iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 Issue: XII Month of publication: December 2023

DOI: https://doi.org/10.22214/ijraset.2023.57043

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue XII Dec 2023- Available at www.ijraset.com

Numerical Simulation of Helical Coil Tube in Tube Heat Exchangers with Grooved Internal Tube

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Abstract: The goal of this work is to analyse the heat transfer effects of providing inner tube with formed groove in helical coil tube in tube HE. In order to investigate further heat transmission improvements, the groove depth was increased to find the comparative study of Nusselt number in different cases analysed in this work. This was performed by use of Ansys CFD Fluent Software package by configuring and employing a compact 3-D model of a real and complex system to solve for the case studies in this research. The context for the topic is discussed, as well as explanation of process breakthroughs in CFD analysis. In order to improve the computational fluid dynamics simulations, information on proper mesh selection and geometry was generated with respect to theoretical concerns and finite CFD practises of element size, nodes, and shape appropriateness. The hot fluid flows through the annulus region and the cold fluid flows through the inner tube in the examined model with counterflow setup. After simulating fluid flow and performing a heat transfer study for a helical coil tube in tube HE with structural configuration as mentioned, post processing techniques is applied to produce the results as furnished by means of graphical representation. Moreover, upon discussion on the impact of variation of Nusselt number and friction factor were established, the analysed results create recommendations with the purpose of better understanding the impact of helical coil grooved tube heat transfer capacity in tube heat exchangers and future research. As a result, grooved inner tube treatment can significantly improve heat exchanger total heat transfer capacity, and the findings of this research can provide assistance theoretically for the development and design of helically coiled tubes in HEs.

I. INTRODUCTION

A heat exchanger is a device that transfers thermal energy from one fluid to another, or between a solid and a liquid, in thermal contact and at various temperatures. Heat exchangers have become increasingly important in terms of energy conservation, conversion, recovery, and the successful application of new energy sources over the last quarter-century. Shell and tube, straight double pipe, cross flow type, helical coiled tube in tube, and other heat exchangers are used to perform heat exchange purposes. In terms of size reduction, thermodynamic efficiency improvement, and pumping power reduction, a rise in the coefficient of heat transfer coefficient is critical. As a result, various approaches for enhancing the heat transfer rate were used. Increasing heat transmission or/and heat transfer surface area per unit volume was the most common method. Helically coiled tube in tube heat exchangers can thus be found in a wide range of industries for heat and mass transfer operations, including chemical and food industries, heat recovery systems, nuclear reactors, medical equipment, and tiny heat exchange activities. Helical coils provide advantages over straight tube heat exchangers in terms of heat and mass transfer processes. In industry and in their products, a wide range of heat exchangers is used. The goal of the section is to provide an overview about helical tube HEs as well as a general understanding of heat exchanger classification methods. This chapter focuses mostly on explaining the terminology and concepts related with a broad range of regularly used industrial heat exchangers.

II. LITERATURE REVIEW

Although the helical coiled heat exchanger has been around for a long time, it is still relatively unknown. Engineers in various sectors are familiar with heat transfer techniques that use traditional shell and tube heat exchangers. The major goal of this chapter is to describe the available literature on heat transfer and fluid flow analysis using helical tubes and double pipe helical coils. Many efforts have been made in recent years to enhance the rate of heat transfer in heat exchangers. There is a vast amount of research that shows how helical coil heat exchangers can improve heat transfer rates. The flow behaviour, friction factor, heat transfer, and numerical analysis are all discussed in the following literature study on helical coils. Transmission of heat properties and hydrodynamics of helical coil heat exchangers were studied by Kumar et al. (2006) for tube in tube type. For both the outer and inner tubes, the Nusselt number and friction coefficient were computed.

The experimental study was done on a counterflow heat exchanger system, and the overall entire heat transfer coefficients were examined, and numerical values produced from the FLUENT CFD software suite were compared. They discovered that with a fixed flow rate in the annulus region, the overall heat transfer coefficient increases with the inner coil dean number.

An experimental and numerical studies of determining the Nusselt number differences around the helical coil's circumference and length done by Jayakumar et al. (2010). Nusselt number prediction was also done in this study. Mishra (2015), an ANSYS CFD Fluent analysis was used for model analysis of a tube in tube helical coil heat exchanger which illustrates the Nusselt Number deviation for various curvature ratios (D/d ratios) and Reynolds Number deviation for various inlet conditions while kept the heat flow of the outside wall as constant.

Xu et.al (2021) studied the impact of different grooving methods and depths on the heat transfer properties of helical coil tube heat exchangers by using numerical simulations and investigation which signifies that grooved treatment can significantly improve the overall heat transmission capacity of heat exchangers. Rennie et al. (2006) investigated the heat transfer parameters of a two-pipe helical heat exchanger using water in both the inner and outer tubes for both co-existing and counter-current flow combinations which are possible. Despite the inner tube's heat resistance remained constant, the resistance to heat in the annulus diminish as the inner tube diameter grows.

