# A review on Solar Air Heater using various artificial roughness geometries

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**Abstract—Solar air heaters provides the efficient use of solar energy, which uses the absorber plate to absorb the incoming solar radiations, converting it to thermal energy at its surface, and transferring the thermal energy to the fluid flowing through the collector. It has been observed that the efficiency of the flat plate solar air heater is low because of low convective heat transfer coefficient between the absorber plate and the air flowing over it. The most common and effective way to improve the performance of the solar air heater is to provide artificial roughness elements on the underside of the absorber plate. However several investigations have been carried out to determine the effect of various roughness element geometries on heat transfer and friction factor in solar heaters. This study provides an extensive review on various investigations carried out on thermal as well as hydraulic performance of solar air heaters by using various roughness element geometries. Heat transfer and friction factor correlations developed by various investigators have been reported for comparative study of the thermohydraulic performance of various solar air heater ducts.**

**Index Terms—Artificial roughness geometries, Solar air heater, Thermal efficiency parameter.**

## I. INTRODUCTION

Energy is required to sustain life. Broadly energy resources can be classified into conventional and non-conventional 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 are those which have the short span of renewal. 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. Solar air heater has been employed to deliver heated air at low to moderate temperatures which can is used for crop drying and several industrial applications. Solar air heating is the most cost effective out of all solar technologies available to us. 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 on underside of absorber plate surface is an effective way to enhance the heat transfer to the flowing air in 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. Thus the objective is to increase the heat transfer coefficient between the absorber plate and air flowing over the plate. Providing roughness element improves thermal efficiency, but it would result in increased frictional losses. Therefore, greater power is requiredby 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

Singh et al. [1] carried out an experimental investigation of thermohydraulic performance, heat transfer and efficiency, of solar air heater. The range of variation of system and operating parameters was investigated within the limits and against variation of Reynolds number and showed that the relative efficiency was maximum for Reynolds Number equal to 22300. It was seen that multiple arc shaped roughness element results in maximum value of TPP i.e. 3.4 at Re, W/w, e/D, p/e and $\alpha$ of 22300, 5, 0.045, 8 and 60° respectively. Kumar et al. [2] made an attempt to review the thermohydraulic performance of artificially roughened solar air heaters. The review focuses on various studies carried out on thermal as well as hydraulic performance of artificial roughened solar air heater ducts. The correlations developed for heat transfer and friction factor for different geometries in roughened ducts of solar air heaters by various investigators have been reviewed and presented.

Prasad et al. [3] made an attempt to analyze the fluid flow and heat transfer behavior in a novel solar air heater having artificial roughness of small diameter wires on three sides (one top side and two side walls) of the rectangular solar air heater duct. The range of parameters values considered were relative roughness pitch (e/p) of 10-20, and relative roughness height (e/D) of 0.020-0.033. The values of average friction factor and average Nusselt number have been found to increase by 2-34% respectively in comparison with the one sided roughened solar air heater and 150-200% more in terms of heat transfer than those of smoothened solar air heaters within the same range of values of roughness and flow parameters.

Alam et al. [4] investigated the effect of non-circular perforation holes in term of circularity of V-shaped blockages attached to one heated wall of a rectangular duct of solar air heater. Five different hole shapes ranging from circular to square to rectangular in the circularity range of 1–0.6 have been used with varying relative pitch of 4–12, relative blockage height of 0.4–1.0, open area ratio of 5–25% and angle of attack of 30–75° and Reynolds number of flow was varied between 2000 and 20,000. Maximum enhancement in Nusselt number was found to be 350 at angle of attack value of 60° at relative pitch of 8.Bekele et al. [5] investigated the performance of conventional solar air heaterfor the range of Reynolds number (Re) from 2100 to 30,000, relative obstacle height (e/H) from 0.25 to 0.75, relative obstacle longitudinal pitch (Pl/e) from 3/2 to 11/2, relative obstacle transverse pitch (Pt/b) from 1 to 7/3 and the angle of incidence (α) varied from 30° to 90°.For angle of incidence of 30°, 60° and 90°, the maximum thermohydraulic performance was found to be 3.89, 3.29 and 2.09 respectively.

