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CFD ANALYSIS OF SOLAR AIR HEATER OF V SHAPE RIBS AT CONSTANT PITCH

Pushpam Kumar Sinha[1] and Vijaykant Pandey[2]
[1](M-Tech Research Scholar, Bhabha Engineering Research Institute, Bhopal (M.P.), India
[2](Assistant Professor, Bhabha Engineering Research Institute, Bhopal (M.P.), India

ABSTRACT

The effective use of a solar duct is limited at its maximum operational junction temperature. The study was conducted by using the Computational Fluid Dynamics (CFD) method. The Ducts are used with flow of air with temperature such as power houses, malls and industrial applications. The major study was done on artificially roughened semicircular shaped V-Ribs with different relative gap widths. The heat transfer media was taken as an air & Aluminum (Al) as Duct material. In our analysis, CFD was used and the model was developed on CREO 5.0. In order to verify the present CFD model, the Nusselt number and the Friction factor are compared with the available experimental results present in the literature. And the design of semicircular shaped V-Ribs with different relative gap widths having gap width of 1.5mm, 2.5mm, 3.5mm, 4.5mm, 5.5mm on roughness. In this study, the simulations of semicircular shaped ribs of roughness at constant wind velocity i.e., 6.5 m/s and the configurations of duct design are proposed. The Experimental result is done by carrying out the simulation work on the ANSYS Fluent 15.0 Work bench.

Keywords: *Solar Air Heater, Duct, Reynolds Number, Nusselt Number, Wind Velocity*

INTRODUCTION

The rise of non-conventional renewable energy sources is being boosted as the world's gasoline reserves, which provide an important useful energy resource, are dwindling. Energy is essential to the existence and improvement of crews and can be a key issue in global politics, economics, naval readiness, and diplomacy. Much attention needs to be paid to improving power and renewable energy sources to reduce the impact of conventional energy sources on the atmosphere again. Solar energy must be truly green, renewable and self-powered. Therefore, as the earth's fossil fuels steadily evaporate, it will undoubtedly become a necessary part of the long-term form of electricity. However, declining power density and seasonal dependence of geographic dependence are major challenges in terms of application capabilities exploiting photovoltaics for heat resources. Therefore, it is highly necessary and practical. Solar energy is free and environmentally friendly, and ranks alongside major potential energy sources.

In the near future, large-scale installation of photovoltaic power generation systems that instantly convert radiation into heat is expected. However, by its nature, solar power is intermittent. There is no sun in darkness. Its fully accessible value is seasonal and depends on site environmental conditions. Unreliability is the biggest lag problem in the use of large-scale solar power. Of course, protecting solar power is also a hassle. It stores energy when the load is exceeded and uses charging power when needed. As a sufficient and permanent energy source, freely available sunlight guarantees environmentally friendly fuel storage. The most comfortable and at the same time the best way to use photovoltaic power is to convert it into thermal energy for heating purposes via sample photovoltaic collectors. Due to their inherent simplicity, solar air heaters are inexpensive and Commonly used sorting equipment. Most functions of solar powered air heaters are site heating. It can also be used for wood seasoning, solidification of commercially available products, curing and drying of concrete and clay structures. Photovoltaic air heaters occupy an important area among photovoltaic heating systems and are attributed to the lowest consumption of material and value.

The thermal efficiency of solar powered air heaters is usually terrible due to the inherently poor heat switching capability between the absorber plate and the air flowing in the ducts, in contrast to solar powered water heaters. For a photovoltaic air heater type to be economically viable, its thermal efficiency must be doubled by improving the thermal switching constant. There are some simple ways to keep the heat transfer between the absorbent panel and the air constant. The first method is to extend the location of the thermal switch through extended surfaces called raised surfaces or fins, without touching the convective thermal switch constant. The 2D methodology increases convective heat switching by creating turbulence at the heat transfer surface. This can be completed by applying artificial unevenness to the underside of the absorbent panel. Many researchers have tried to develop rough parts that can minimize frictional losses and beautify convective heat switches.

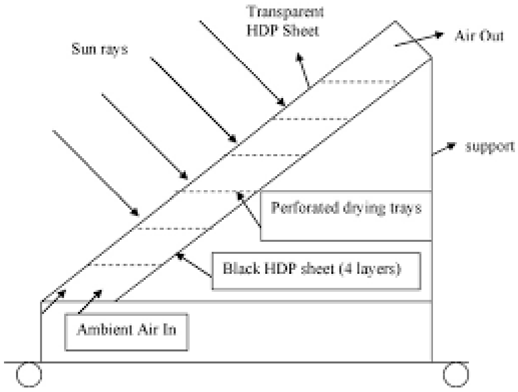

Figure 1 Solar Duct

LITERATURE REVIEW

Varun Pratap Singh et.al. (2022) The scientific literature extensively mentions the use of a solar air heater (SAH) by utilizing solar energy for heating purposes. The poor heat-transfer rate of an SAH with a flat plate is caused by developing a laminar sub-layer near the heated base plate. The plate temperatures improve significantly, resulting in losses and a decrease in performance. The passive approach entails the placement of fins/turbulators/pouring material/ribs to the surface where the boundary layer forms to disrupt it. Artificially roughened SAH for gathering and efficiently using solar radiations for thermal purposes is extensively described in the literature. This paper includes a thorough literature overview of the history, basics, roughness evolution, forms of SAH, and recent breakthroughs in thermal performance improvement techniques for SAH compiled by several researchers. This paper uses a comparative evaluation of several roughness geometries and kinds of SAH to uncover thermohydraulic performance factors that may be considered in future research to pick the optimal configuration.