III. LITERATURE GAPS

It has been found that calculating the overall heat transfer coefficient in coiled heat exchangers has received little attention. This could be because most study on the fluid-solid interface has focused on either constant wall temperature or heat flux boundary conditions. The fluid-to-fluid heat transfer condition was discovered to be overlooked in helical coil heat exchanger investigations. Heat transfer in helical coil tubes has been widely researched in both laminar and turbulent flows for Newtonian and non-Newtonian fluids. There has been a lot of work done on the inner heat transfer coefficient in coiled tubes for both Newtonian and non-Newtonian fluids; however, the outer heat transfer coefficient has gotten less attention.

Despite the fact that significantly less study has been done on heat exchangers come up with helical coil, Nusselt variation has not been linked in any research with the impact on usage of tube grooving method on the heat transfer properties of helical coil tube in tube heat exchangers.

IV. MODELLING METHODOLOGY

In my research, looking at a double tube helical coil heat exchanger, also known as a tube in tube helical coil heat exchanger, with two (2) turns had been analysed. In current numerical analysis, two turns have been considered and high number of turns can be considered in practise with respect to needs. The coil diameter (D) kept as 80mm and length of the exchanger (L) respect to coil diameter. The inner tube (d) was 8mm in diameter. The tube's thickness (t) was allowed at 0.5mm. The outer tube diameter (d1) was measured at 17 millimetres come with thickness (t) same as inner. To see the influence grooves on heat transfer characteristics of a helical tube in tube heat exchanger, provided groove on inner tube (r = 0.25mm & 0.50mm) and varied the inner tube velocities. The coil's pitch was chosen to be 30mm, resulting in a tube with a total height of 60mm. Tube of copper material was used in the heat exchanger. For the sake of analysis, the fluid property was assumed to be fixed. The counter flow heat exchanger was used in this investigation because it has a higher heat transfer rate than the parallel heat exchanger. In their separate tubes, the cold and hot fluids move in opposite directions. Turbulent fluid flow was included in this work for analysis. According to the correlation described earlier in the introduction chapter, both hot and cold fluids flow with a velocity for which the Reynolds number is greater than the critical Reynolds number. The hot fluid flow rate was kept constant while the cold fluid flow rate was altered to determine the rate of heat transferring, f, and optimise HE for heat transfer efficiency at max and min pressure loss. The study was evaluated in ANSYS 2021R2 under various conditions at boundary as mentioned later after building the geometry on Ansys SpaceClaim and meshing / solutions in ANSYS Fluent.

V. METHODS

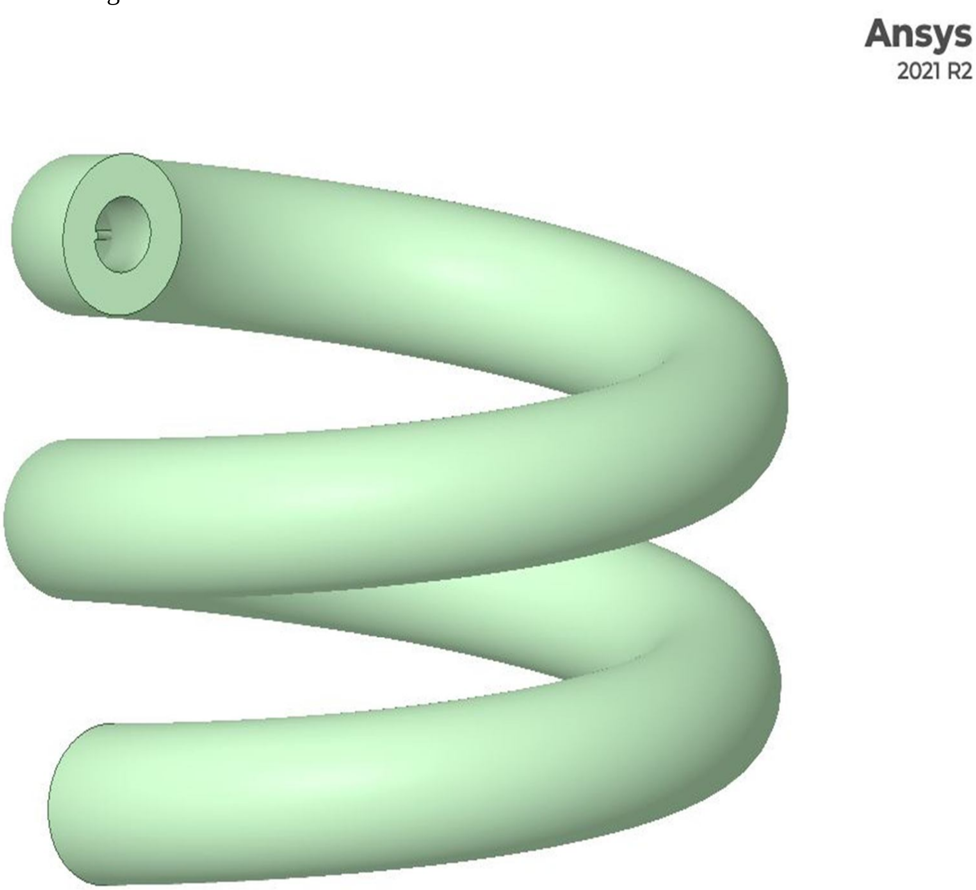
A. Creation of Geometry

Ansys SpaceClaim interface platform was used for geometry creation The ZX plane has been selected for the surface creation. Using circle option, the circular surface created for with corresponding inner and outer diameter of the tube of heat exchangers. Using line command, the reference line for helical sweep requirements had been created perpendicular to the Z-axis. The centre reference for the circular references at surface need to be moved to the line path created and to be aligned the coil diameter with respect to meet the curvature ratio D/d=10.

