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A Review of Lobed Cross Sections in Helical Coil Heat Exchangers Using Computational Fluid Dynamics to Consider Geometrical Factors in Heat Transfer Analysis

***Rajan Kumar* [1], *Prof. Abhishek Bhandari* [2]**

[1]*NRI Institute of Research and Technology, Research Scholar, RGPV Bhopal, MP, INDIA*
[2]*NRI Institute of Research and Technology, Professor, RGPV Bhopal, MP, INDIA*

ABSTRACT

To examine the flow characteristics and heat transfer applications of a helical coil with a lobed cross section, computational fluid dynamics (CFD) is being used in this study. The flow is laminar, the Reynolds number changes from 1200 to 2400, and the temperature of the helical coil's wall is always 373 K in all simulations. Findings show that a coil with n=6 displays the greatest Nusselt number (Nu) and the lowest friction factor coefficient (f).

In this study, we are using aluminum (Al_2O_3)-based nanofluid's forced convection heat transfer in a helical tube was investigated using a 3-dimensional numerical (3-D) simulation. We use internal helical tubes with varying Reynolds numbers (Re) at a constant wall heat flux to examine the impact on heat transfer and Nusselt number. The spiral flow significantly boosts heat transfer efficiency while increasing pressure drop.

Last but not least, the effect of adding CuO nanoparticles to water is taken into account. As can be observed, using CuO-Water nanofluid as the working fluid raised the Nusselt number by nearly 33%. However, it is evident that the friction factor coefficient has barely changed. Furthermore, it is evident that higher volume concentrations cause heat to transfer at a quicker pace. The numerical data is then used to highlight the correlation for anticipating the Nusselt number.

Keywords: Computational fluid dynamic, copper (CuO)-based nanofluid, nanoparticles, Nusselt number, lobbed tubes section.

I. INTRODUCTION

In a broad variety of applications, including heat storage, heat recovery processes, air conditioning, and chemical reactors, curved tubes known as "helical coil tube heat exchangers" are utilized [1]. These uses are generally found in industry. The temperature of the lubricating oil for the pumps is also lowered by using them in petroleum units as shell and coil heat exchangers and twin pipe heat exchangers. This kind of heat exchanger uses fluid to go through curved tubes, which creates centrifugal force. A secondary flow is brought on by centrifugal force, and it has a big impact on how the original flow behaves. Compared to straight tubes, secondary flow is a more complex phenomenon in curved tubes. Additionally, the pressure drop for flow in a curved tube is higher than that of a straight tube for the same flow rate and tube length. The two primary outcomes of this phenomenon are a drop in pressure and a faster rate of heat transfer. On the basis of prior studies, several investigations have been carried out to increase the efficiency of helical coil heat exchangers.

II. LITERATURE REVIEW

Jamshidi et al. conducted experimental study on the enhancement of heat transmission using a heat exchanger with helical coils and a casing. They examined the flow parameters as well as geometrical elements like coil pitch and diameter. Every experiment used water flowing in a laminar regime as the working fluid. Maowed [6] conducted an experimental study on the effects of flow and geometrical parameters on forced convection in helical coils.

Mohamad Omidi, Mousa Farhadi al. (2022), In this paper, flow characteristics and heat transfer applications of a helical coil with four different lobed cross sections are investigated numerically. The flow is laminar, Reynolds number changes from 1300 to 2500 and the wall of the helical coil in all the simulations has a constant temperature of 373 K. Effects of cross section lobe number (n) on heat transfer rate and pressure drop are studied. The results show that a coil with n=6 presentsthe highest Nusselt number (Nu) and the lowest friction factor coefficient (f). In the next step, effects of different geometrical parameters (coil pitch, height, and diameter) and different fluids(Prandtl number) are studied. It is observed that the coil diameter has the greatest effect in comparison to the other geometrical parameters. Last but not the least, the effect of adding Al2O3 nanoparticles to water is discussed.