Yadav and Bhagoria [6] carried out numerical investigation to analyse the two dimensional incompressibleNavier–Stokes flows through the artificially roughened SAH for Reynolds number range 3800 to 18,000. Twelve different configurations of equilateral triangular sectioned rib (P/e= 7.14–35.71 and e/d= 0.021–0.042) have been used as roughness element. The maximum enhancement in the Nusselt number was found to be 3.073 times over the smooth duct corresponds to relative roughness height (e/D) of 0.042 and relative roughness pitch (P/e) of 7.14 at Reynolds number (Re) of 15,000 in the range of parameters investigated. The maximum enhancement in friction factor was found to be 3.356 times over the smooth duct corresponds to relative roughness height (e/D) of 0.042 and relative roughness pitch (P/e) of 7.14 at Reynolds number (Re) of 3800.

Alam et al. [7] investigated experimentally the effect of geometrical parameters of the V-shaped perforated blocks on heat transfer and flow characteristics of rectangular duct. Range of parameters considered were relative blockage height (e/H) of 0.4–1.0, relative pitch ratio (P/e) of 4–12 and open area ratio (β) of 5–25% at a fixed angle of attack (α) of 60° for Reynolds number 2000-20,000. The maximum enhancement in Nusselt number and friction factor were found to be 6.76 and 28.84 times to that of smooth duct, respectively.

Yadav and Bhagoria[8] carried out numerical investigation for the heat transfer and fluid flow characteristics of fully developed turbulent flow in a rectangular duct having repeated transverse square sectioned rib roughness on the absorber plate.Twelve different configurations of square sectioned rib P/e= 7.14-35.71 and e/D= 0.021-0.042 had been considered. The flow Reynolds number of the duct varied in the range of 3800-18,000. The maximum enhancement of average Nusselt number and friction factor has been found to be 2.86 and 3.84 times that of smooth ductrepectively, for relative roughness pitch of 7.14 and for relative roughness height of0.042.

Prasad [9] investigated experimentally the effects of artificial roughness on heat transfer and frictional characteristics of outdoor solar air heaters. Thin G.I. wires of varying diameter have been provided on the flow side of the absorber plate normal to the fluid flow direction at varying pitch as roughness so as to give the value of the relative roughness height e/D, in the range of 0.0092–0.0279, relative roughness pitch p/e, in the range of 10–40. The flow Reynolds number variedin the range of 2959–12631, while the mass flow rate varied between 0.0063 and 0.0259 kg/s. The maximum values of the ratio of collector heat removal factor, collector efficiency factor and thermal efficiency of roughened solar air heaters to those of the smooth solar air heaters have been found to be 1.786, 1.806 and 1.842 respectively within the range of the parameters investigated.

Yadav and Bhagoria [10] studied the effects of heat transfer and fluid flow characteristics in artificially roughened solar air heater using CFD. The effects of small diameter of transverse wire rib roughness on heat transfer and fluid flow have been investigated. The maximum value of average Nusselt number was found to be 117 for relative roughness pitch of 7.14 and forrelative roughness height of 0.042 at a higher Reynolds number,18,000. The maximum enhancement of average Nusseltnumber and frictional factor was found to be 2.31and 0.0317 times that of smooth duct forrelative roughness pitch of 7.14 and for relative roughnessheightof 0.042.

Kumar et al. [11]carried out an experimental investigation of heat transfer and friction in the flow of air in rectangular ducts having multi v-shaped rib with gap roughness on one broad wall. The investigation encompassed Reynolds number (Re) from 2000 to

20,000, relative gap distance (Gd/Lv) values of 0.24-0.80, relative gap width (g/e) values of 0.5-1.5, relative roughness height (e/D) values of 0.022-0.043, relative roughness pitch (P/e) values of 6-12, relative roughness width ratio (W/w) values of 1-10, angle of attack (α) range of 30°-75°.

Sethi et al. [12] carried out an experimental investigation to analyse the effects of artificial roughness on heat transfer and frictional characteristics of rectangular duct having dimple shaped elements arranged in angular fashion (arc) as roughness elements. Range of parameters considered were aspect ratio (W/H) of 11, relative roughness pitch (p/e) 10-20, relative roughness height ($e/D_h$) 0.021- 0.036, arc angle (α) 45-75° and Reynolds number from 3600-18,000. The value of maximum Nusselt number was found to be 135 for values of (p/e) value of 10, arc angle (α) of 60° and ($e/D_h$) value of 0.036.