Thus it performed by move tool by anchoring the central axis of the surface and providing the X-axis distance required from the central axis of helical rotation. Once the surface path created to as needed, the pull option will used to revolve the regions in helical design for the tubing layout and the topology shared to the meshing interface in Ansys Workbench.

B. Creation of Hot Fluid Region

In the outer helical coil, a hot fluid is flowing. The space claim's pull option is employed to create the hot fluid zone. For using revolve tool in pull tool, surface been created as requirement. Thus, the surface circular path is produced in ZX plane is adopted using circular surface reference created. The surface path which is having diameter corresponds to diameter of the outer tube and it lies from the origin equal to the coil's radius which is corresponding to the outer diameter allowed. The profile is a line in the Z-axis, and which is straight. This length is calculated by multiplying the number of revolutions by the pitch. The helical coil hot fluid solid region is created by selecting the revolve option and specifying the profile pull axis, pitch, and height. The type is changed from solid to fluid and renamed as hot fluid region.

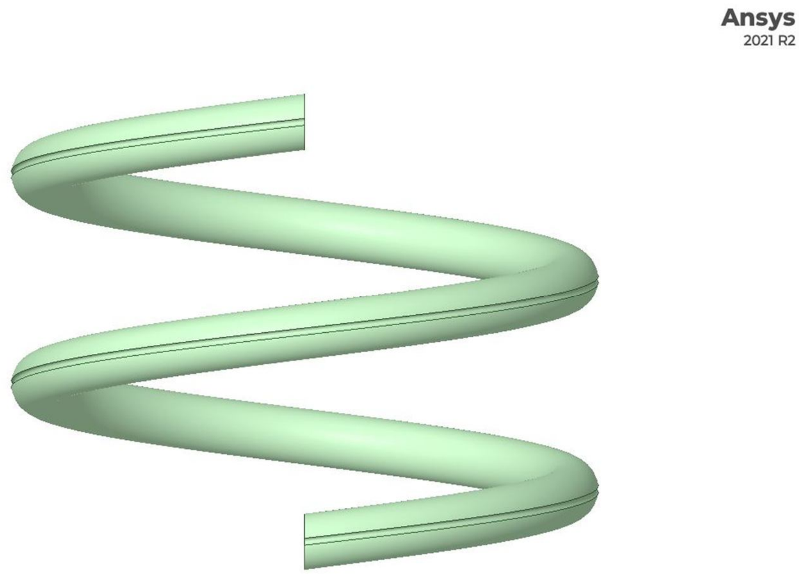


C. Creation of Cold Fluid Region

The inner helical coil is filled with cold fluid and considered grooved tube for the study. For producing cold fluid path, the pull tool in the space claim utilised and the hot region created to be locked using lock input option. For using revolve tool in pull tool, a surface for circular profile is required. Thus, grooved pattern & circular surface is developed in ZX is adopted using circular surface reference created. The circular pattern produced with inner helical tube's diameter, and it is situated at a distance from the origin equal to the coil's radius which is corresponding to the inner diameter allowed. The profile will be a line with the Z-axis and length equals the sum of the number of rotations and the pitch. The helical coil hot fluid solid region is generated by giving profile pull axis, pitch and height at revolve option upon selection axis of rotation. The type is changed from solid to fluid and rename as cold fluid region.