Wang, D., Liu, J., Liu, Y., Wang, Y., Li, B., & Liu, J. (2020) - Compared with liquid photo voltaic collectors, the thermal effectivity of photo voltaic air heaters is usually low. To enhance the thermal effectivity of a photo voltaic air collector, an multiplied photo voltaic air heater with s-shaped ribs with gaps is proposed; the photo voltaic air heater can beautify the warmness switch between air and warmness absorber plate sufficiently. At the identical time, to decrease the go with the flow resistance of air, a hole of sure width used to be created on the ribs. In this study, the outcomes of an experimental investigation on collector effectivity and stress drop in a photo voltaic air heater with more than one s-shaped ribs with gaps as the roughness factor are presented. The predominant elements together with the rib geometry size, namely, the rib spacing, rib width, rib clearance width, channel height, photo voltaic radiation intensity, air mass float charge have been evaluated. The outcomes of these elements on the warmness effectivity of photo voltaic air heater and the temperature distinction between inlet and outlet have been analyzed. Compared with a easy plate, the thermal effectivity of solar air heater with synthetic roughness was once extended with the aid of 13% to 48% underneath unique conditions. [01]

Saravanakumar, P. T., Somasundaram, D., & Matheswaran, M. M. (2021) - Present learn about offers with thermo hydraulic overall performance enhancement of photo voltaic air heater (SAH) with various design configurations. Analytical modeling is carried out to learn about the impact of absorber plate built-in with arc fashioned rib roughened barrier with fins and baffles on thermal and positive effectivity of SAH. Variations of waft elements such as Reynolds variety and temperature upward push parameter with reference to baffle layout parameters are presented. The proposed SAH improves the power and superb effectivity by using 28.3% and 27.1% in contrast with arc structure rib roughened photo voltaic air heater. From the results, it is additionally concluded that decrease baffle width and size values grant most wonderful effectivity at greater mass float rates. Further, the correlations as a feature of Reynolds number, baffle width, size and variety of fins is developed for predicting the values of wonderful efficiency. Thereafter, a plot is developed for evaluating analytical positive effectivity with envisioned fantastic effectivity and it is located that the averaged deviation of 13%. This existing mathematical mannequin for proposed SAH is validated with fashions on hand in the literature.[02]

Kumar, R., & Chand, P. (2018) - The existing work predicts the thermal and thermos hydraulic overall performance of the prolonged floor absorber photo voltaic air heating collector outfitted with twisted tape inserts of twist ratio Y=2, 4, 6 and eight A mathematical mannequin has been formulated based totally on strength conservation equations of the a number of factors of the collector underneath consideration. The mannequin is numerically solved the use of the MATLAB codes. Effects of mass float rate, twist ratios and the photo voltaic depth of the overall performance of the heater have been investigated. The effects acquired are in contrast with the consequences of traditional and finned absorber photo voltaic air collector. Results conveyed that at mass drift fee of 0.025 kg/s, with enlarge in solar depth from five hundred W/m2 to a thousand W/m2, the thermal effectivity of the collector with twist ratio Y=2 will increase through 8.3%. Furthermore, integrating fins and twisted tape (FTTs) with the absorber plate, a most enhancement of 22.56% in the thermal effectivity has been completed as in contrast to 11.49%, when solely fins are attached. This maximum enhancement is discovered with the tape with minimal twist ratio. Hence, the collector having absorber plate connected with fins and twisted tapes of twist ratio Y=2 is the most efficient.[03]

LufangDuan et al. (2020) investigated the turbulence and heat transfer properties of double-tube structure inner fin tubes and flower-shaped inner fins. A sample containing three flower-shaped lamellae was investigated experimentally and numerically at six different air flow rates and a constant air inlet temperature. The Reynolds number on the air side varied from 3255 to 19580. The simulation results obtained are in good agreement with the experimental data. We subsequently analyzed the effect of geometric finned-tube structures (different number of fins and different core tube diameters) on thermal behavior. As a result, we found that increasing the number of fins resulted in a more uniform distribution of the temperature and velocity fields. The heat transfer performance of the inner finned tube with 3 and 4 petal-shaped fins was similar and both were significantly higher than the inner finned tube. With two flower-shaped fins. An optimal ratio of (do/Tu 0.28) existed, resulting in better cost-effectiveness. Compared to corrugated fins, petal fins are more suitable for operating conditions with tight pressure drop limits, especially in waste heat recovery systems [4].

M.J. Lee et al. [2019] In this paper, he experimentally investigated a new type of smooth plate fins with 12 delta winglet vortex generators around each tube of the finned-tube heat exchanger proposed by the authors. To compare the overall properties of the proposed fins with circular corrugated fins, tests are performed on four full-scale heat exchanger surfaces. Two corrugated finned tube heat exchangers (short 10 corrugation and 12 corrugation) with 6 rows of tubes with 2.54 mm or 2.117 mm fin spacing. and two proposed finned-tube heat exchanger surfaces with five tube rows with equal fin spacing (10-LVG and 12-LVG, respectively). The air-side inlet velocity varies from 1.5 m/s to 7.5 m/s, and the water-side flow velocity is fixed at a constant value at each air inlet velocity. Experimental results show that the heat transfer coefficient and pressure penalty of the heat exchanger surface with the proposed five-row tube fins are almost the same as those of the corrugated heat exchanger surface with six-row tubes. . The correlation between the Nusselt number Nu on the air side and the coefficient of friction f is obtained. Perform entropy analysis to reveal the thermal amplification mechanism. Mohammed [5].

