Numerical Analysis of Artificially Roughened Solar Collector Tube using ANSYS

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Abstract: The conventional design of absorber tube in parabolic collectors has smooth surface. The smooth surface has lower heat transfer rate which can be improved by the use of artificial roughness. The current research investigates the application of C shape and V shape artificial roughness in absorber tube using techniques of Computational Fluid Dynamics. The CAD model is developed in creo design software and CFD analysis is conducted using ANSYS software. RNG K epsilon turbulence model is used for analysis which gives reasonably good prediction for swirl flow conditions. The CFD results have shown significant increase in heat transfer rate with the use of artificial roughness.

Keywords: Artificial Roughness, Collector tube, CFD.

I. INTRODUCTION

With increase in population worldwide, the consumption of conventional resources like coal, oil has increased manifold posing serious threat to environment. This problem can be overcome by the use of ecofriendly and everlasting means of energy. The solar energy can be used to heat fluid which in turn can run turbines to generate electricity. The solar energy can be harnessed using flat plate collector, parabolic concentrating solar collector. Various geometric factors like design and concentration ratio, absorber tubes geometry, thermophysical properties of working fluid influences efficiency of collector. With usage of artificial roughness, the absorber tube can also significantly increase heat transfer rate. Different components of parabolic trough collector are shown in figure 1 below which comprises of central heat pipe, reflector, parabolic shape reflective trough, absorber tube and collector supports..

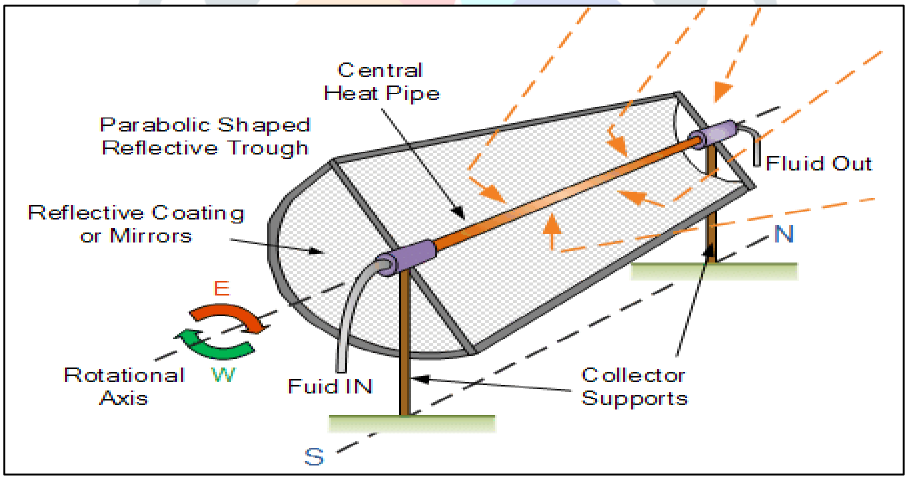

Figure 1: Solar Parabolic Trough Collector

II. LITERATURE REVIEW

Fuqiang et al. [1] studied the usage of symmetric outward convex corrugated tube for the parabolic trough receiver to increase the heat transfer performance and decrease the thermal pressure of metallic tube. An outward convex corrugated tube design helped to increase the turbulence inside the metallic tube therefore complements the heat transfer overall performance of the HTF inside the tube and decrease the thermal deformation of the tube.

Huang et al. [2] studied the heat transfer enhancement within the inner tube because of the usage of dimples, protrusions and helical fins and determined that dimples overall performance is the nice. The findings have shown that changing designs of the internal tube of the parabolic trough receiver tubes (PTRs) using dimples, protrusions and helical fins increased the surface area that increased the heat transfer from solar radiation to heat transfer fluid (HTF). Results shown that, the dimpled tube design is much higher than the alternative two designs.

Reddy et al. [3] studied an impact of placing a porous disc into the receiver floor to augment heat transfer to the fluid. The distinctive configurations of the porous disc inserted into the receiver tube were backside porous disc receiver (BPDR), u-formed backside porous disc receiver (UBPDR), bottom porous disc receiver (IBPDR) and alternative porous disc receiver (APDR). Effects confirmed that porous disc more desirable receiver was a great deal better than the conventional tubular receiver as the thermal gradient among the fluid and receiver wall floor and throughout the receiver move phase became smaller.