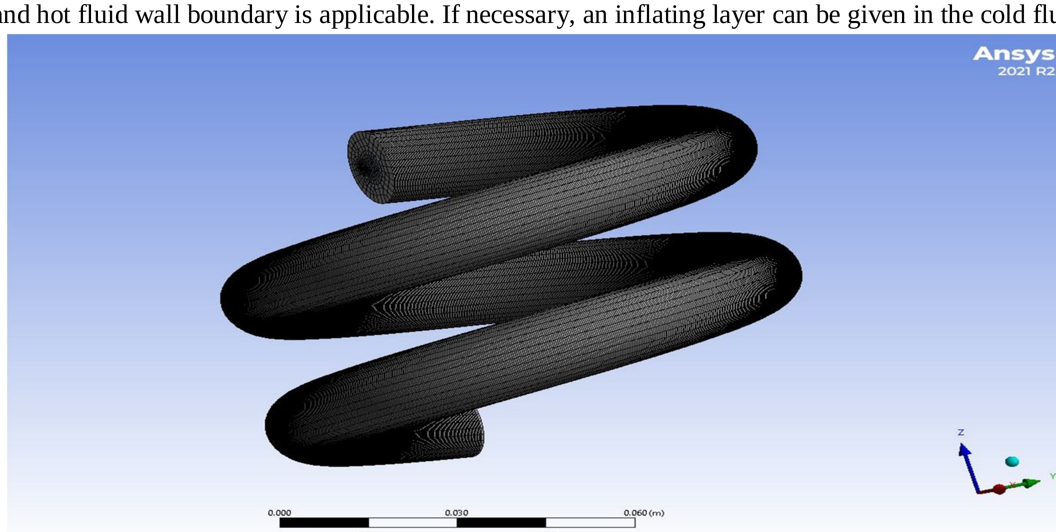
D. Creation of Grooves

For creating grooved inner tube cold fluid region with respect to outer helical tube is made, the surface reference which is made again to be used. The creation of groove profile on inner tube while executed by creating circular surface with diameter which twice the depth required at ZX surface created for inner tube. Trim off geometries in the profile to form grooved path of the inner tube surface. Revolve tool on pull option is used for the helical grooved profile forming as per profile created circular surface Thus, along the path helical profile with respect to outer tube and coil diameter, the cold fluid region with grooved internal tube path is obtained



VI. MESH GENERATION

The geometry should be checked at contact regions and topology for cold / hot regions at CFD requirement before generating mesh. The mesh dimension is set based on options available at mesh adjustment tool bars, giving information of meshing size. Adjusted the face size of the mesh and elements. The amount of elements and nodes were examined and details checked on mesh statistics. The skewness and orthogonal quality of an element determine its quality and to obtain a reasonable mesh, the values were made to be within a specific range. Inflation layer application in hot and cold fluid regions ca be applied, the choice of inflation choose hot fluid geometry and hot fluid wall boundary is applicable. If necessary, an inflating layer can be given in the cold fluid zone.



Upon completion of meshing, the annotation mesh components for the simulation analysis are performed by creation name selection for appropriate faces. The faces annotated as cold inlet cold fluid, outlet cold fluid, inner cold wall comprising of grooved area, and inlet hot fluid, outlet hot fluid, hot fluid wall.

VII. BASICS ASSUMPTIONS

1) Considered counter-flow set up for HE.
2) Cases considered with turbulent flow.
3) Heat transfer conditions in steady state
4) Inner and outer fluids come up with heat transfer under conjugate mode.
5) Radiation and natural convection were not taken into account.

VIII. TURBULENCE MODELLING

A conventional k-ε model was used to model the influence of turbulence in the model under study. In ANSYS FLUENT software, heat transfer and flow efficiency capability properties of heat exchangers shell side are investigated for various grooving arrangement. The pressure outlet is established, the interface is set, and adiabatic side walls and core. The study carried out, the pressure factors and velocity are linked using the COUPLE algorithm and is employed. The second-order upwind style is deployed, tables below summarises the key boundary conditions and corresponding residuals.

A. *Values of Parameters Used*

Table 1. Water (Fluid) Properties

Parameters	Values	S.I
Density	8978	kg/m^3
Thermal Conductivity	387.6	W/m-k
Specific Heat	381	J/kg-K

Table 2. Copper Tube Properties

Parameters	**Notation**	**Values**	**S.I**
Thermal Conductivity	Cp	4182	W/m-k
Density	ρ	1000	kg/m^3
Specific Heat	μ	0.001003	J/kg-K

Table 3. Dimensions Used in Study for HEs

In Structural Parts	Values
Diameter of Coil (D)	80mm
Diameter of Tube Inner (d)	8mm
Diameter of Tube Outer (d')	17mm
Coil Pitch	30mm
Height of Coil	60mm
No of Turns	2
Grooving Depth	0.25mm - 0.50mm

B. *Boundary Conditions Used*

The boundary conditions taken into account as follows.

- Rate at which hot fluid flows has been maintained at constant.
- Rate of flow of cold fluid was varied & Critical Reynolds number.
- Turbulent flow the velocities cold fluid at 1 m/s to 1.6 m/s & hot fluid at 0.9942 m/s.
- Hot fluid inlet with temperature of 348 K
- Cold fluid inlet with temperature of 283 K
- Reynold’s number (Re) ranges from 10000 to 16000