Mohamad Omidi, Mousa Farhadiet al. (2018) Turbulent flow characteristics and heat transfer applications of a twisted double-pipe heat exchanger (DPHE) with four different lobed cross sections are numerically investigated. Geometrical modifications are made for both inner and outer tubes of double-pipe heat exchangers. The numerical analyses are done based on the performance evaluation criterion (PEC), which is the relation between heat transfer rates and pressure losses. It is found out that PEC increase is more considerable regarding the outer tubes of the DPHEs. Upon simulations, it is observed that heat transfer and pressure drop decrease with the increase of lobe number in a tube, while the other tube was held smooth. At this point, maximum of respectively 240 and 85% increase in Nusselt number and pressure drop are observed

Mohamad Omidi, Mousa Farhadi al. (2017) Growing need to develop and improve the effectiveness of heat exchangers has led to a broad range of investigations for increasing heat transfer rate along with decreasing the size and cost of the industrial apparatus accordingly. One of these many apparatuses which are used in different industries is double pipe heat exchanger. This type of heat exchanger has drawn many attentions due to simplicity and wide range of usages. In recent years, several precise and invaluable studies have been performed in double pipe heat exchangers. In this review, the development procedure that this type of heat exchanger went through has been analysed in details and the heat transfer enhancement methods in aforementioned heat exchangers have also been widely discussed.

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Zhan Liu, Yanzhong Liet al. (2016) Full use and effective management of cold capacity are significant for improving the performance of heat exchanger in the thermodynamic vent system (TVS). To understand the operation principle of TVS easily, the thermodynamic analysis, based on the ideal gas state equation and energy conservation equation, is detailed introduced. Some key operation parameters are optimized and suggested. As the low mass flow rate and low heat fluxes are involved in flow boiling of the annular pipe fluid, the Kandlikar's boiling heat transfer correlation is selected to predict the flow boiling process, after validated with the related experimental results.

Z.S.Lu, L.W.Wang al. (2012) A heat pipe type adsorption refrigerator system is proposed and investigated, which can be powered by solar energy or waste heat of engine. The study assesses the performance of compound adsorbent (CaCl2 and activated carbon)–ammonia adsorption refrigeration cycle with different orifice sets and different mass and heat recovery processes by experimental prototype machine. Specific cooling power (SCP) and coefficient of performance (COP) were calculated with experimental data to analyze the influences of operating condition. The results show that the jaw opening of the hand needle nozzle can influence the adsorption performance obviously and the thermostatic expansion valve (TEV) is effective in the intermediate cycle time in the adsorption refrigeration system

III. GEOMETRY SETUP AND MODELLING

The geometry used for simulation analysis is based on work by Mousa Farhadi, Mohamad Omidi, and others (2022). A schematic illustration of the Helical tube and its computing domain is shown in Figure 5.1. The input fluid is introduced into the computational environment using a helical tube. Examining how lobed cross sections affect heat transfer and pressure loss in helical coils is the main objective of the current work.

Additionally, the helical coil under consideration has a pitch of 21.4 mm, a coil diameter of 12.0 mm, and a tube diameter of 110 mm. The three elements that make up the boundary condition of the current coil are the velocity inlet, pressure outlet, and wall. The intake fluid has a temperature of (27 °C), and specific Reynolds values are associated with its axial velocity. A no-slip boundary condition is shown by zero fluid velocity on the wall and a constant fluid temperature of (100 °C). Additionally, the pressure outlet value of zero has been taken into account.