Mwesigye et al. [4] showed the thermodynamic optimization of a parabolic trough receiver with inserted perforated plate. There are 3 important geometrical parameters that make contributions to the receiver structure with perforated plates inserts layout: the spacing among sequential perforated plates (p), the attitude of orientation (β) that is high-quality in anticlockwise path and measured from y-axis and the diameter of perforated plate (d).

III. PROPOSED WORK

The objective of this project is to analyze the effect of artificial roughness on inner wall of absorber tube with respect to enhancement of heat transfer characteristics. The roughness profile used for analysis is U shape and V shape. The CAD model of tube is developed using Creo 2.0 and CFD analysis is conducted using ANSYS CFX software.

IV. METHODOLOGY

The CAD model is developed using extrude, revolve, sweep and pattern tool. The blades developed after extrusion is assembled using coincident constraint, axis pattern and angle offset. This CAD model is saved and converted into. iges format to be exported in ANSYS software. The dimensions of absorber tube are taken from literature [5].

Table 1: Dimensions of absorber tube [5]

Inner Tube Width	27mm
Outer Coating	28mm
Length of collector	1000mm

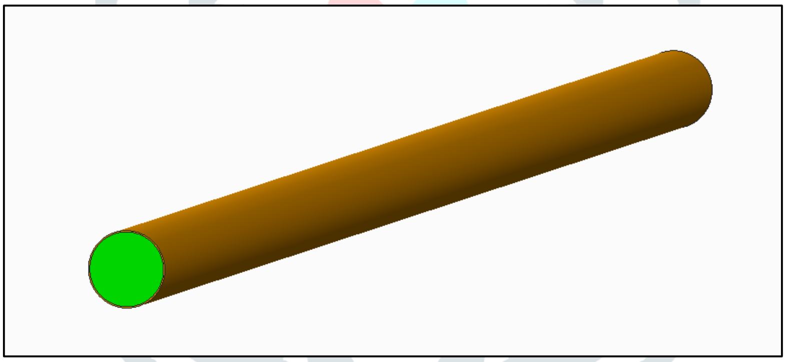

Figure 2: CAD Model of parabolic trough collector without roughness

The CAD model developed in Creo is imported in ANSYS design modeler as shown in figure 3 below. Here it is checked for geometric errors like hard edges, hard angles and other data losses.

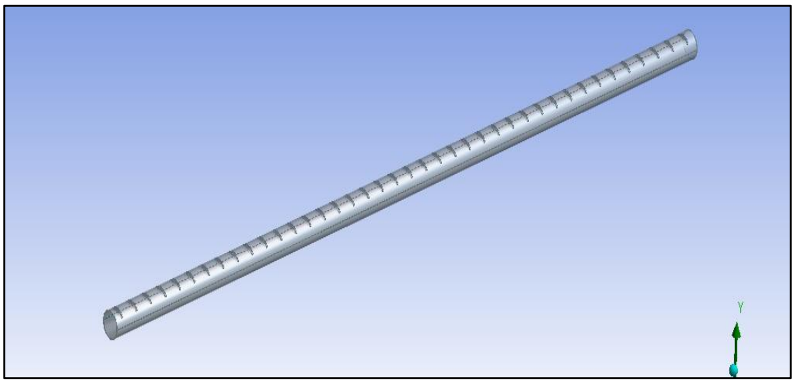

Figure 3: Imported CAD model in ANSYS design modeler

The model is meshed using tetrahedral elements of fine sizing and curvature size function. The relevance center is set to medium, span angle canter set to fine, smoothing set to medium.

