.25 times when compared with smooth plate for relative roughness pitch 10.

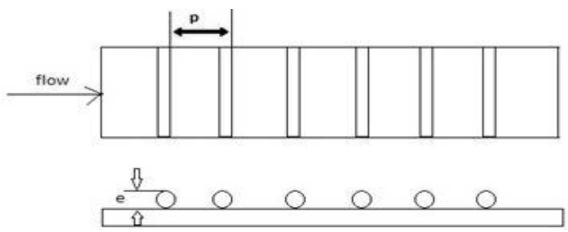

Fig.4 Transverse wire roughness geometry

Verma and Prasad experimentally investigated with transverse wire roughness geometry in outdoor experimental set up. Parameters used for study were relative roughness height (e/D_h) as 0.01 to 0.03, relative roughness pitch (p/e) of 10 and Reynolds number varies from 5000 to 20,000. The maximum enhancement in efficiency was 71%.

Gupta et al experimentally investigated with transverse wire roughness geometry for transitional flow rough regime in solar air heater. Parameters used for study were relative roughness height (e/D_h) as 0.018 to 0.052, relative roughness pitch (p/e) of 10, aspect ratio (W/H) as 6.8 to 11.5 and Reynolds number varies from 3000 to 18,000. They reported that in transitional flow regime Stanton number increases with Reynolds number. Maximum value of Stanton number was obtained at Reynolds number of 12,000.

2.3.2 TRANSVERSE BROKEN RIBS ROUGHNESS GEOMETRY

Sahu and Bhagoria experimentally investigated with transverse broken ribs roughness geometry in solar air heater. Parameters used for study were roughness pitch (p) of 10 mm to 30 mm, roughness height (e) of ribs as 1.5 mm, aspect ratio (W/H) as 8 and Reynolds number varies from 3000 to 12,000. Maximum enhancement in Nusselt number achieved for pitch 20 mm. Increase in heat transfer coefficient value by 1.25 to 1.4 times as compared with smooth plate.

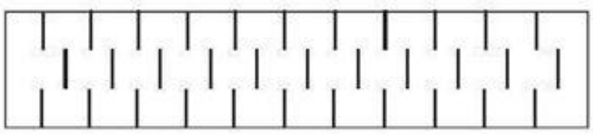

Fig.5 Roughness geometry of transverse broken ribs

2.4 INCLINED RIBS ROUGHNESS GEOMETRY

2.4.1 CONTINUOUS RIBS ROUGHNESS GEOMETRY

Gupta et al experimentally investigated with continuous inclined ribs roughness geometry. Parameters used for study were relative roughness height (e/D_h) as 0.018 to 0.052, relative roughness pitch (p/e) of 10 and Reynolds number varies from 3000 to 18,000.Thermal efficiency increased by 1.16 to 1.25 times as compared with smooth plate under similar conditions.

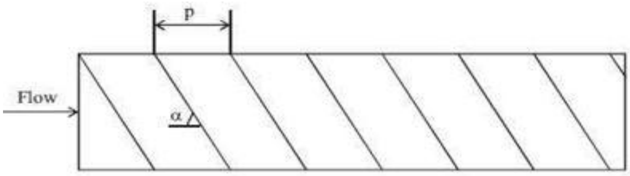

Fig.6 Inclined Continuous ribs roughness geometry

2.4.2 BROKEN INCLINED RIBS ROUGHNESS GEOMETRY

Aharwal et al experimentally investigated on broken inclined ribs with gap. Gap allow to release of secondary flow and main flow of air by introducing local turbulence. Parameters used for study were relative roughness height (e/D_h) as 0.0377, aspect ratio as 5.84, angle of attack 60^o, relative roughness pitch (p/e) of 10 and Reynolds number varies from 3000 to 18,000. Gap width (g/e) and gap position were in the range of 0.5 to 2 and 0.1667 to 0.667 respectively. Maximum value of Nusselt number and friction factor was obtained 2.59 and 2.87 times as compared with smooth plate. Maximum thermo-hydraulic performance obtained for relative gap position and relative gap width of 0.25 and 1.0 respectively.

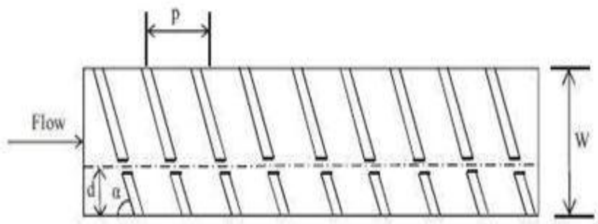

Fig.7 Broken inclined ribs with gap roughness geometry

2.5 WIRE MESH ROUGHNESS GEOMETRY

2.5.1 DISCREDITED METAL MESH ROUGHNESS GEOMETRY

Karmare and Tikekar experimentally investigated with discredited metal mesh roughness geometry as shown in the figure. Parameters used for study were relative roughness height (e/D_h) as 0.035 to 0.044, relative roughness pitch (p/e) of 12.5 to 36, roughness parameter

(1/s) as 1.72 -01 and Reynolds number varies from 4000 to 17,000. They found optimum performance at roughness parameter as 1.72 and relative roughness pitch as 17.5.

