Optimization of Thermal-Hydraulic Efficiency of Solar Air Heater with Roughened Absorber Plate by CFD

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Abstract: *The thermal performance of solar air heater is generally poor due to low heat transfer coefficient between the absorber plate and air flowing in the duct. In order to improve the thermal performance artificial roughness is provided on the underside of absorber plate due to which turbulence is created in the heat transfer zone and ultimately performance of solar air heater improves considerably and analyzes by CFD. In the present work the performance of a solar air heater duct provided with artificial roughness in the form of thin wire in V-shaped, V-shaped rib with gap geometries has been analyzed using ANSYS –FLUENT 15. The effect of these geometries on thermal-hydraulic efficiency, heat transfer, friction factor, Nusselt number. Reynold's number, pressure drop and performance enhancement was investigated covering the range of roughness parameters V-shaped, V-shaped rib with gap and working parameters by using Renormalization k-epsilon model . Different turbulent models have been used for the analysis of heat transfer and friction factor and their results are compared with Diettus-Boltier Empirical relationship for smooth surface.*

Key words: *Solar Air Heater,CFD Analysis, Artificial Roughness, Roughness Geometry ,thermo-hydraulic performance, Reynolds number,Nusselt number, Friction Factor.*

1. INTRODUCTION:

Solar air heater is one of the basic types of solar collectors which absorbs the incoming solar radiations and converted it into thermal energy for various thermal applications. It has been found that the conversion of solar radiation to thermal energy is poor in the conventional solar air heater due to the low heat transfer coefficient between the absorber plate and working fluid of the solar air heater. The use of artificial roughness on the absorber plate is one of the effective techniques to enhance the rate of heat transfer to flowing fluid in a solar air heater. It has been observed that the artificial roughness applied on the absorber plate breaks the laminar sub layer, which reduces thermal resistance and increase heat transfer coefficient. Solar air heater are the cheapest and extensively used solar energy collection devices employed to deliver heated air at low to moderate temperatures for various applications. These types of solar air collectors collect solar energy and covert this energy in form of hot air. Conventional type of solar air collector have lower thermal efficiency than concentrating type of solar air collectors, but because of low operating cost and maintenance cost, they are widely used as a heating media. Useful heat energy from flat plate solar air heaters can be used in many thermal applications in drying agricultural products such as in seeds, fruits, and vegetables and residential also some time in industries and as a auxiliary heater for heating building in winter time.

There are few drawbacks in model testing also. They are:

- Model testing is time consuming, costly and not all the variables can be found out using it.
- Also all the input variables cannot be altered to find out detailed results.
- Lot of time is also lost.

All these limitations can be overcome by using CFD (Computational Fluid Dynamics). CFD has the following advantages:

- Time is saved in designing and manufacturing.
- Input conditions can be altered which is not possible experimentally.
- Reduction in project cost.
- Reduction in experimental work.

2. OBJECTIVE & SCOPE OF WORK:

- To optimize thermal-hydraulic efficiency of solar air heater with using different artificial roughness and with using different value of relative roughness pitch with the help of ANSYS-FLUENT 15.
- To know the effect on Nusselt number, Reynolds number, Pressure drop by using different artificial roughness like v shape, v shape with gape and V-shape with different relative roughness height.
- To find out which roughness geometry gives best results to improve the efficiency of solar air heater.

3. METHODOLOGY:

3.1 METHODLOGY OF ARTIFICIAL ROUGHNESS:

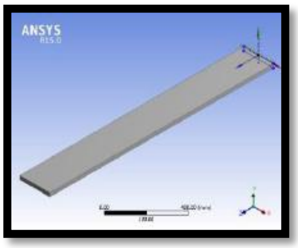
Whenever air flows over a heated surface, a very thin layer exists below the core turbulent region in which the flow remains predominantly laminar due to viscous effects called viscous sub layer, the heat transfer rate from absorber surface to air is very low. Therefore the application of artificial roughness is to break that sub layer & creates local wall turbulence due to separation & reattachment of flow between two consecutive roughness elements. Thus turbulence created by various roughness elements significant enhances the heat transfer rates between the absorber surface & flowing fluid i.e. air.