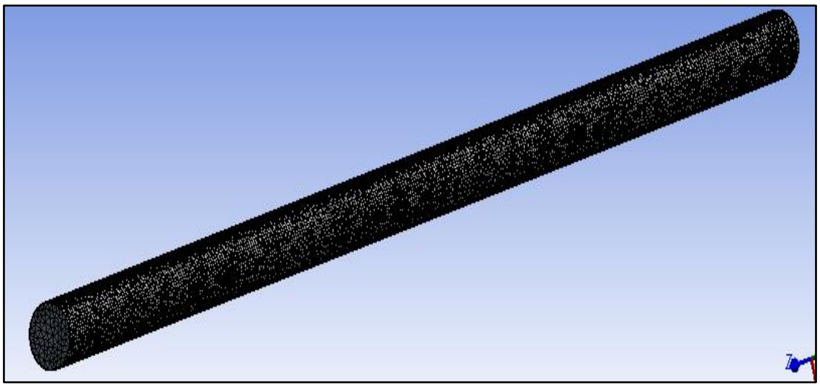

Figure 4: Meshing CAD model in ANSYS

Number of nodes generated is 55961 and number of elements generated is 181668. Domain is defined as fluid with isothermal energy condition and reference pressure set to 1 atm. RNG k-epsilon turbulence model is set for analysis which is 2 equation model and helps in fast computation and useful in prediction of simpler fluid flows. Appropriate inlet and outlet boundary conditions are defined using different mass flow rates, inlet temperature of 32^{0}C.

Table 1: Roughness type and depths

Cases	**Mass Flow rate (Kg/s)**	**Water Inlet Temp (^{0} C)**	**Turbulence Model**	**Wall Heat Flux (W/m^2)**
1	.005	32	RNG K-epsilon	744
2	.010			
3	.015			

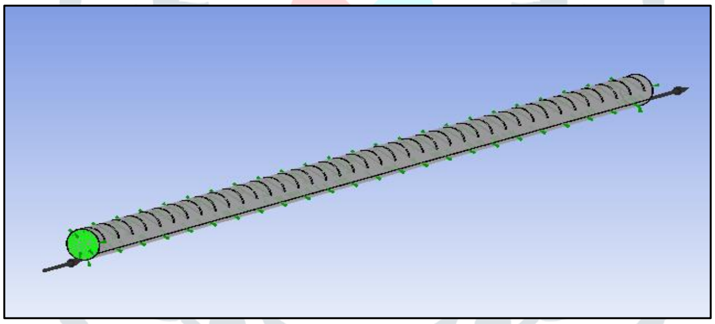

Figure 5: Water inlet boundary condition

The inlet boundary conditions for water is defined as shown in figure 5 above with different mass flow rates as discussed in table 1. The outlet boundary considition is defined with 0 relative pressure difference. Solver settings are defined using RMS residual values set to 1e-4 and iterations to 200, advection scheme high resolution upwind, turbulence numeric set to 1st order, length scale option to conservative.

V. RESULTS AND DISCUSSION

The CFD analysis is conducted for different types and depths of roughness. From each analysis pressure drop, temperature plot and heat transfer coefficient is determined. Nusselt number vs Reynolds number curve is then determined.

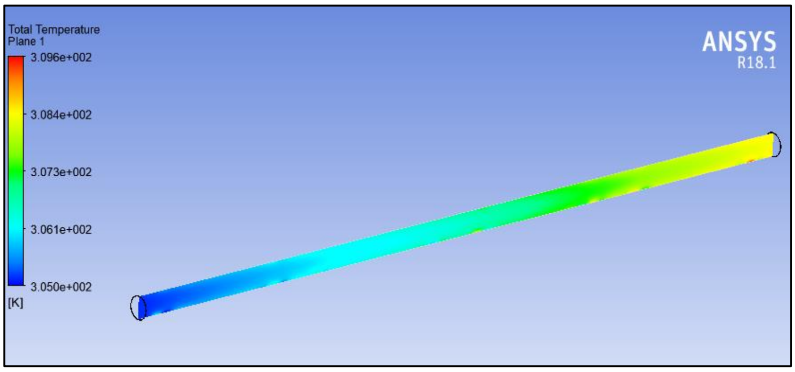

Figure 6: Temperature plot of absorber tube without roughness

A lateral plane is considered for plotting temperature variation as shown in figure 6 above. The temperature plot shown above shows low inlet temperature which increases as we move towards outlet of absorber tube. The temperature near inlet is 305K and increases to 308K towards exit.