Lanjewar et al. [13]carried out the experimental investigation of heat transfer and friction factor characteristics of a rectangular duct roughened with W-shaped ribs arranged at an inclination with respect to the flow direction on underside of absorber plate. The duct had a width to height ratio (W/H) of 8.0, relative roughness pitch (p/e) of 10, relative roughness height ($e/D_h$) of 0.03375 and angle of attack of flow (α) of 30–75° and Reynolds number between 2300–14,000 was used. Maximum thermo-hydraulic performance for W-down ribs was found to be 1.98 while it was 1.81 for W-up ribs in the range of parameters investigated. El-Sebaii et al. [14] carried out an investigation of thermal performance of double pass flat-plate and v-corrugated plate solar air heaters. The results showed that the double pass v-corrugated plate solar air heater is 11-14% compared to double pass flat plate solar air heater. The thermohydraulic efficiency of double pass v-corrugated plate SAH is 14% higher than that of double pass flat plate solar air heaters.

Lanjewar et al. [15]carried out an experimental investigation of heat transfer and friction factor characteristics of rectangular duct roughened with W-shaped ribs on its underside on one broad wall. Range of parameters considered were Duct has width to heightratio (W/H) of 8.0, relative roughness pitch (p/e) of 10, relative roughness height ($e/D_h$) 0.018-0.03375and angle of attack of flow (α) 30-75°. For relative roughness height of 0.03375 and at angle of attack of 60°, W-shape ribs enhanced value of Nusselt number by 2.21 times over smooth plate at Reynolds number of 14,000.

Karmare and Tikekar [16] studied fluid flow and heat transfer in solar air heater by using Computational Fluid Dynamics (CFD). Lower side of collector plate was made rough with metal ribs of circular, square and triangular cross-section, having $60^o$ inclinations to the air flow. The grit rib elements were fixed on the surface in staggered manner to form defined grid. Amongst the different shape and orientations analyzed, the absorber plate of square cross-section rib with $58^0$ angle of attack gave the best possible results. The percentage increase in the heat transfer for $58^0$ rib inclination plate over smooth plate was found to be 30%.

Bhushan and Singh [17] made an attempt to review the various methodology used in duct of solar air heaters. An attempt has been made to categorize and review the reported roughness geometries used for creating artificial roughness. Heat transfer coefficient and friction factor correlations developed by various investigators for roughened ducts of solar air heaters have been reported in their study. Varun et al. [18] have done thermal efficiency optimization of solar air heater having combination of inclined and transverse ribs on the absorber plate by using Taguchi Method. The range of parameters considered were Reynolds number (Re) 2000-14,000, relative roughness pitch (p/e) 3-8 and fixed value of relative roughness height (e/d) of 0.030. The maximum effective efficiency computed was 0.717 for Reynolds number 11,600.

Karmare and Tikekar [19] carried out an experimental investigation of thermohydraulic performance, heat transfer and efficiency, of solar air heater. The range of variation of system and operating parameters was investigated within the limits of, e/Dh: 0.035–0.044, p/e: 15–17.5 and l/s as 1.72, against variation of Reynolds number, Re: 3600–17000. The experimental results showed that the maximum value of effective efficiency was found to be 0.7 for Reynolds Number 17030, when the value of isolation reached to 870 $W/m^2$.

Kumar and Saini [20] used Computational Fluid Dynamics (CFD) for performance analysis of solar air heater having artificial roughness in the form of thin circular wire in arc shaped geometry. The effect of arc shaped geometry on heat transfer coefficient, friction factor and performance enhancement was investigated covering the range of roughness parameter. Different turbulent models have been used for the analysis and their results are compared. Overall enhancement ratio with a maximum value of 1.7 has been found for the roughness geometry corresponding to relative arc angle (α/90) of 0.333 and relative roughness height (e/D) of 0.0426 for the range of parameters considered.