1) Inner Fluid Boundary Condition

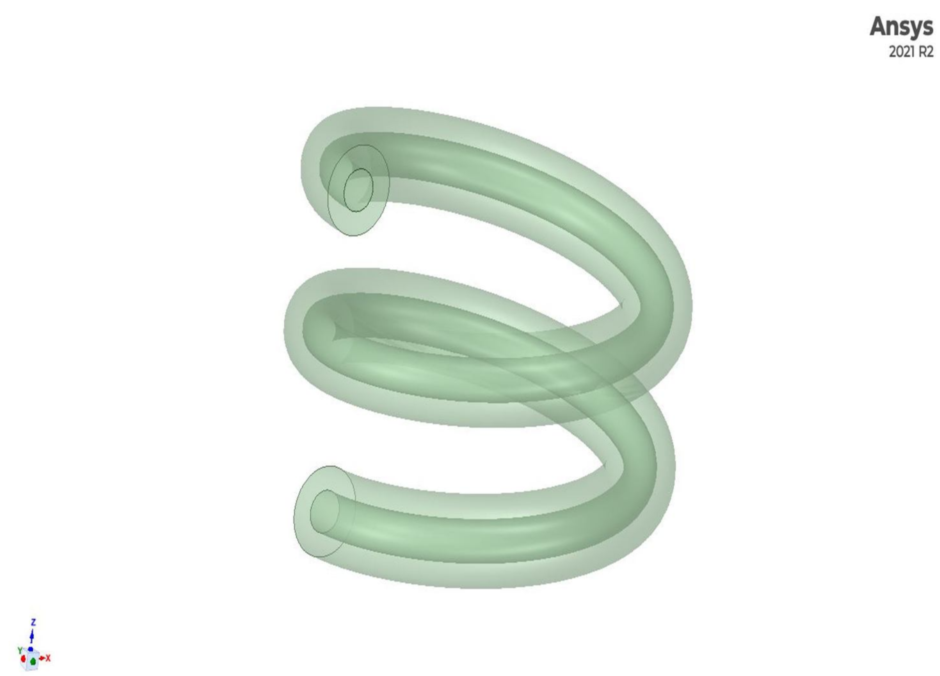
Condition at Inlet	*Velocities at Inlet (varied - 1 m/s to 1.6 m/s)*
Outlet Condition	Pressure Outlet - Zero Pascal
Inlet Temperature	283K

2) Annulus Fluid Boundary Condition

Condition at Inlet	*Inlet Velocity 0.9942 m/s*
Outlet Condition	Pressure Outlet - Zero Pascal
Inlet Temperature	348K

IX. MODEL VALIDATION

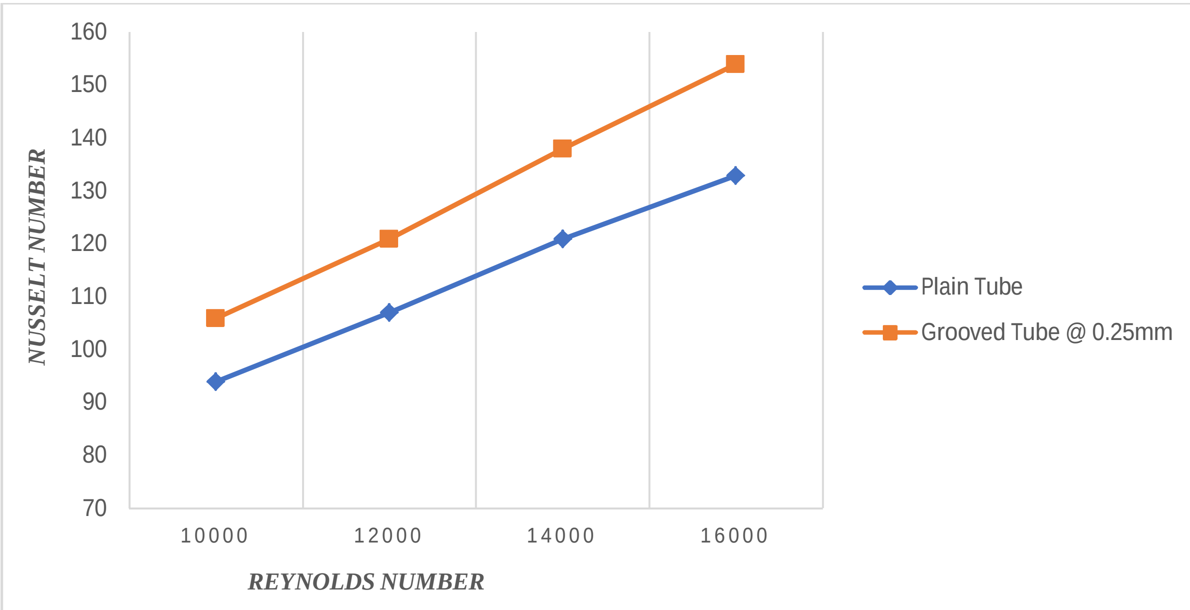
At present, the numerical research on helical coil grooved tube-in-tube heat exchangers have not been conducted, independent analysis and model validation were carried out for helical coil plain tube in tube heat exchangers. Convergence and independence for grid conducted by use of heat exchanger models in accordance with numerical simulation analysis. RNG k-turbulence model findings are comparatively nearer to the experimental results and their trends overall shows a 1.3 % average error percent. It is observed that most researchers Yang (2016), Wang et al. (2019b), Chaturvedi et al. 2018) had simulated the HCTT heat exchangers for k- ε turbulence model RNG k-ε turbulence model and were utilised. However, the choice between these two models is not determined accurately. With reference to Jamshidi et al. (2013), using same heat exchanger turbulence models, these were chosen for simulations and experimental value comparisons of numerical study. As the inflow flow rate increases, the Nusselt number increases. Therefore, the procedure of the study is to allow RNG k-ε turbulence model for research using appropriate boundary conditions as noted in above sections, further the convergence would be checked for the models analysed in ANSYS fluent for various case studies and results to be optimised.