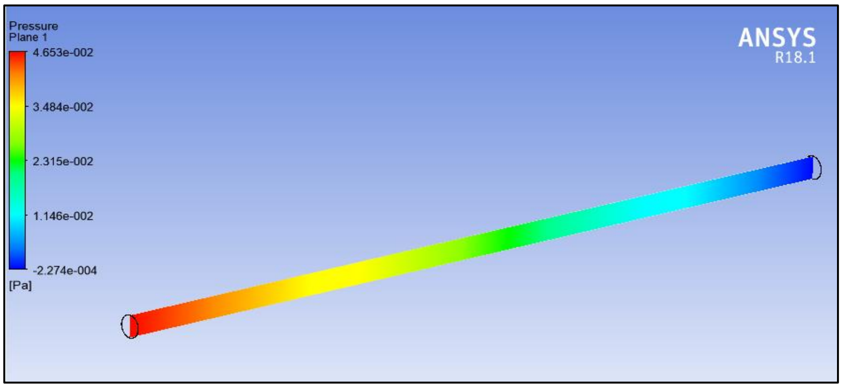

Figure 7: Pressure plot of absorber tube without roughness

The pressure plot shown in figure 7 above shows higher pressure at inlet of magnitude .004 Pa shown by red contour which reduces on moving towards exit as shown by light blue and dark blue contour.

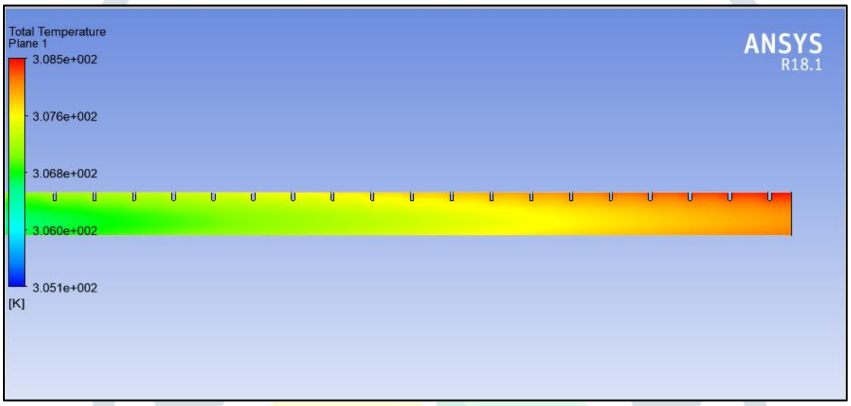

Figure 8: Temperature plot of absorber tube with C shape roughness

A lateral plane is considered for plotting temperature variation as shown in figure 8 above. The temperature plot shown above shows low inlet temperature which increases as we move towards outlet of absorber tube. The temperature near inlet is 305K and increases to 308.5K towards exit. The temperature near the wall is higher as compared to fluid away from wall.

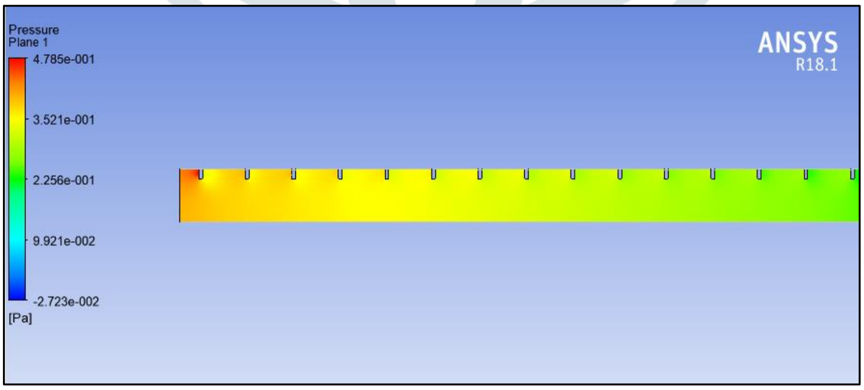

Figure 9: Pressure plot of absorber tube with C shape roughness

The pressure plot shown in figure 9 above shows higher pressure at inlet of magnitude .47 Pa shown by red contour which reduces on moving towards exit as shown by light blue and dark blue contour.