COMPUTATIONAL FLUID DYNAMICS

Computational fluid dynamics, as the name implies it is a subject that deals with computational approach to fluid dynamics with numerical solution of the equations which bring about the flow of the fluid and although it is also called computational fluid dynamics; it does not just deal with the equations of the fluid flow, it is also generic enough to be able to solve simultaneously together the equations that direct the energy transfer and as well the equations that determine the chemical reaction rates and how the chemical reaction proceeds and mass transfer takes place; all these things can be tackled together in an identical format. So, this outline enables us to deal with a very complex flow circumstances in reasonably fast time, such that for a particular set of conditions, an engineer will be capable to simulate and see how the flow is taking place and what kind of temperature distribution there is and what kind of products are made and where they are formed, so that we can make changes to the parameters that are under his control to modify the way that these things are happening. So, in that case CFD becomes a great tool of design for an engineer. It is also a great tool for an analysis for an examination of a reactor or equipment which is not functioning well because in typical industrial applications.

METHODOLOGY

PRE PROCESSING

A geometry is formed in modelling software CREO 5.0 and it's imported to the ANSYS workbench 15.0 where meshing is completed, and exports the mesh to FLUENT. The boundary conditions, material properties, and encompassing properties are set through parameterized case files. FLUENT solves the problem until either the convergence limit is met, or the amount of iterations specified by the user is achieved.

The procedure for resolving the problem is:

- Create the geometry.
- Meshing of the domain.
- Set the material properties and boundary conditions.
- Obtaining the solution

Preparation of the CAD model

Duct Length L(mm)	Duct Thickness (mm)	Rib Number N	Duct Width (mm)	Rib-to-Rib distance
1100	25	5	300	200

Table 1 Geometry Parameters of Duct

Model	Rib Height (mm)	Rib Gap(mm)
V-Rib Roughness	1.5	2
V-Rib Roughness	2.5	2
V-Rib Roughness	3.5	2
V-Rib Roughness	4.5	2
V-Rib Roughness	5.5	2
V-Rib Roughness	6.5	2

Table 2 Dimensions of Roughness on Duct

As we have to vary the Solar Duct with Semi Semi-circular V-Rib roughness (1.5mm-6.5mm) and gap is constant 200mm is constant and also the profile (Semi-circular) so this is taken into the consideration and another various models are prepared.