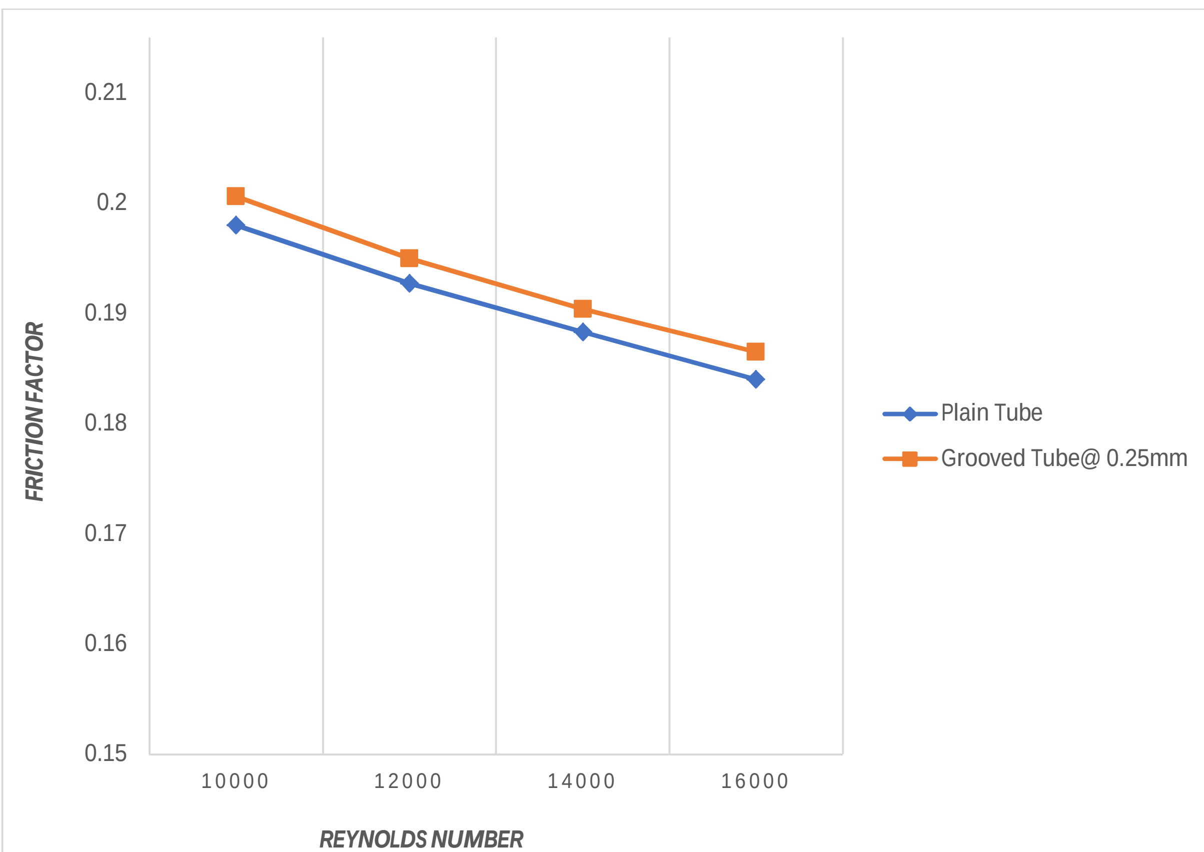
X. RESULTS

A. Effects of groove method on the heat transfer capacity of helical coil heat exchangers compared to plain tube heat exchangers.