Saini and Saini [21] carried out an experimental study for enhancement of heat transfer coefficient of solar air heater provided with arc shaped parallel wires as roughness elements. The effect of system parameters such as relative roughness height (e/d) and arc angle (α/90) have been studied on Nusselt number (Nu) and friction factor (f) with Reynolds number (Re) varied from 2000 to 17000. Considerable enhancement in heat transfer coefficient has been achieved with such roughness element. The maximum enhancement in Nusselt number (Nu) has been obtained as 3.80 times compared with smoother plate, for corresponding relative arc angle (α/90) of 0.3333 at relative roughness height of 0.0422. However, the increment in friction factor corresponding to these parameters has been observed 1.75 times only.

Saini and Verma [22] carried out an experimental study to investigate the effect of roughness and operating parameters on heat transfer and friction factor in a roughened duct provided with dimple-shape roughness geometry. Correlations for Nusselt number and friction factor have been developed for solar air heater duct provided such artificial roughness geometry. The maximum value of Nusselt number has been found to be 11,600 corresponding to relative roughness height (e/D) of 0.0379 and relative pitch (p/e) of 10. While minimum value of friction factor has been found to be 0.05 corresponding to relative roughness height (e/D) of 0.0289 and relative pitch (p/e) of 10.

Aharwal et al. [23] discussed heat transfer and friction factor characteristics of a rectangular duct roughened with repeated $60^0$ inclined square cross-section split-ribs with a gap and also conclude that a discretization based on the optimization of gap width and gap position leads to a thermohydraulically superior arrangement. 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 having Reynolds numbers from 3000 to 18,000. The increase in Nusselt number and friction factor is in the range of 1.48–2.59 times and 2.26–2.9 times of the smooth duct, respectively.

Jaurker et al. [24] carried out an experimental investigation on the heat transfer and frictional characteristics of rib grooved artificial roughness. The Reynolds number range used from 3000 to 21,000; relative roughness height 0.0181–0.0363; relative roughness pitch 4.5–10.0, and groove position to pitch ratio 0.3–0.7. The rib-grooved duct with relative roughness pitch (p/e) of 6.0 and position of groove to pitch ratio (g/p) of 0.4 provides the maximum value of the Nusselt number in the order of 2.75 times of the smooth duct and 1.57 times ofribbed duct whereas for ribbed duct with similar rib height and rib spacing provides the Nusselt number values of the order of 1.7 times of the smooth duct for the range of experimentation, the maximum value of the friction factor for rib-grooved duct was 3.61 times that of the smooth duct and 1.17 times that of ribbed duct whereas a ribbed duct with similar rib height and rib spacing results in the friction factor value of the order of 3.00 times that of the smooth duct.

## III. METHODS FOR PROVIDINGROUGHNESS

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:

*a.* Multiple arc shaped elements

Singh et al.[1] 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.

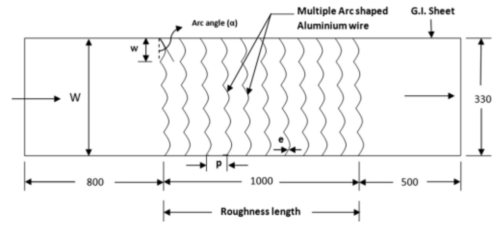


Figure 1: Multiple Arc shaped elements on absorber plate [1].

*b.* 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.

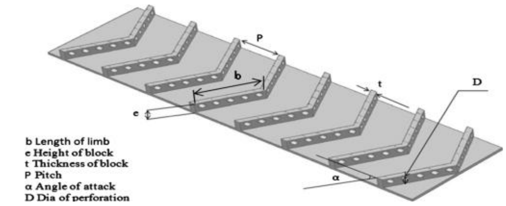


Figure 2: V-Shaped perforated holes on absorber plate [2].

*c.* **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 (Figure 3) solar air heater using small diameter wires on the top and side walls as depicted in Figure 4.

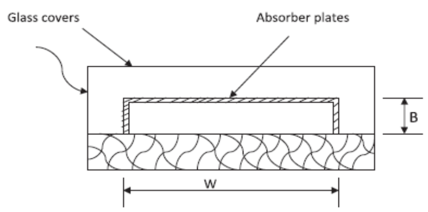

Figure 3: Three sided roughened and one sided smooth rectangular duct [3].