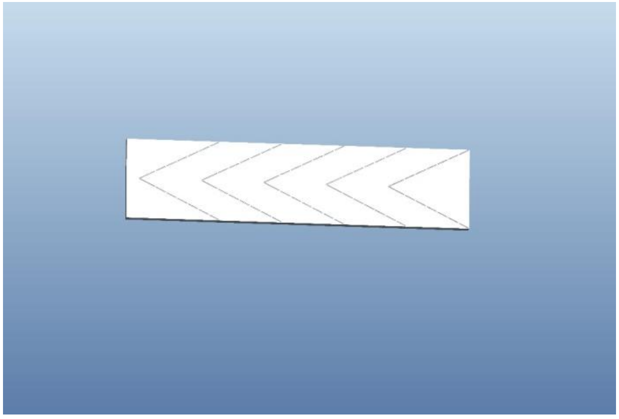

Figure 2- 3D Model 1.5 Solar Duct with Semi Semi-circular V-Rib roughness

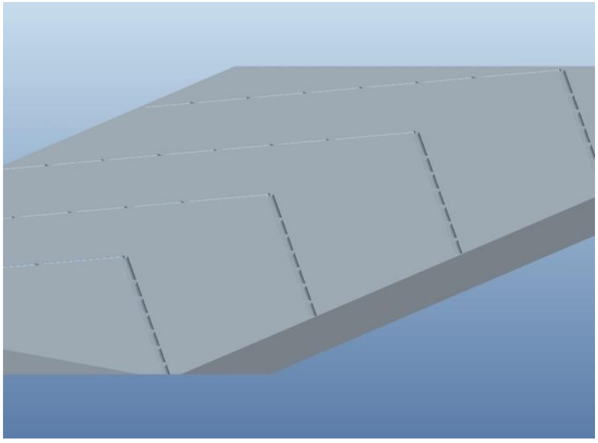

Figure 3- 3D Model of 2.5 Solar Duct with Semi Semi-circular V-Rib roughness

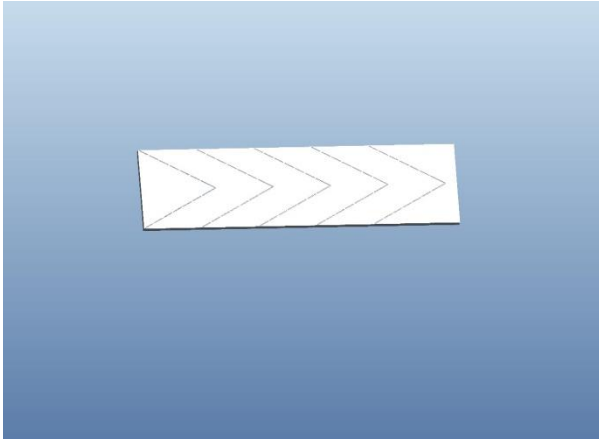

Figure 4- 3D Model of 3.5 Solar Duct with Semi Semicircular V-Rib roughness

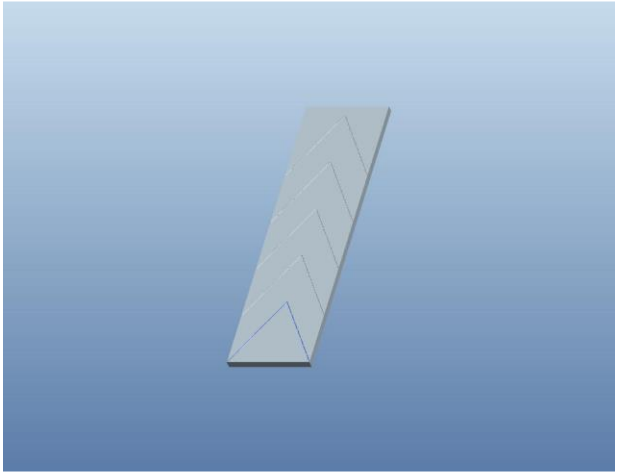

Figure 5- 3D Model of 4.5 Solar Duct with Semi Semi-circular V-Rib roughness

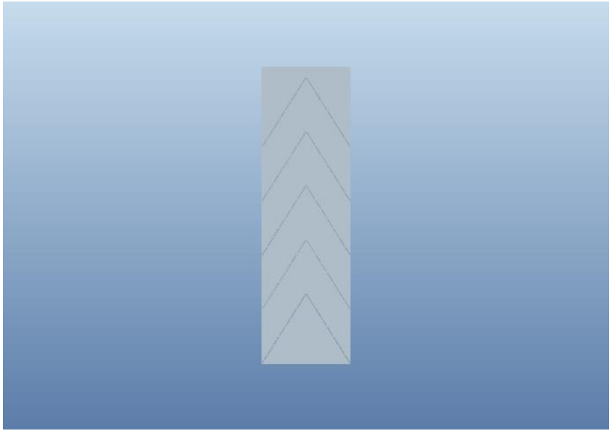

Figure 6- 3D Model of 5.5 Solar Duct with Semi Semi-circular V-Rib roughness

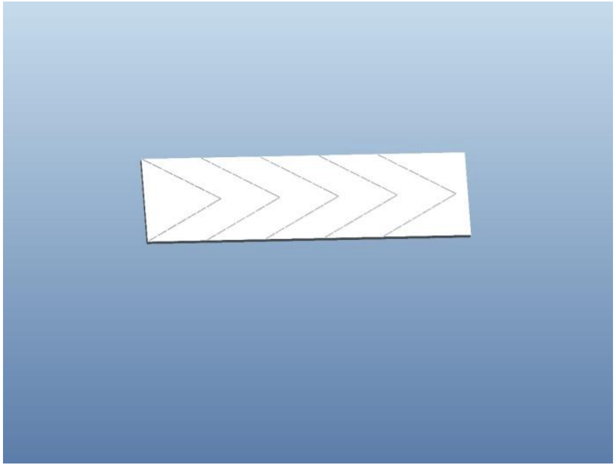

Figure 7- 3D Model of 6.5 Solar Duct with Semi Semi-circular V-Rib roughness

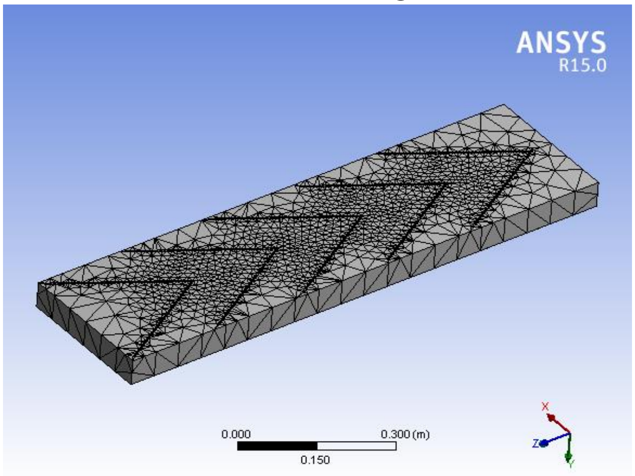

Figure 8- Mesh of the Solar Duct with Semi Semi-circular V-Rib roughness

Set the material properties

(i) Material

(a) Air (fluid)
(b) Aluminium (solid)

Properties	**Air**	**Aluminium**
Density, ρ	1.225 Kg/m^3	2719 Kg/m^3
Thermal Conductivity, K	0.0242 W/m-K	202.4 W/m-K
Specific Heat, C_p	1006.43 J/Kg-K	871 J/Kg-K
Viscosity, μ	1.7894x10^{-5}	-----------------

Table 3: Materials Properties

Roughness Profile	Roughness type	Velocity (m/s)	Heating power (W/m^2)	Periodic boundary condition
	Plane Duct with no Roughness	6.5	1000	Translate in Z direction
Semi Semicircular V-Rib roughness	Plane Duct with 1.5mm Roughness	6.5	1000	Translate in Z direction
	Plane Duct with 2.5mm Roughness	6.5	1000	Translate in Z direction
	Plane Duct with 3.5mm Roughness	6.5	1000	Translate in Z direction
	Plane Duct with 4.5mm Roughness	6.5	1000	Translate in Z direction
	Plane Duct with 5.5mm Roughness	6.5	10	Translate in Z direction