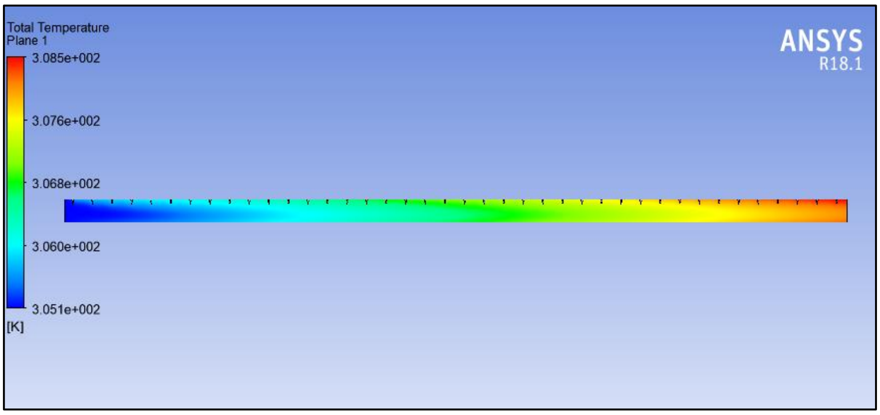

Figure 10: Temperature plot of absorber tube with V shape roughness

A lateral plane is considered for plotting temperature variation as shown in figure 10 above. The temperature plot shown above shows low inlet temperature which increases as we move towards outlet of absorber tube. The temperature near inlet is 305K and increases to 308.56K towards exit. The temperature near the wall is higher as compared to fluid away from wall.

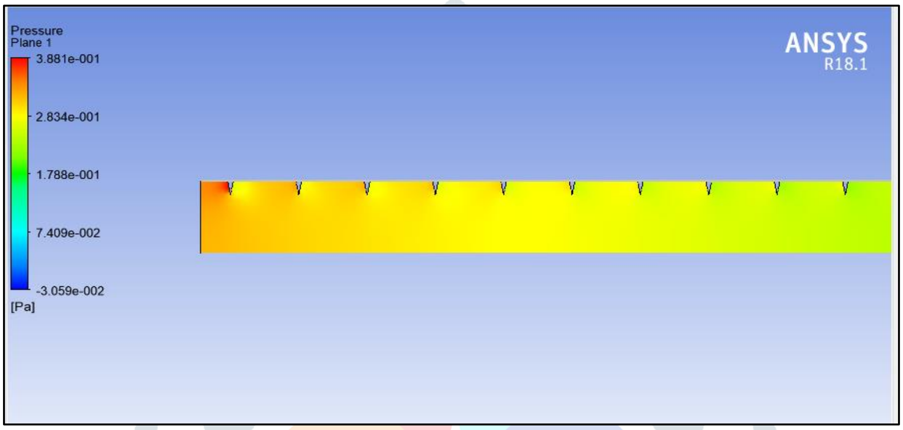

Figure 11: Pressure plot of absorber tube with V shape roughness

The pressure plot shown in figure 11 above shows higher pressure at inlet of magnitude .47 Pa shown by red contour which reduces on moving towards exit as shown by light blue and dark blue contour.