1) Variation of Nusselt number with Grooving Method on Inner Tube

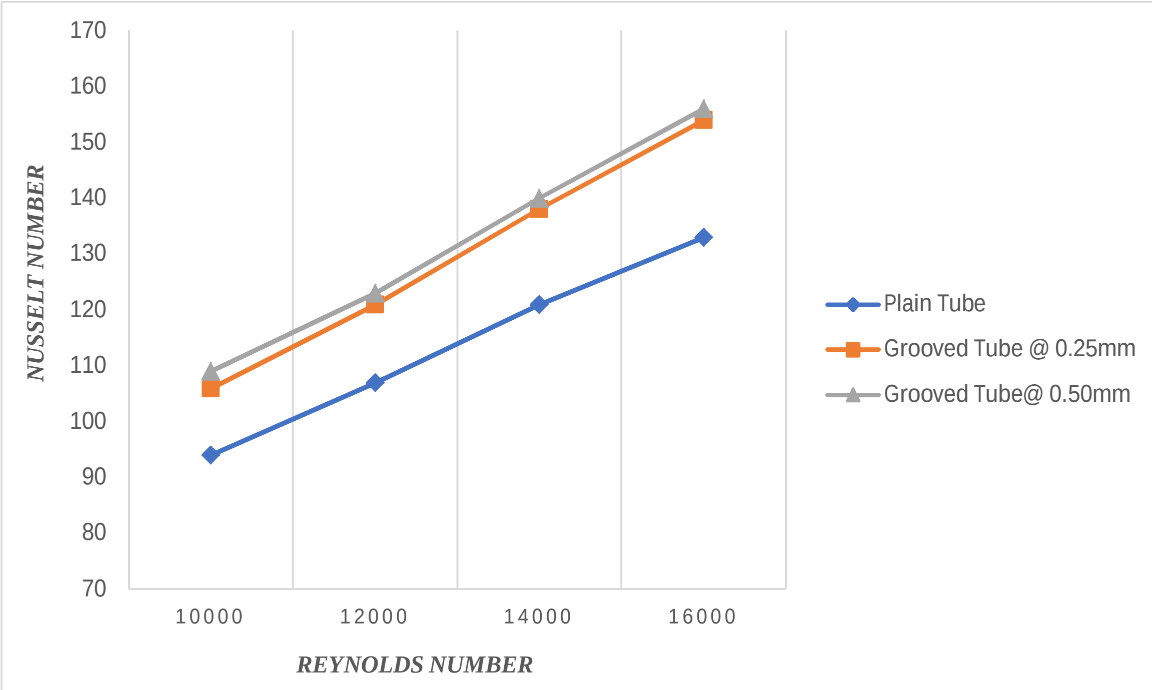


2) Variation of Friction Factor with Grooving Method on Inner Tube

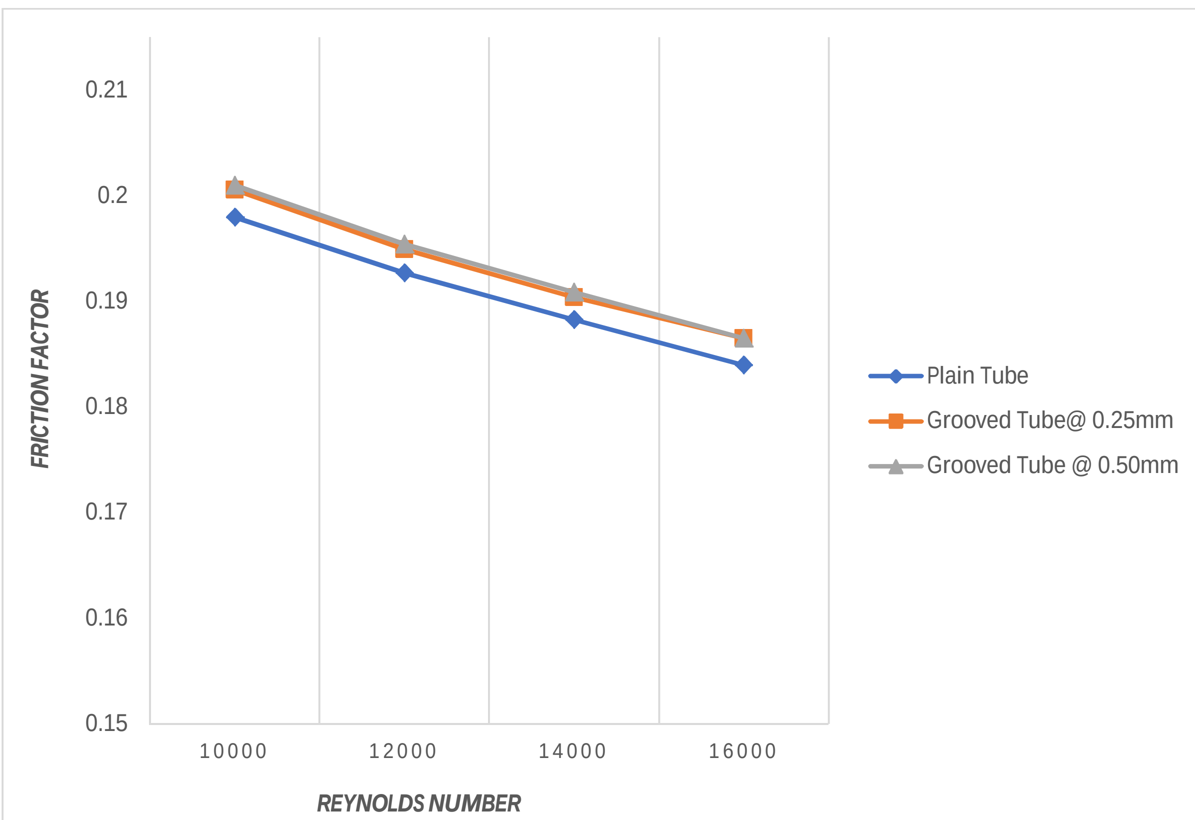


B. Effects of Groove Depth Grooved tube heat Exchangers on heat Transfer Capacity.

1) Variation of Nusselt number with Groove Depths



2) Variation of Friction Factor with groove Depths



XI. CONCLUSION

Grooving on the plain tubes' outer base can erode the boundary layer at the tube wall's surface and increase fluid disturbance near the wall, enhancing the heat exchanger overall heat transfer performance. The grooving methods can significantly enhance the HEs capacity for total heat exchange, according to results. This effect, however, increases flow resistance.

Helical coil grooved tube in tube heat exchangers has a larger Nusselt number and friction factor than of the helical plain tube in tube heat exchangers. In the grooved tube heat exchangers, when depth groove increases, Nusselt number got increased. Because the groove's fluid agitation got boosted, this increases capacity of heat exchange of the fluid & wall, is due to the increment of groove depth. For the same working setup and at groove depth of 0.50 mm, the helical coil grooved tube in tube heat exchangers showed the greatest heat transfer and enhancement performances, it has a 20% higher heat transfer efficiency when compared to the other heat exchanger configurations studied.