Table 4: Boundary conditions

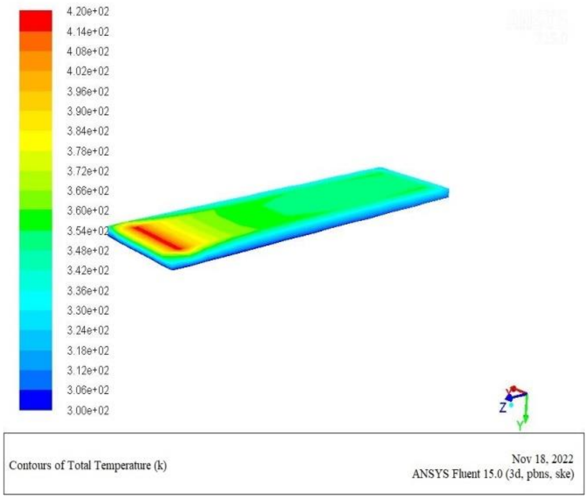

Figure 9: Temperature distribution in smooth plate duct with 6.5m/s velocity

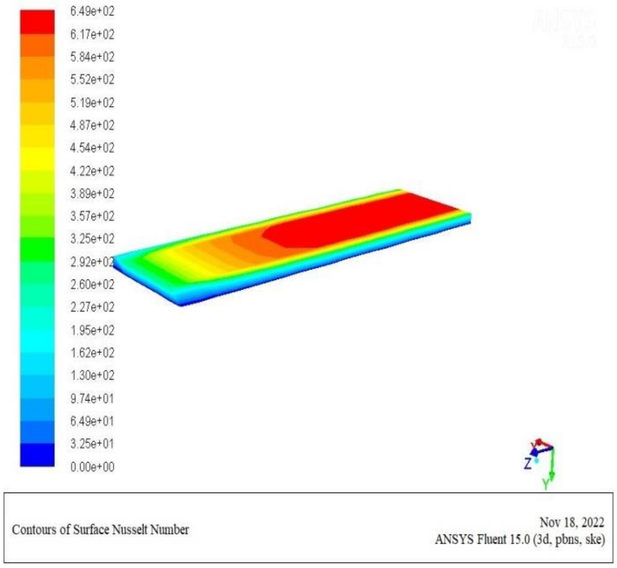

Figure 10: Nusselt number in smooth plate

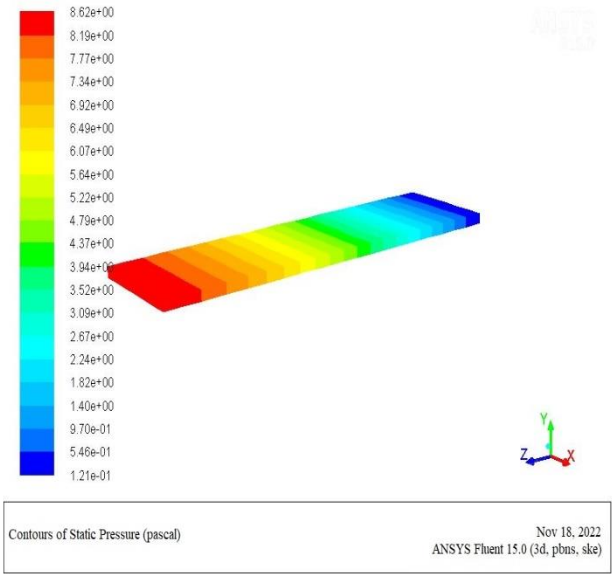

Figure 11 Pressure distribution in smooth plate duct with 6.5m/s velocity

Table: 5 Simulation of various Heat sinks Pin Model

Roughness Model	Wind Velocity (m/s)	Heating Power (w/m^2)	Friction Factor (f)	Reynolds no. (k)	Nusselt Number (Nu)
Plane Model	6.5	1000	0.002	2000	10
1.5mm	6.5	1000	0.004	4000	14
2.5mm	6.5	1000	0.006	6000	28
3.5mm	6.5	1000	0.004	8000	39
4.5mm	6.5	1000	0.003	10000	46
5.5mm	6.5	1000	0.002	12000	58

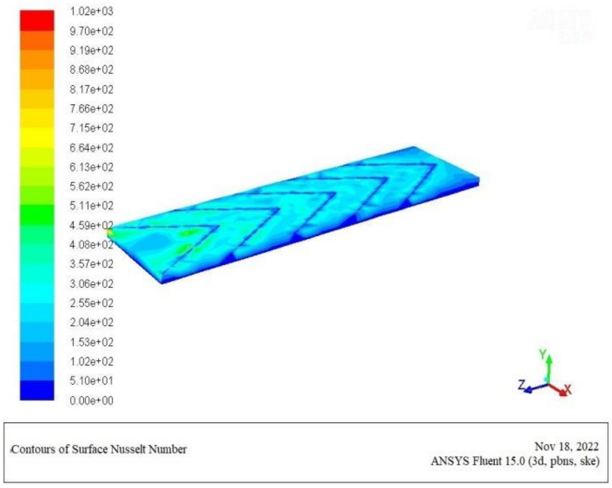

Figure 12: Nusselt no. in 1.5 Relative gap width of semicircular shaped roughened duct with 6.5m/s velocity