3.2 RANGE OF PARAMETERS:

SMOOTH SURFACE	V-SHAPE	V -SHAPE	V-WITH GAPE	V-WITH GAPE
1. Duct :- W= 200mm H = 25mm L= 1500mm 2. Re=3000-5,000	1. Duct :- W = 200mm H = 25mm L= 1500mm 2. Re= 3000-5,000 3. P = 16 4. e = 1.6 5. p/e = 10 6. e/Dh = 0.036 7. α = 60º	1. Duct :- W = 200mm H = 25mm L = 1500mm 2. Re= 3000 -15,000 3. P = 12.8 4. e = 1.6 5. p/e = 8 6. e/Dh = 0.036 7. α = 60º	1. Duct :- W = 200mm H = 25mm L=1500mm 2. Re= 3000-5,000 3. P = 16 4. e = 1.6 5. p/e = 10 6. Ld = 75 7. Ld/LV=0.65 8. GD = 1.6 9. e/Dh = 0.036 10. α = 60º	1. Duct :- W = 200mm H= 25mm L=1500mm 2. Re=3000-15,000 3. P = 16 4. e = 1.6 5. p/e = 10 6. Ld = 65 7. Ld/LV=0.56 8. GD = 1.6 9. e/Dh = 0.036 10. α = 60º

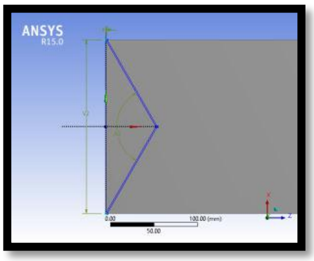
4. GEOMETRIC MODELING:

- The geometry of duct having a height (H) OF 25 mm, width (W) of 200mm and length of 1500mm is generated by using ANSYS-FLUENT R15 as shown in fig.1



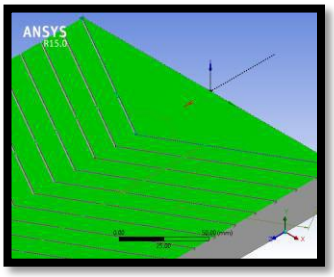
(Fig.1 Geometry of smooth surface)

- As shown in fig.2 In the geometric modeling of V-shape artificial roughness we have taken a two geometries one with relative roughness pitch (p/e = 10) and second with relative roughness height (p/e = 8) .In both cases relative roughness height (e/Dh = 0.036) is remain constant. Other parameters are as given below.



(Fig.2 Geometry of V-shape having p/e = 8 & 10)

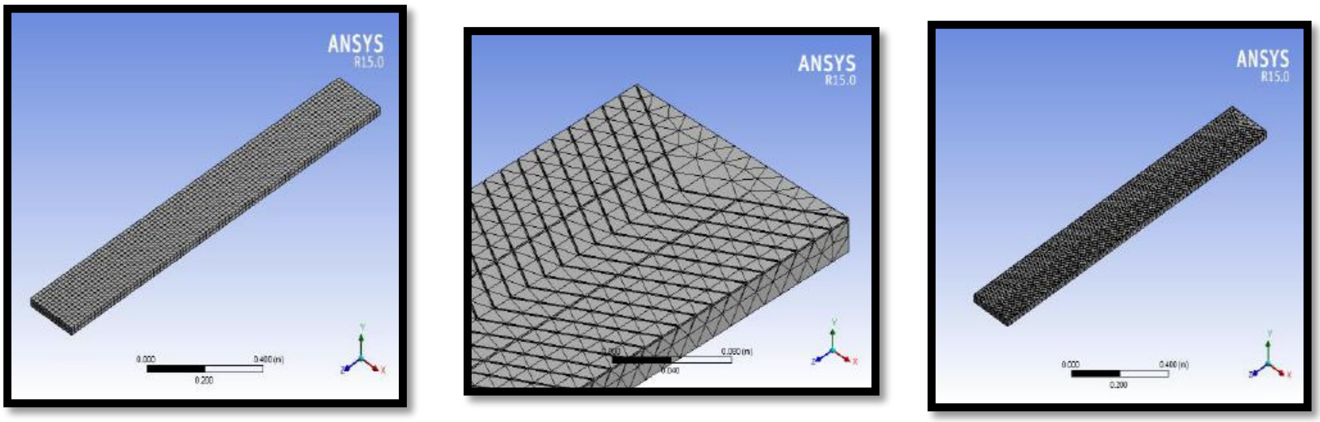
- As shown in fig.3 In the geometric modeling of V-shape artificial roughness with gape we have taken a two geometries one with relative gape distance (Gd/Lv=75mm) and second with relative gape distance (Gd/Lv = 65mm).