The cost of groove forming process in pipe or tube surface is higher, on the other hand a boost the heat transmission rate by nearly 20% by use groove methodologies when compared to a smooth tube. These grooved tube helical heat exchangers are appropriate for such type of heat transfer purposes in engineering requirements when space is limited, and it is needed to reduce size and gross heaviness of the heat exchanger. Because grooved pipes promote heat transfer, a short tube length can be used to provide the similar heat transferring impact in place of plain lengthy tubes.

XII. FUTURE WORK

In addition to numerical simulation conducted in this research work, the performance of experimental validation to determine the reliability of the data produced can be done. The current research is restricted to single phase fluid flow through grooved tubes in tube helical coil heat exchangers, but it can be expanded to include two phase mixed fluids in the same configuration. In order to conduct additional research, the groove direction pattern and number of grooves can be changed in a comparable way in helical coil heat exchanger design for analysis.

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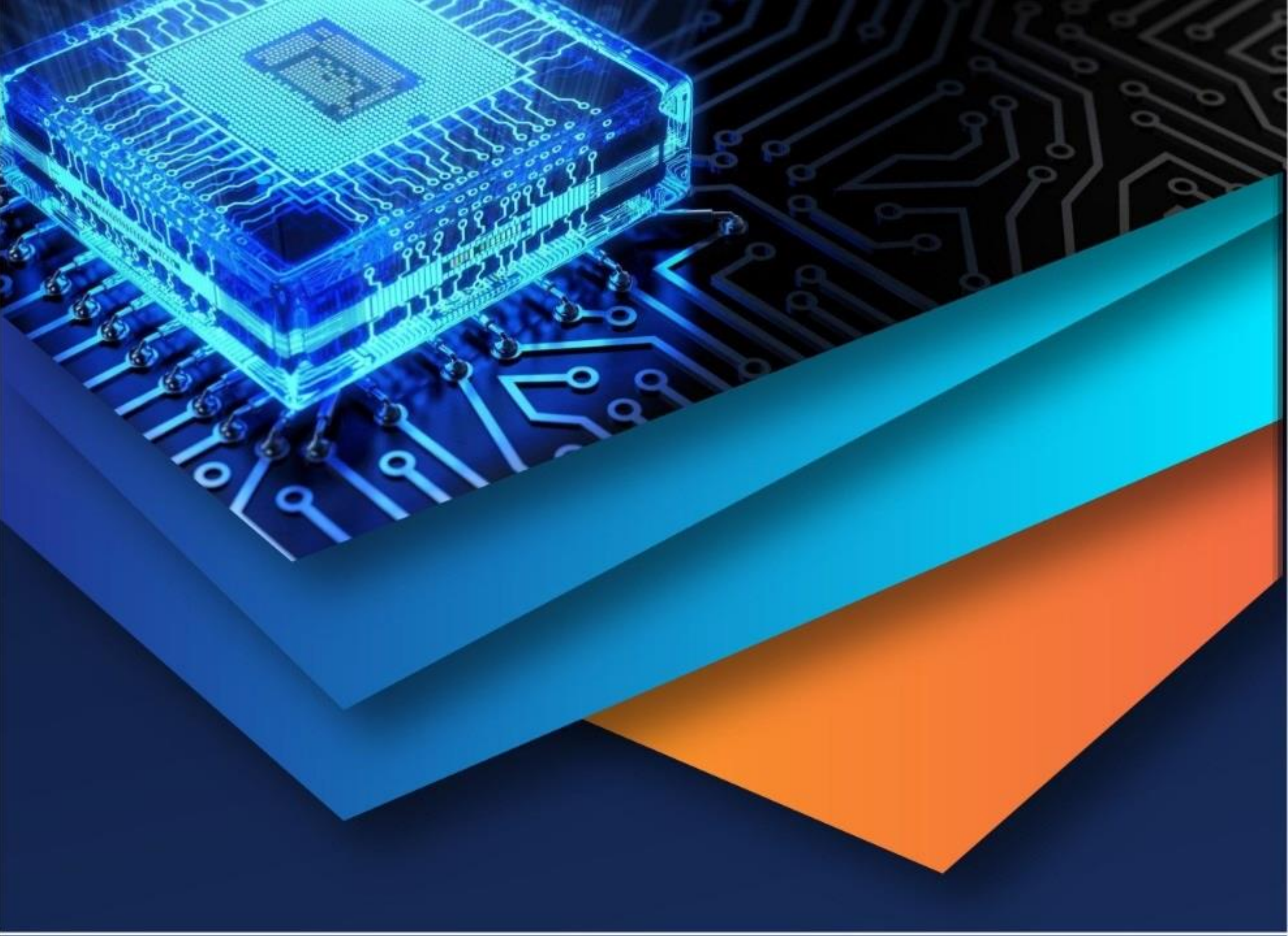

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