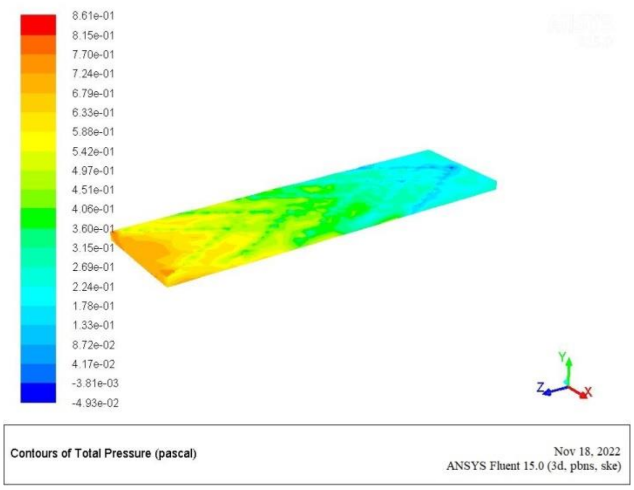

Figure 13: Pressure distribution in 1.5 Relative gap width of semicircular shaped roughened duct with 6.5m/s velocity

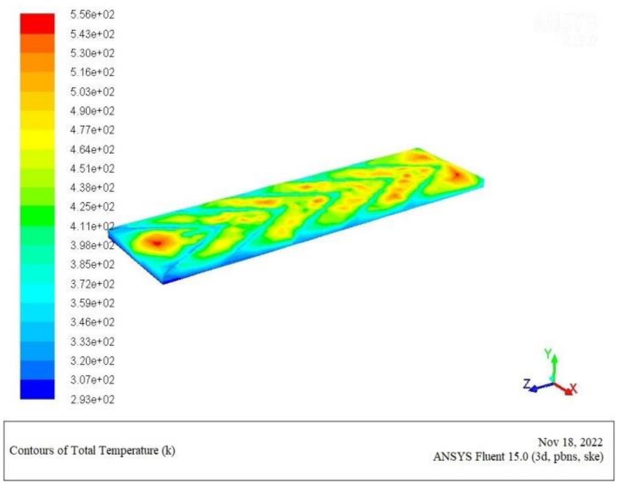

Figure 14: Temperature distribution in1.5 Relative gap width of semicircular shaped roughened duct with 6.5m/s velocity

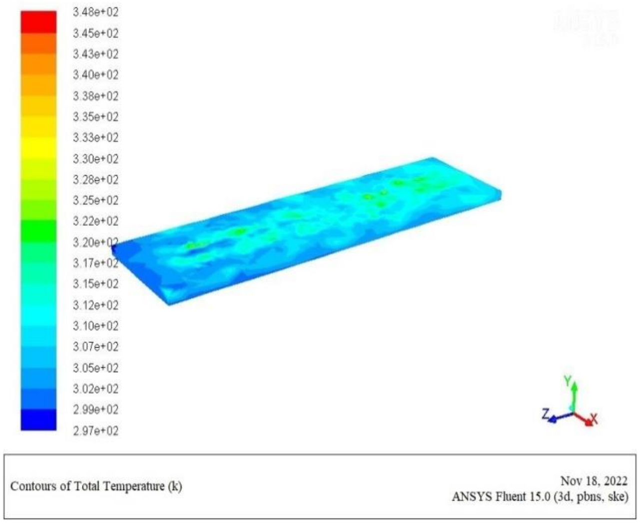

Figure 15: Temperature distribution in 2.5 Relative gap width of semicircular shaped roughened duct with 6.5m/s velocity

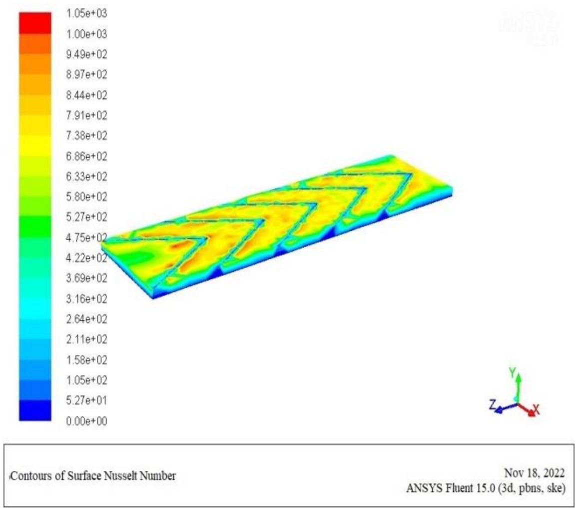

Figure 16: Nusselt no. in 2.5 Relative gap width of semicircular shaped roughened duct with 6.5m/s velocity

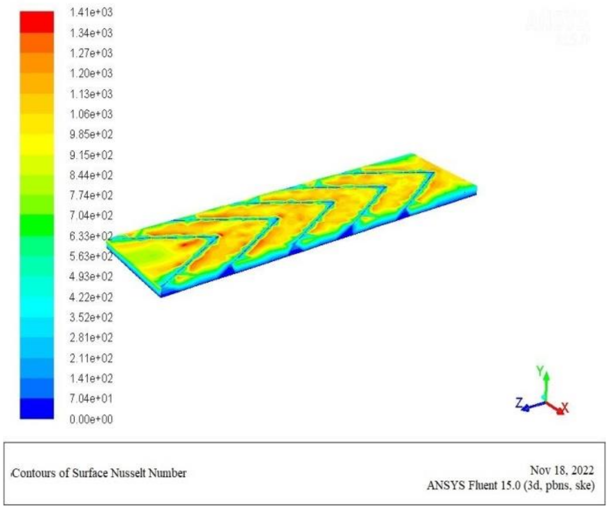

Figure 17: Nusselt no. in 3.5 Relative gap width of semicircular shaped roughened duct with 6.5m/s velocity