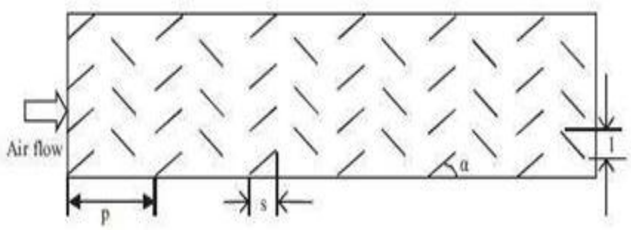

Fig.8 Discretized metal mesh roughness geometry

2.5.2 EXPANDED METAL MESH ROUGHNESS GEOMETRY

Saini et al experimentally investigated with expanded metal mesh roughness geometry. He investigated the effect of mesh (s/e) on friction factor and heat transfer. The maximum enhancement in friction factor and heat transfer coefficient value of 5 and 4 times respectively as compared with smooth duct at angle of attack 61.9° to 72°.

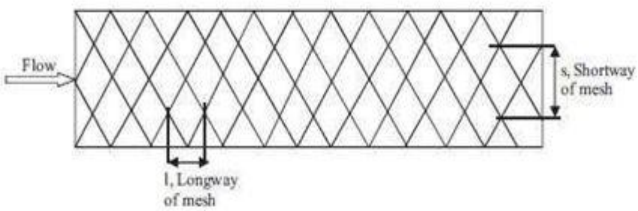

Fig.9 Expanded metal mesh roughness geometry

2.5.3 CHAMFERED RIBS ROUGHNESS GEOMETRY

Karwa et al experimentally investigated with chamfered ribs roughness geometry on the underside of absorber plate. Parameters used for study were relative roughness height (e/D_h) as 0.0141 to 0.0328, relative roughness pitch (p/e) as 4.5 to 8.5 and Reynolds number varies from 3000 to 20,000. Friction factor and Stanton number increased up to 3 and 2 times respectively. Maximum value obtained for both Stanton number and friction factor at an angle of 15°.

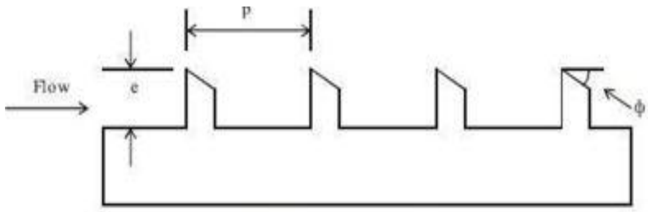

Fig.10 Integral chamfered ribs roughness geometry

2.6 TRANSVERSE WEDGE SHAPED ROUGHNESS GEOMETRY

Bhagoria et al experimentally investigated with transverse wedge shaped roughness geometry. Maximum enhancement in value of friction factor and Nusselt number was 5.3 and 2.4 as compared with smooth plate under similar conditions. Maximum value of heat transfer occurred at relative roughness pitch (p/e) of 7.57, at wedge angle of 10°.

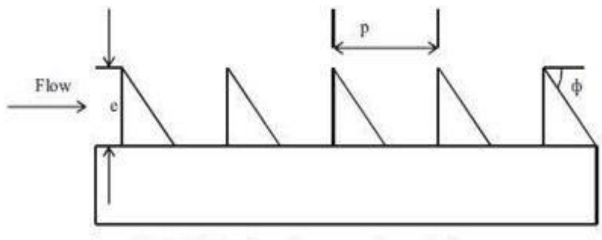

Fig.11 Transverse wedge shaped roughness geometry

2.7 W SHAPED ROUGHNESS GEOMETRY

2.7.1 DISCRETE W RIBS ROUGHNESS GEOMETRY

Kumar et al experimentally investigated with discrete W-shaped ribs roughness geometry on the underside of absorber plate. Parameters used for study were relative roughness height (e/D_h) as 0.0168 to 0.0338, relative roughness pitch (p/e) as 10, angle of attack 30 to75° and Reynolds number varies from 3000 to 15,000. Maximum enhancement in value friction factor and Nusselt number was 2.75 and 2.16 times as compared with smooth plate at angle of attack 60 , relative roughness height 0.0338.