(Fig.3 Geometry of V-shape-with gap having Ld = 65 mm & 75 mm)

5. MESH GENERATION:

The geometry made is divided into small parts for analysis which is called mesh and the process of doing it is called meshing. The shape of mesh elements in 2-D can be triangular or quadrilateral and in 3-D it can be tetrahedral, hexahedral or prism depending upon dimensions of the specified geometry. The shape and size of the mesh elements can be varied. The size of mesh depends upon geometry, accuracy required, computational power of the system and memory. The complete draft tube consists of one domain named flow region. Fig.4 shows meshing of smooth surface,V- shaped roughness surface and V-shaped roughness surface with gape.



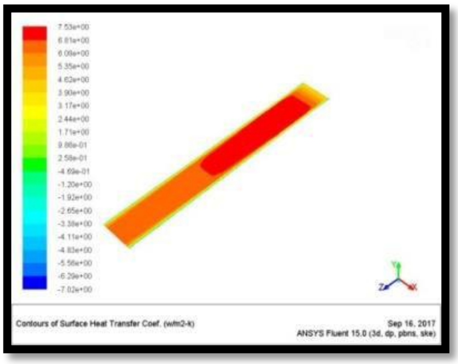
(Fig,4 Meshing of different roughness geometries)

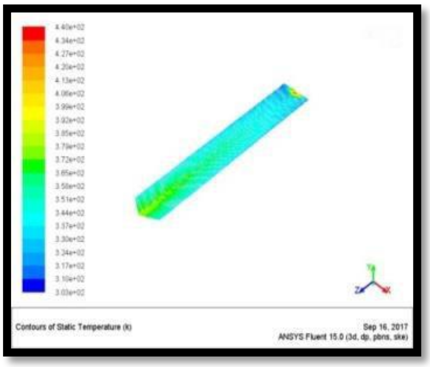
6. RESULTS AND CONCLUSION:

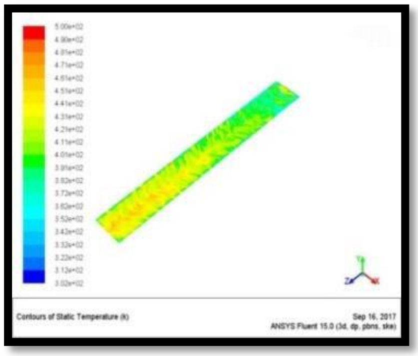
The major objectives of this investigation is to see the effects of V-shaped ribs having relative roughness height (p/e =10 and 8) and v-shaped ribs with gap having Ld = 75mm and 65 mm of a roughened solar air heater duct with the help of Computational fluid dynamics (CFD) software on heat transfer, Nusselt number (Nu), Pressure Drop (ΔP), friction factor (f) and thermal-hydraulic efficiency.

7. TEMPERATURE PROFILE:

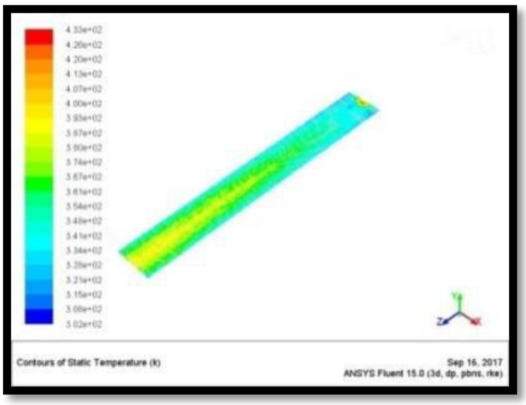
As shown in the Fig.5,6,7,8,9 variation of the static temperature of the smooth surface solar air heater duct in three dimensional and top of the duct is considered a hot absorber plate and uniform distribution of heat flux. Atmosphere air enters at the rectangular duct and flows under the absorber plate (smooth surface) and flow is uniform. Most of the flow which occurs in practical applications is in general turbulent in nature. In the turbulent region, the velocity of the particles very near to surface becomes almost zero. In this region the particle have very low kinetic energy. This region is called laminar sub-layer. As shown in the Fig. V-shaped ribs are attached underside of the absorber plate these ribs breaking and disturbing the laminar sub layer and flow is wavy flow.