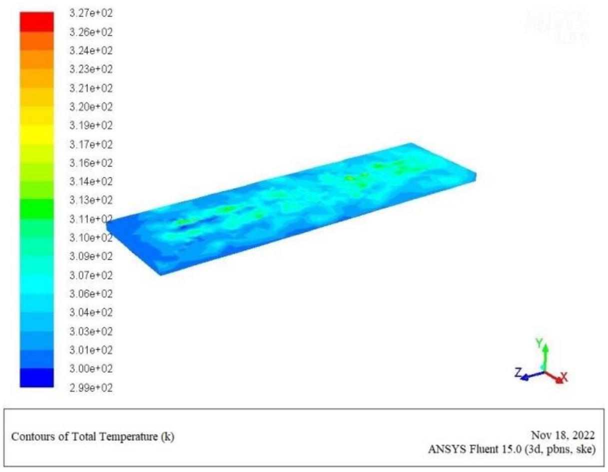

Figure 18: Temperature distribution in 3.5 Relative gap width of semicircular shaped roughened duct with 6.5m/s velocity

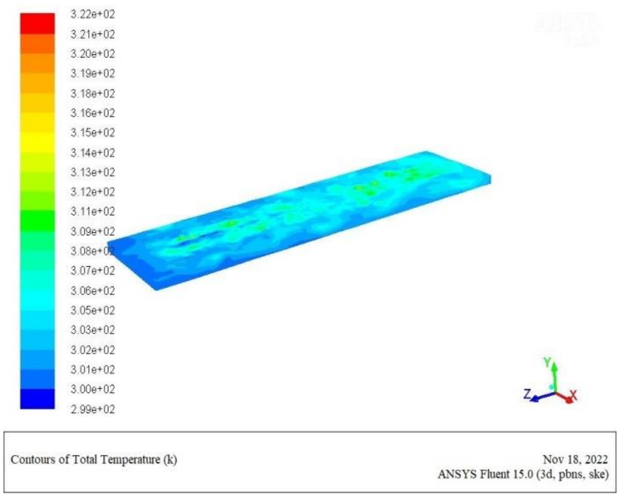

Figure 19: Temperature distribution in 4.5 Relative gap width of semicircular shaped roughened duct with 6.5m/s velocity

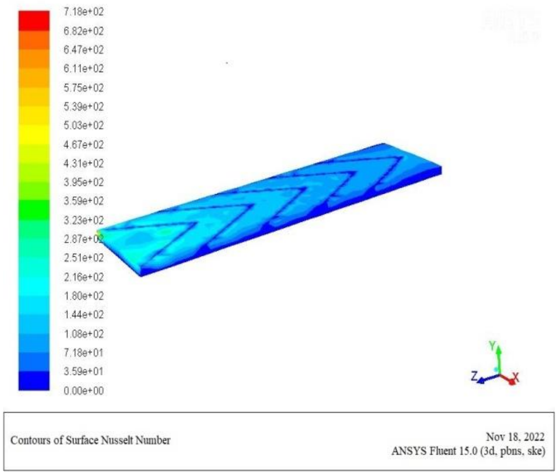

Figure 20: Nusselt no. in 5.5 Relative gap width of semicircular shaped roughened duct with 6.5m/s velocity

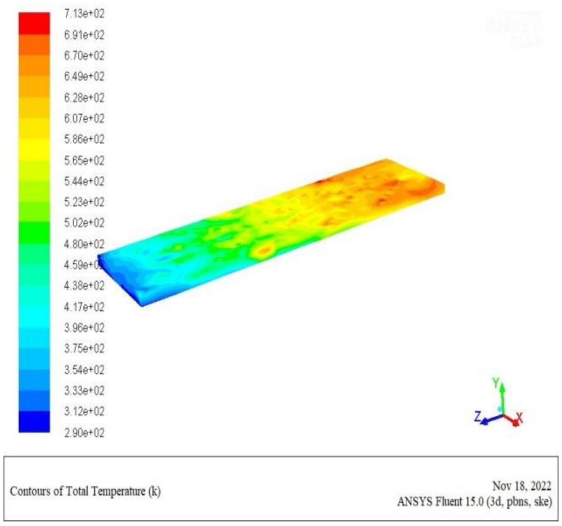

Figure 21: Temperature distribution in 5.5 Relative gap width of semicircular shaped roughened duct with 6.5m/s velocity

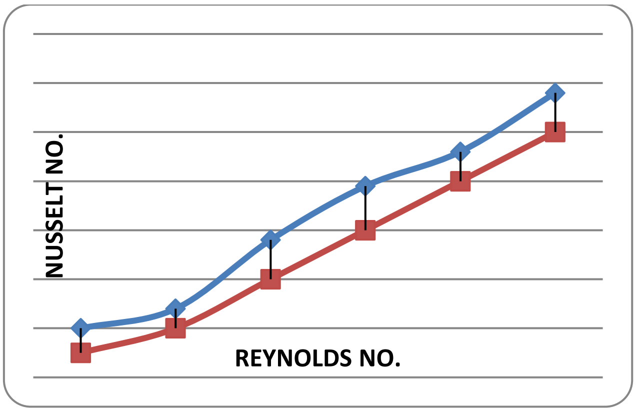

Figure 22 Nusselt no. Variations for Different Profile of Relative Gap Width of Solar Duct with Semi Semi-circular V-Rib roughness

The above figure shows the Nusselt nuber variations for different relative gap width roughness profile of semi-circular profile roughness with compare the experimental result of circular as well as smooth duct and simulation result of various roughened profile of semi-circular gives a constant deviation but in similar manner. This figure shows the increase in the nusselt no with increase in the Reynolds no.