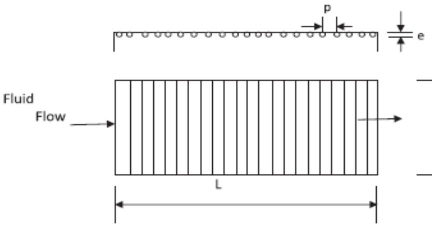


Figure 4: Top side of absorber plate with small diameter wires [3].

*d.* 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 as shown in Figure 5.

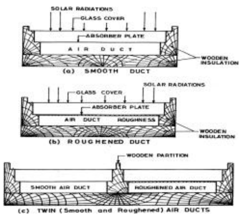


Figure 5: (a-c) Smooth, roughened and twin solar air heater [9].

*e.* Dimple shaped roughness elements in angular fashion

Sethi et al. [12]carried out an experimental investigation in order to analyse the effect of heat transfer and friction characteristics in solar air heater having dimple shaped elements arranged in angular fashion as depicted in Figure 6.

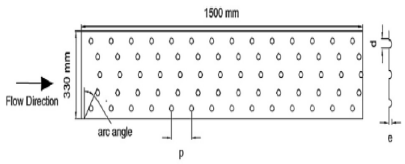


Figure 6: Dimple shaped elements arranged in angular fashion [12].

*f.* 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 Figure 7.

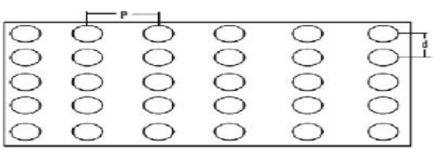


Figure 7: Dimpled Ribs on absorber plate [22].

*g.* 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. The geometry is as depicted in Figure 8.

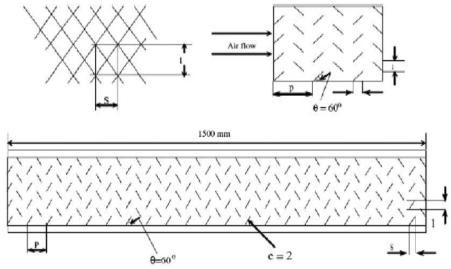


Figure 8: Rib grit roughness element on collector plate [16.19].

*h.* 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 9.

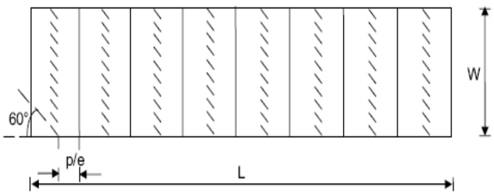


Figure 9: Inclined and transverse ribs on absorber plate [18].

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.

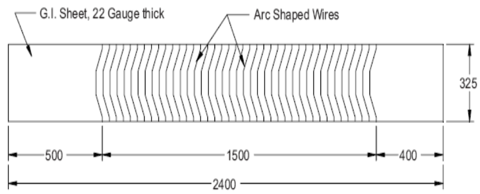


Figure 10: Arc shaped elements on underside of plate [20].

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 11.

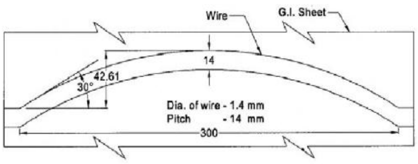


Figure 11: Arc shaped ribs [21].

*a.* 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 12.

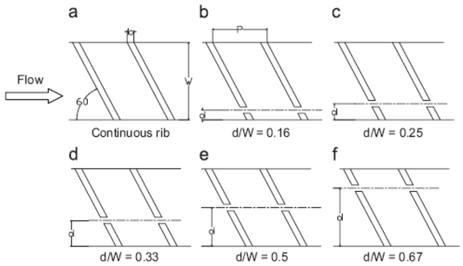


Figure 12: Inclined ribs with Gap [23].

*b.* Rib- grooved arrangement

Jaurker et al. [24] performed experimental investigation on heat transfer and frictional characteristics of rib-grooved artificial roughness on one board heated wall of rectangular duct. The arrangement of groove pattern is as depicted in Figure 13.

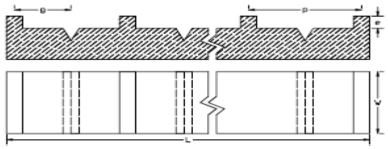

Figure 13: Rib groove arrangement on absorber plate [24].