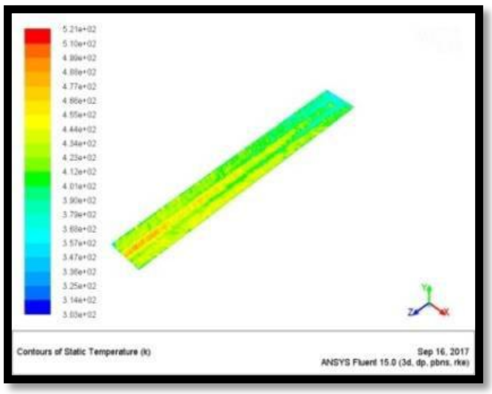






(Fig.5 Static temp.profile of smooth duct.) (Fig.6 Static temp.profile of v-shape rou ghness(p/e=8) (Fig.7 Static temp.profile of V-shape roughness(p/e=10)

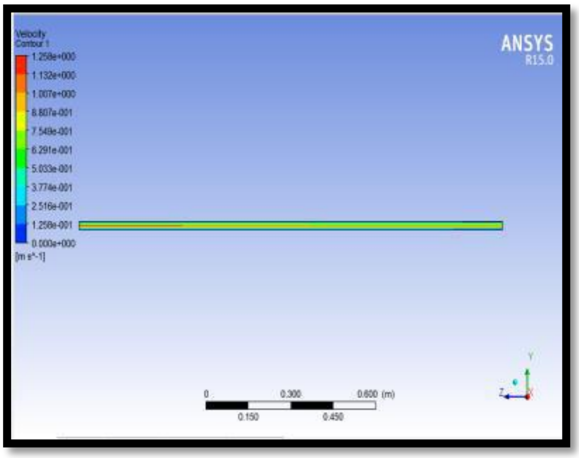




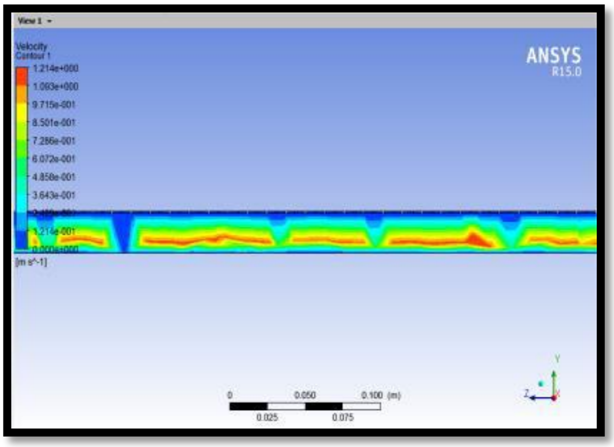
(Fig.8 static temp. profile of V-shape with gape (LD=65) (Fig.9 static temp.profile of V-shape with gape (LD=75)

8. VELOCITY PROFILE:

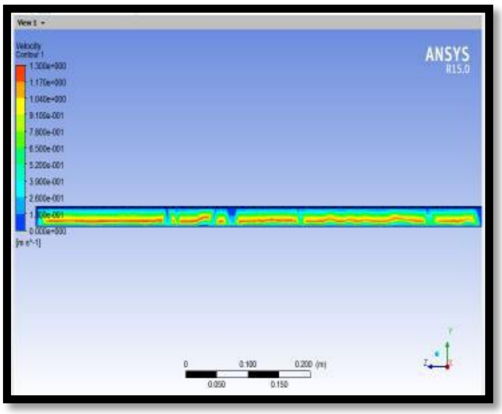
As shown in the Fig.10. velocity profile on the smooth surface and increase the fluid temperature along the length of the duct and outlet of the duct a fluid temperature is maximum. V-shape ribs having relative roughness pitch p/e =8 help in the formation of two leading ends (where heat transfer rate is high) and a single trailing ends (where heat transfer rate is low) resulting in much large increase of heat transfer as shown in the Figs.11 & 12 shown heat transfer rate in V-shape ribs having p/e= 10. As shown in Fig.13 & 14 in the present Computational fluid dynamics (CFD) based analysis v-shaped ribs with gap having Ld = 65 mm & 75 mm considered underside of the absorber plate. Creating gap in the v-shaped ribs allow release of the secondary flow along the rib joins the main flow to accelerate it, which energizes the retarded boundary layer flow along surface resulting in enhancement of heat transfer as shown in Fig.14. the air temperature increase (indicate red color is maximum temperature) along the length of the duct.