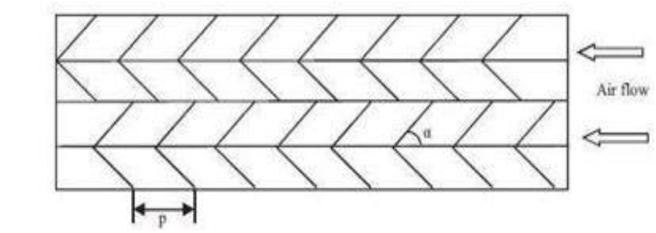

Fig.12 Discrete W ribs roughness geometry

2.7.2 CONTINUOUS W RIBS ROUGHNESS GEOMETRY

Lanjewar et al experimentally investigated with Continuous W ribs roughness geometry. Parameters used for study were relative roughness height (e/D_h) as 0.018-0.03375, angle of attack 30-75^o, relative roughness pitch (p/e) of 10. Optimum value of thermo-hydraulic performance obtained at angle of attack 60^o in W down arrangement. Maximum enhancement in value of friction factor and Nusselt number was 2.01 and 2.36 as compared with smooth plate at angle of attack 60^o.

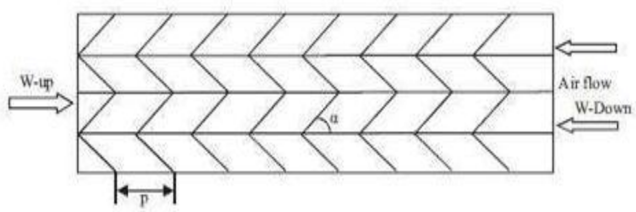

Fig.13 Continuous W ribs roughness geometry

2.8 ROUGHNESS ELEMENT COMBINATION GEOMETRY

2.8.1 TRANSVERSE RIBS GROOVE COMBINATION ROUGHNESS GEOMETRY

Jaurker et al experimentally investigated with Transverse ribs groove combination roughness geometry. Maximum value of heat transfer occurred at relative roughness pitch (p/e) of 6. Optimum value of heat transfer was achieved for groove position to pitch ratio of 0.4.

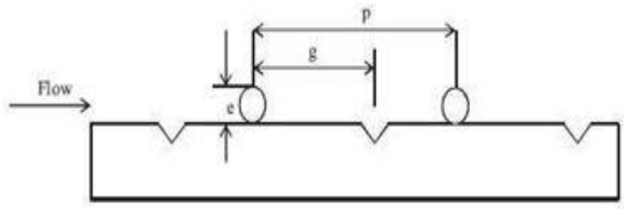

Fig.14 Transverse ribs groove combination roughness geometry

2.8.2 TRANSVERSE AND INCLINED RIBS COMBINATION ROUGHNESS GEOMETRY

Varuna et al experimentally investigated with Transverse and inclined ribs combination roughness geometry. Parameters used for study were relative roughness height (e/D_h) as 0.030, relative roughness pitch (p/e) as 3 to 8 and Reynolds number varies from 2000 to 14,000. Best performance occurred at relative roughness pitch 8.

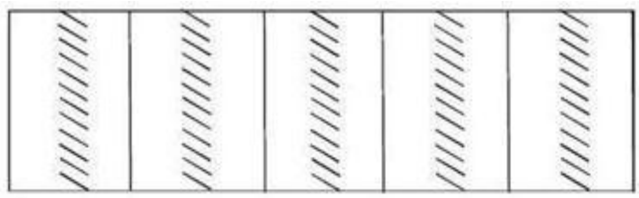

Fig.15 Transverse and inclined ribs combination roughness geometry

2.8.3 CHAMFERED RIBS GROOVE COMBINATION ROUGHNESS GEOMETRY

Layek et al experimentally investigated with Chamfered ribs groove combination roughness geometry. Parameters used for study were relative roughness height (e/D_h) as 0.019 to 0.043, chamfer angle 5- 30^o, relative roughness pitch (p/e) of 4.5 to 10, relative groove position as 0.3 to 0.6 and Reynolds number varies from 2000 to 21,000. Maximum enhancement in value of friction factor and Nusselt number was obtained 3.78 and 3.24 times as compared with smooth plate at relative groove position of 0.4.

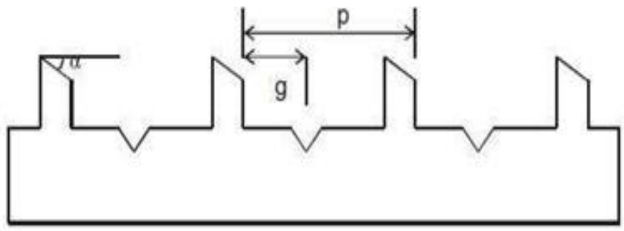

Fig.16 Chamfered ribs groove combination roughness geometry

2.9 V- SHAPED RIBS ROUGHNESS GEOMETRY

2.9.1 CONTINUOUS V- SHAPED RIBS ROUGHNESS GEOMETRY

Momin et al experimentally investigated with Continuous V shaped ribs roughness geometry for better performance than transverse ribs due to increase of secondary v ortices. Parameters used for study were relative roughness height (e/D_h) as 0.02 to 0.034, angle of attack as 30 to 90°, relative roughness pitch (p/e) 10 and Reynolds number varies from 2500 to 18,000. Maximum enhancement in value of friction factor and Nusselt number was obtained 2.83 and 2.30 times as compared with smooth plate at angle of attack 60°.