C. 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 14) and upstream W-up (Figure 15) to the flow.

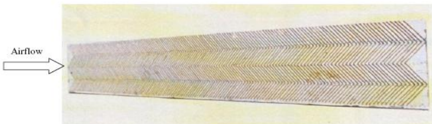


Figure 14: W- down roughness geometry [13].

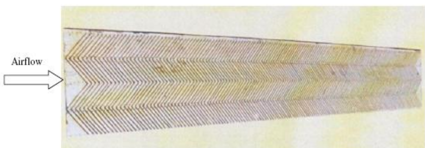


Figure 15: W- up roughness geometry [13].

D. 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 16.

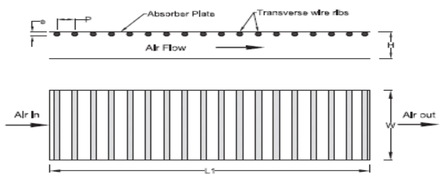


Figure 16: Roughened plate with continuous transverse wire ribs [10].

E. 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 17.

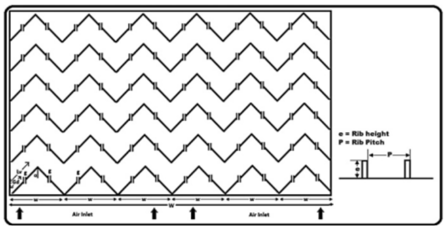

Figure 17: Multiple V-shaped ribs with gap [11].

F. 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. The roughened plate is as shown in Figure 18.

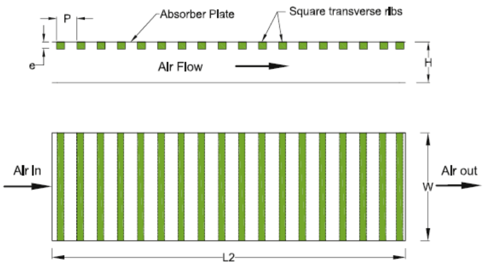


Figure 18: Roughened plate with square transverse ribs [8].

## 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 listed below:

Table 1: Values for various roughness parameters.

| **Sr. No.** | **Investigator** | **Rib Geometries** | **Value of P/e** | **Value of $e/D_h$** | **Value of α** |
|---|---|---|---|---|---|
| 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. | Prasad [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° |
| 11. | Sethi et al. [12] | Dimpled plate | 10-20 | 0.021-0.036 | 45-75° |
| 12. | Lanjewar et al. [13] | w-shaped ribs | 10 | 0.03375 | 30-75° |
| 13. | Lanjewar et al.[15] | w-shaped ribs | 10 | 0.018-0.0337 | 30-75° |
| 13. | Karmare and Tikekar [16] | Rib grit roughened | 17.5 | 0.044 | 58° |
| 14 | Varun et al. [18] | Transverse and inclined ribs | 3-8 | 0.030 | 60° |
| 15. | Karmare and Tikekar [19] | Metal rib grits | 15-17.5 | 0.035-0.044 | 60° |
| 16. | Kumar and Saini [20] | Arc shaped ribs | 10 | 0.029-0.0426 | 30-60° |
| 17. | Saini and Saini [21] | Arc shaped wires | 10 | 0.0213-0.042 | 30-60° |
| 18. | Saini and verma [22] | Dimple shape | 8-12 | 0.018-0.037 | - |
| 19. | Aharwal et al. [23] | Inclined continuous ribs | 10 | 0.0377 | 60° |
| 20. | Jaurker et al. [24] | Rib grooved plate | 4.5-10 | 0.0181-0.0363 | - |

## V CASE STUDY

A. CFD analysis of smooth plate solar air heater

Modeling of 3D model 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.

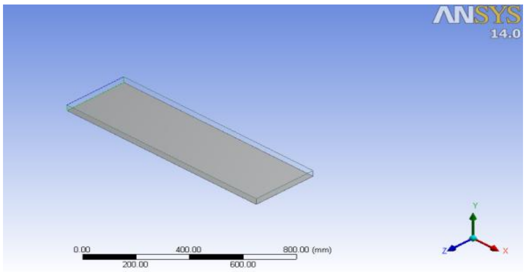


Figure 19. 3D model of duct

The boundaries and continuum as inlet, outlet, heated wall, insulated wall and the fluid zones 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. Further to solve for the temperature variations Energy equation must be kept on.