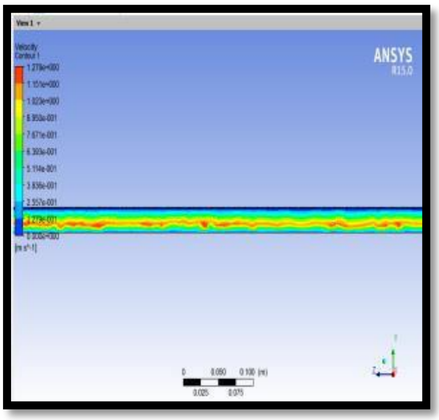
(Fig.10 Velocity profile of smooth duct.)



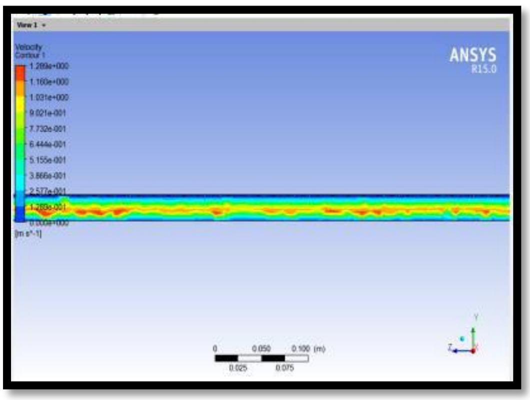
(Fig 11 Velocity profile of v-shape roughness (p/e=8)



(Fig.12. Velocity profile of V-shape roughness(p/e=10)

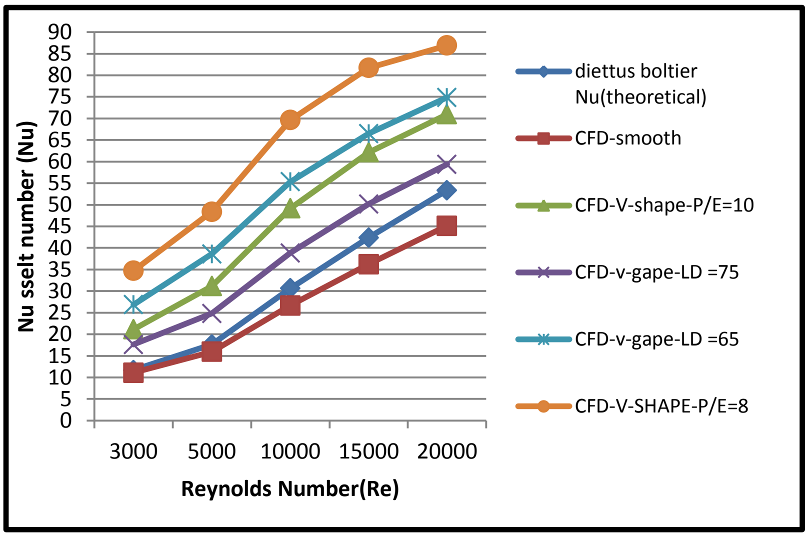


(Fig.13. Velocity profile of V-shape with gape (L_D=65)



(Fig.14. Velocity profile of V-shape with gape (L_D=75)

9. Effect of different shaped roughness geometries on Nusselt number (Nu):

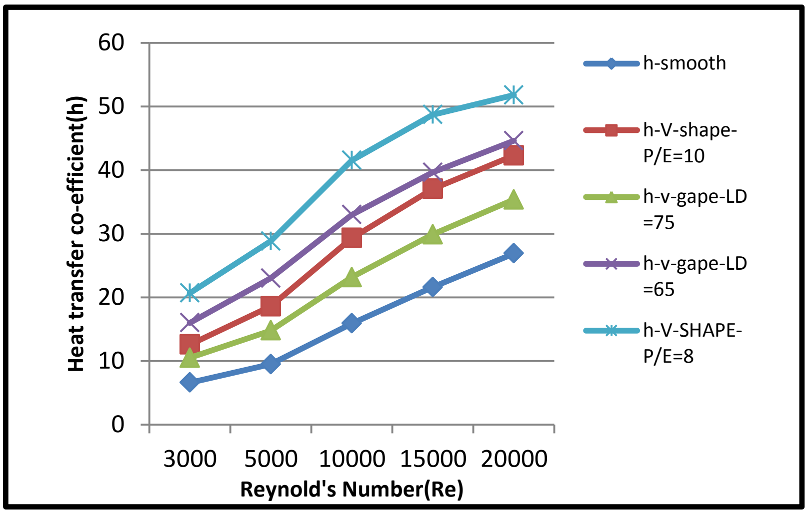


(fig.15 Effect on Nusselt number)