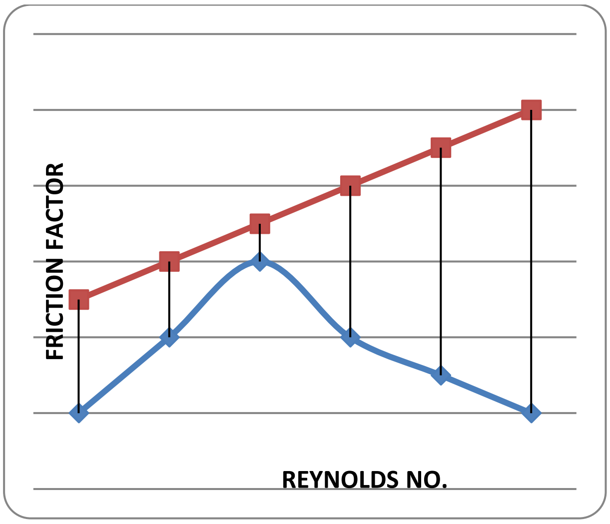

Figure 23 Friction Factor Variations for Different Profile of Relative Gap Width of Solar Duct with Semi Semicircular V-Rib roughness.

The above figure shows the Friction Factor variations for different profile of semicircular roughness with compare the experimental result of smooth & circular duct and simulation result of various fin profile of semicircular roughness gives a constant deviation in semicircular roughened duct but in similar manner of experimental results. This figure shows the decrease in the friction factor with increase in the Reynolds no.

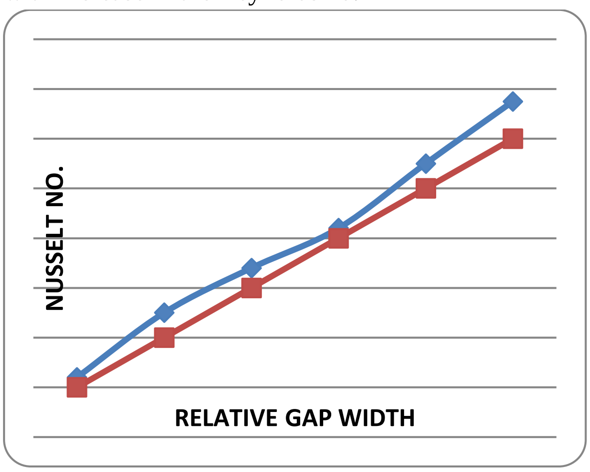

Figure 24 Nusselt Number Variations forDifferent Profile of Relative Gap Width of Solar Duct with Semi Semi-circular V-Rib roughness

The above figure shows the Nusselt number variations for different Relative gap width with compare the experimental result of circular and smooth duct a simulation result of various duct roughened profile of solar duct gives a constant deviation. This figure shows the increase in the Nusselt number with different relative gap width. This is better result of experimental result.

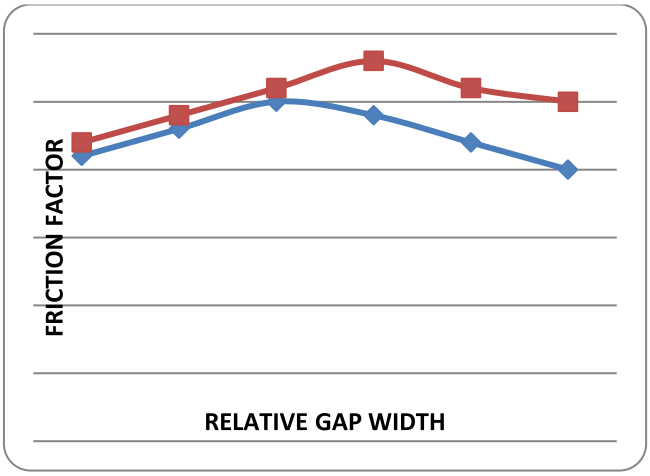

Figure 25 Friction Factor Variations forDifferent Profile of Relative Gap Width of Solar Duct with Semi Semi-circular V-Rib roughness.

As the Relative gap width increases the friction factor decreases along the Duct length because of growing boundary layer thickness.

CONCLUSION

The internal consistency of results confirms the validity of the CFD model. Solar channels with different relative gap widths, constant velocity (6.5 m/s) and constant heat input of 1000 (W/m2) with semi-circular roughness were simulated. From the above results, the semi-circular roughened channel has the lowest coefficient of friction, which is 1.5mm or 0.002, then 1.5mm or 0.002. From the above results, the best Nusselt number is obtained with a semi-circular roughness with a relative gap width of 1.5mm, i.e. 58, then with a relative gap width of 4.5mm, i.e. 46. From the above, it can be concluded that a relative gap width of 5.5mm at constant velocity provides better heat transfer coefficient due to the increase in Nusselt #. Decreased friction coefficient compared to experimental results.

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