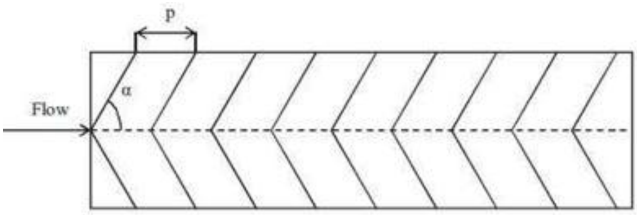

Fig.17 Continuous V shaped ribs roughness geometry

2.9.2 DISCRETE V-SHAPED RIBS ROUGHNESS GEOMETRY

Karwa et al experimentally investigated with discrete V-shaped ribs roughness geometry on the underside of the absorber plate. Parameters used for study were relative roughness length (B/S) as 3 and 6, angle of attack as 45° and 60°, relative roughness pitch (p/e) 10.62 and Reynolds number varies from 2850 to 15,500. Performance of 60° ribs geometry better than 45° and discrete ribs better than discontinuous ribs roughness geometry.

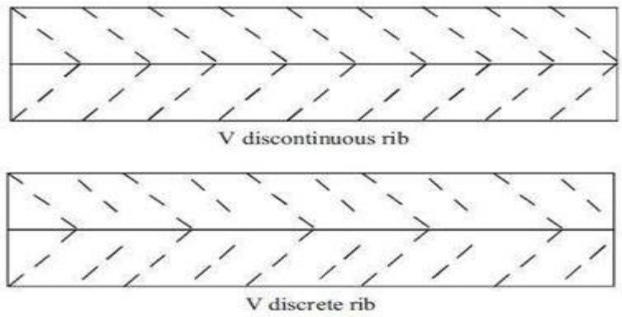

Fig.18 V-shaped ribs in different orientation of different patterns

Muluwork et al experimentally investigated with discredited V-shaped ribs roughness geometry, they compared thermal performance of staggered discrete V-down ribs and V-apex up with corresponding staggered discrete ribs. In the investigation they found that Stanton number of V -down discrete ribs higher than corresponding transverse discrete ribs and V-up ribs. Enhancement in Stanton number was found that 1.32 to 2.47 in range of parameters investigation.

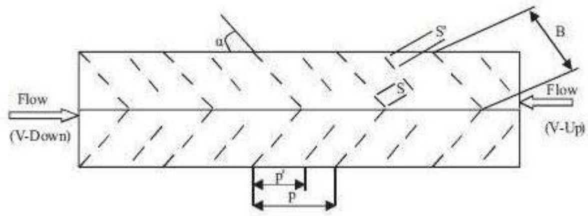

Fig.19 Discrete V shaped ribs roughness geometry

Singh et al experimentally investigated on discrete V-shaped down ribs on the underside of the absorber plate. Parameters used for study were relative roughness height (e/D_h) as 0.015 to 0.045, relative roughness pitch (p/e) of 4 to 12, relative gap position (d/w) and relative gap width (g/e) in range of 0.20-0.80 and 0.5-2.0 respectively, angle of attack 30-75, and Reynolds number varies from 3000 to 15,000. Maximum increase in value of friction factor and Nusselt number was 3.11 and 3.04 times as compared with smooth plate respectively. Rib parameter corresponding to increase in friction factor and Nusselt number were g/e=1.0, d/w=0.65, e/D_h=0.043, angle of attack 60º and p/e=10.

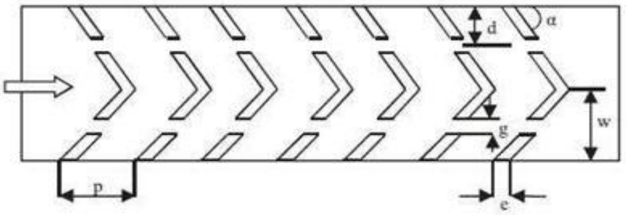

Fig.20 Discrete V-shaped down ribs roughness geometry

3. CONCLUSIONS

The present review of paper concludes that lots of efforts to increase the heat transfer rate of solar air heater by employing the concept of artificial roughness of various shapes and sizes are carried out.

For a long while different correlations for friction factor and heat transfer to incorporate in duct of solar air heaters having artificial roughness of various geometries have been investigated. This formulated correlation can be used to determine the thermo-hydraulic as well as thermal performance of solar air heater having roughened duct.

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