Fig.15 shows that CFD values of different roughness ribs having different parameters are vary nearer to the value of Diettus Boltier generated by equation. Fig.10 shows the effect of different shaped roughness geometries on Nu with respect to the different value of Reynolds's number arranges from 3000 to 20,000.It is observed that with the increase of Reynolds's number, the Nusselt number increases and found the best result in V-shape roughness with gape having a Ld = 65 mm as compare with the V-shape roughness with gape having a Ld = 75 mm and smooth surface. V-shape roughness rib having a p/e =8 gives best result in comparison with smooth surface-shape roughness having p/e =10 and V-shape with gape.

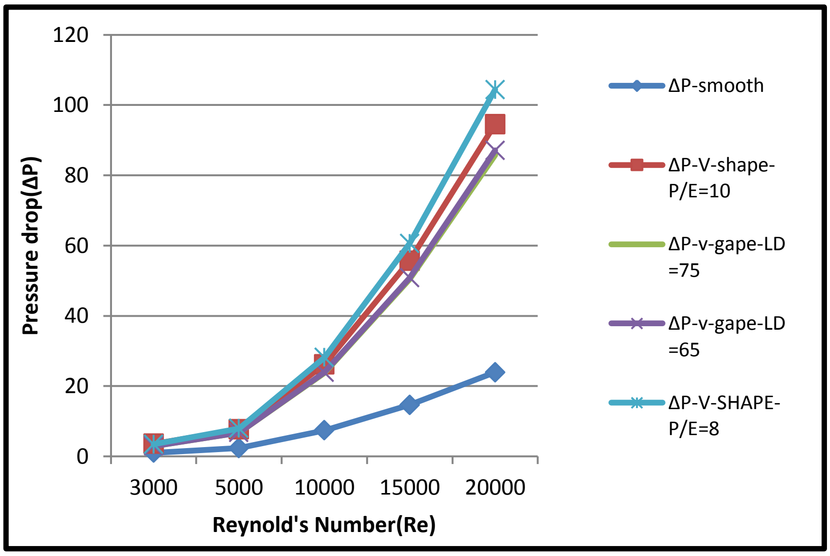
10. Effect of different shaped roughness geometries on heat transfer co-efficient (h):

Fig.16 shows the effect of different shaped roughness on surface heat transfer with respect to the various Reynold's number. With the increase in Re. surface heat transfer coefficient increases and fund the best results in V-shape roughness with gape having a Ld =65 mm than smooth surface, v shape having p/e=10 and V-shape roughness with gape having Ld= 75 mm. V-shape roughness rib having a p/e =8 gives best result in comparison with smooth surface-shape roughness having p/e =10 and V-shape with gape.



(FIG.16 Effect on heat transfer co-efficient)

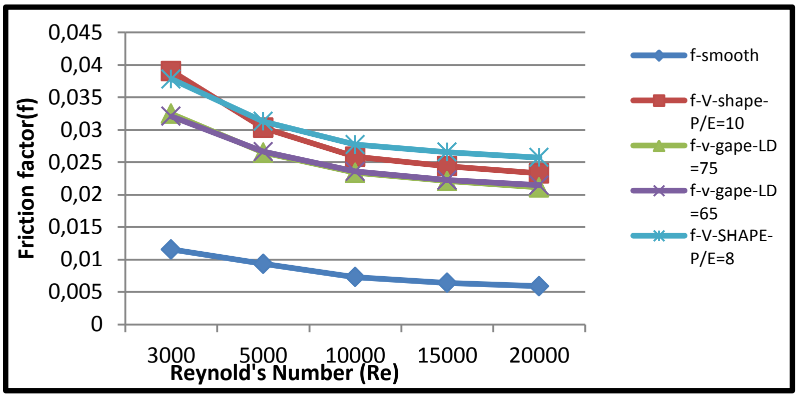
11. Effect of different shaped roughness geometries on Pressure drop:



(FIG.17 Effect on Pressure drop)

Fig.17 shows the effect of different shaped roughness geometries on pressure drop with respect to Re. With the increase in Re. number the pressure drop increases. The value of pressure drop is low in the V-shape roughness with gape having Ld= 65 mm than that of the value obtain in smooth surface, v shape having p/e =10 and V-shape roughness with gape having Ld= 75 mm. The value of pressure drop is less in v shape having p/e= 8 than smooth surface shape having p/e=10 and v shape with gape with respect to the various Reynold's numbers.