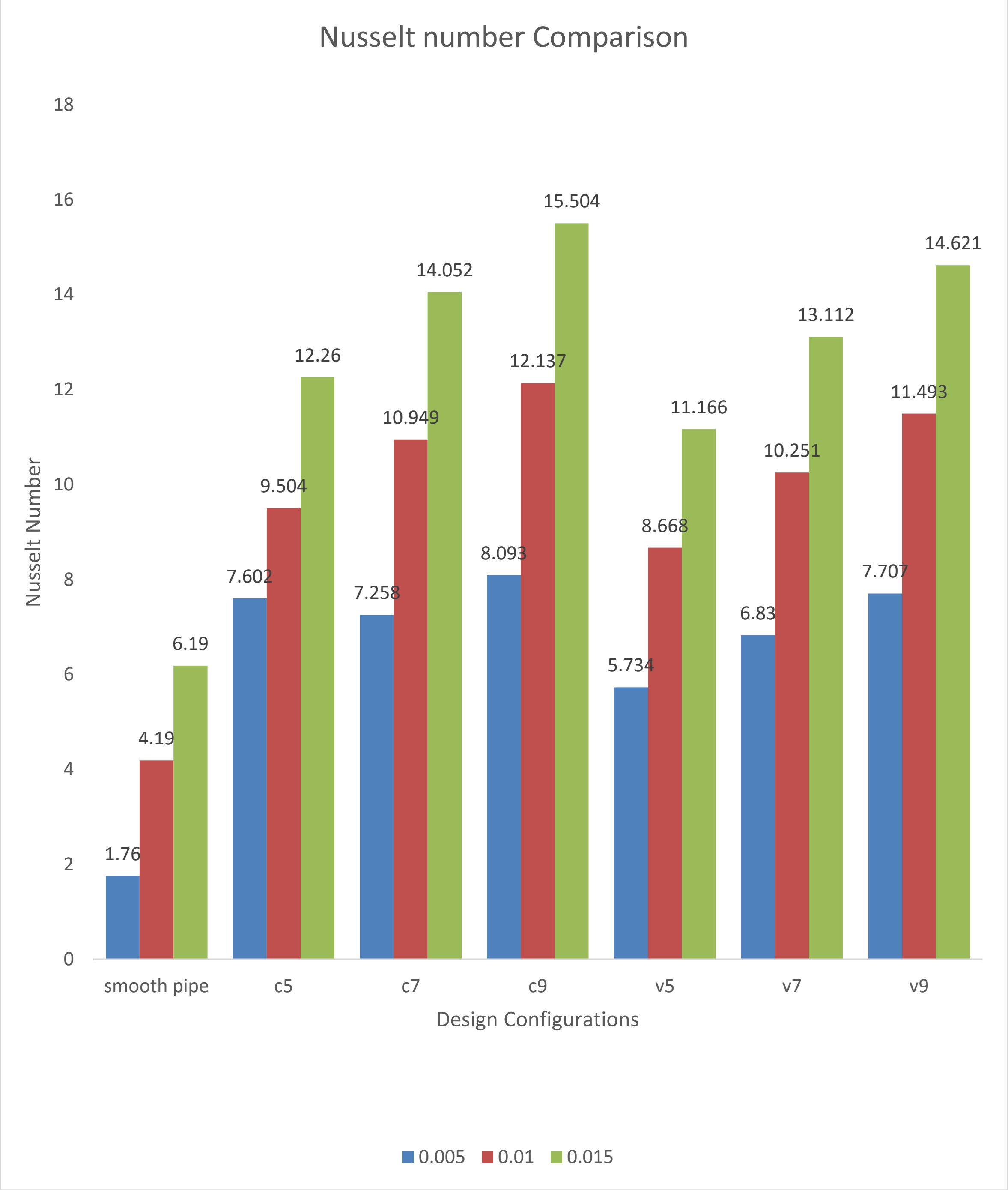

Figure 12: Nusselt number for different roughness configurations

There has been significant increase in heat transfer rate by incorporating artificial roughness in absorber tube. The Nusselt number comparison chart shows that smooth tube has lowest heat transfer rate as compared to v shape and c shape. The c shape roughness profile has higher heat transfer rate as compared to v shape profile for corresponding mass flow rates of .001Kg/s, .002Kg/s and .003Kg/s.

VI. CONCLUSION

Numerical analysis is conducted on single tube absorber with smooth surface and the modified absorber with C shape and V shape artificial roughness of varying roughness depth of 5mm,7mm and 9mm. The CFD analysis shows significant augmentation of heat transfer with incorporation of artificial roughness for all mass flow rates i.e. .005Kg/s, .010Kg/s and .015Kg/s as shown by Nusselt number values. The absorber tube with C shape roughness profile has highest heat transfer characteristics with 6.01%. The RNG k-epsilon turbulence model gave reasonably good prediction for swirl generated which caused turbulent flow heat transfer.

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