As the flow was turbulent, k–e model was selected as turbulent model for further analysis of the problem. Energy equation was also kept ON as a heat transfer model. Air was selected as working fluid. The different boundary conditions for the geometries were selected as: air inlet velocity = 2 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 320 K. All the other walls were considered to be completely insulated with zero heat flux. No slip condition was applied to all the 'walls'.

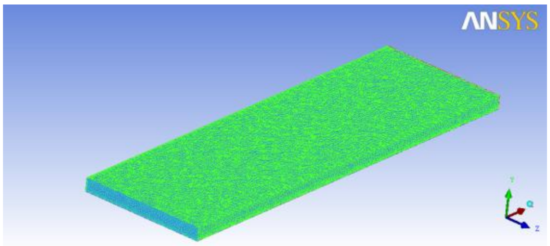


Figure 20.Volumetric Meshing of duct

**Computational analysis**

Table 2. 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 200 iterations within which it gives well converged solution so that accurate results were displayed. The contours were displayed by using post processor.

B. Results and Discussion

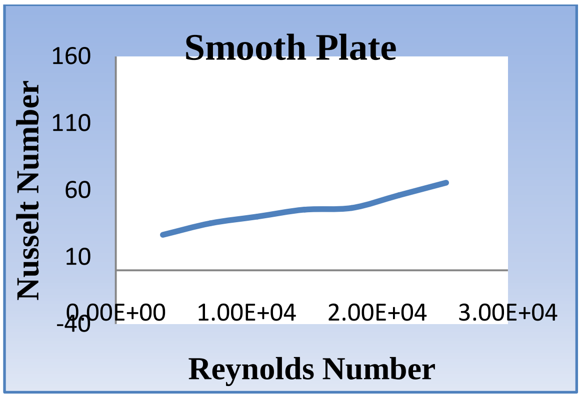


Figure 21: Nu no. Vs Re no. (Smooth plate)

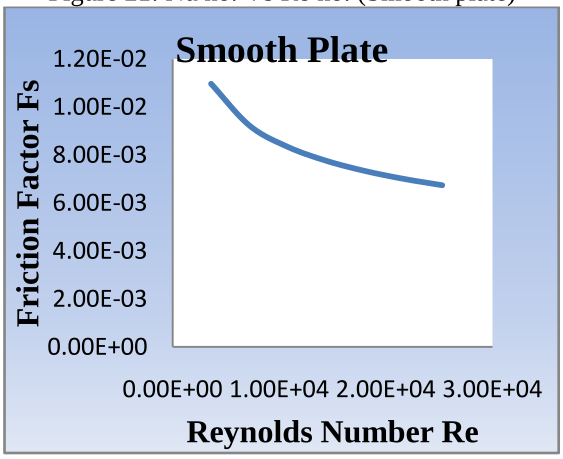


Figure 22: Friction factor Vs Re no. (Smooth plate)

Figure 21 and 22 shows Nusselt number and friction factor behaviour respectively, with respect to increasing Reynolds number. Figure 23 and 24 shows contours of temperature and pressure respectively across the smooth absorber plate.

**Temperature contours**

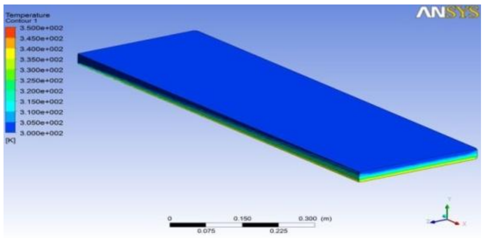


Figure 23: Contours of Static Temperature

**Pressure contours**

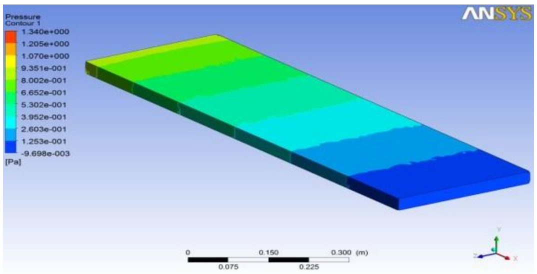


Figure 24: Contours of Static Pressure

# 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 elementsincludes 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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