12. Effect of different shaped roughness geometries on Friction factor:

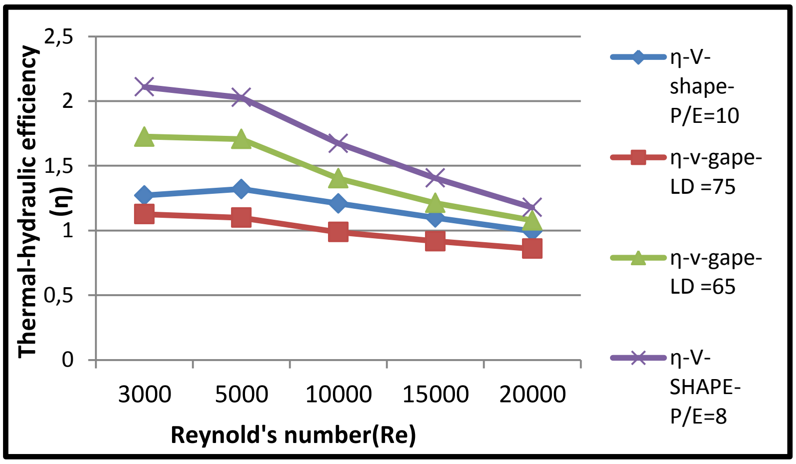


(FIG.18 Effect on Friction faactor)

Fig.18 shows the effect of different shaped roughness geometries on friction factor and with the increase in Reynold's number, the friction factor decreases. The value of friction factor with respect to the Reynold's number is found low in V- shape with gape having Ld=65 mm as compare to the smooth surface, V-shape having p/e=10 and V-shape with gape having Ld=75 mm.The best result is found in V-shape having a p/e= 8 than the other different roughness geometries.

13. Effect of different shaped roughness geometries on Thermal-hydraulic efficiency:

Fig.19 showsthe effect of different shaped roughness geometries on Thermal-hydraulic efficiency with respect to Re as compared with smooth surface. With the increase in Re., Thermal hydraulic efficiency decreases and we found the highest result with Re=3000.In comparison with the smooth surface, V-shape with gape having Ld=75 mm and V shape having p/e = 10, the V-shape with gape having Ld= 65 mm gives best result. The highest result found in v shape having p/e =8 than v shape having p/e =10, v shape with gape having Ld= 65 mm and 75 mm as compare with smooth surface.



(FIG.19 Effect on Thermal-hydraulic efficiency)

14. CONCLUSION:

After the CFD analysis of Solar Air Heater with different roughness geometries, the following results generated:

- With the increase in Reynold's number, Nusselt number increases. V-shape with gape gives best result than V-shape and smooth surface. With decreases in relative roughness pitch (p/e),Nu. number increases for constant relative roughness height (e/d).
- With the increase in Reynold's number, Surface heat transfer increases. V-shape with gape gives best result than V-shape and smooth surface. With decreases in relative roughness pitch (p/e),surface heat transfer increases for constant relative roughness height (e/d).
- With the increase in Reynold's number, Pressure drop increases. V-shape with gape gives lowest pressure drop than V-shape and smooth surface. With decreases in relative roughness pitch (p/e),pressure drop is less for constant relative roughness height (e/d).
- With the increase in Reynold's number, friction factor decreases. V-shape with gape gives lowest pressure drop than V-shape and smooth surface. With decreases in relative roughness pitch (p/e),friction factor is less for constant relative roughness height (e/d).
- With the increase in Reynold's number, thermal-hydraulic efficiency decreases. V-shape with gape gives highest thermal-hydraulic efficiency than V-shape and smooth surface at Re=3000. With decreases in relative roughness pitch (p/e),thermal-hydraulic efficiency is highest at Re=3000 for constant relative roughness height (e/d).
- CFD results have been also validated the smooth duct and different CFD model results were compared with Dittus-Boelter empirical relationship for smooth surface. Among all the models used, Renormalization k-epsilon model results have been found to have good agreement.

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