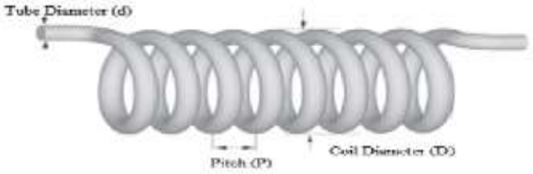


Figure 1. Geometry model of helical tube section

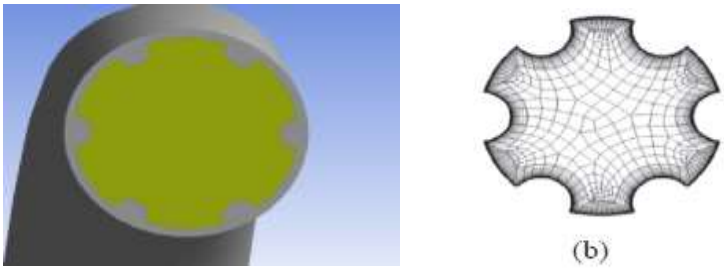


Figure 2 Lobbed section (n=6) in helical tube

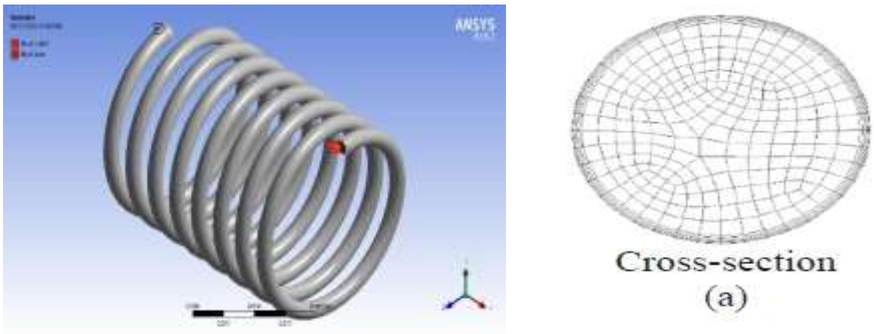


Figure 3. circular cross section helical tube

The three-dimensional discretized model was created during the ANSYS FLUENT R 19.2 pre-processor stage. Even though there is a connection between grid types and simulation outcomes, the programmed ANSYS generates a coarse mesh. Due to this need, the final volume discretizes the structure as a whole. Unit-sized ICEM Tetrahedral cells with triangular frontier faces make up the mesh. In this investigation, a mesh metric and a medium fluid curvature are used.

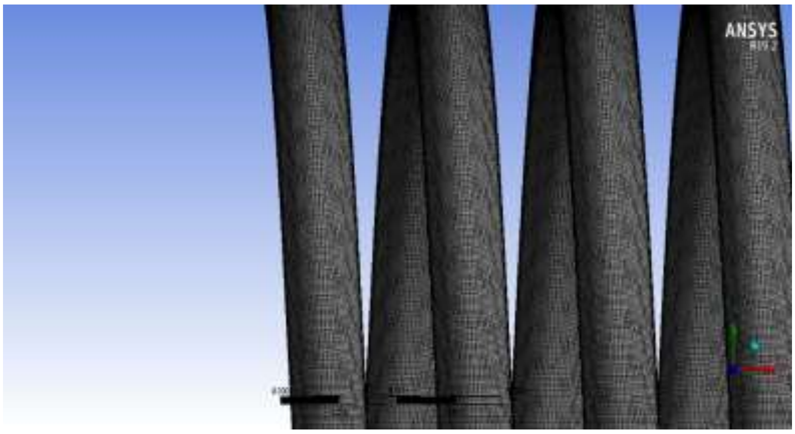


Figure 4. Meshing of helical pipe structure.

Table 1. Meshing detail of model

S. No.	*Parameters*	
1	*Curvature*	*On*
2	*Smooth*	*Medium*
3	*Number of nodes*	*8762877*
4	*Number of elements*	*7201077*
5	*Mesh metric*	*None*
6	*Meshing type*	*Tetrahedral*

In order to compute, the Fluent 19.1 was utilized. In studies, a finite element method was employed to distinguish between the governing equations. The flow and energy equations were combined with the usual k-epsilon equation to solve turbulence. This suggests the following theories:

1) There is negligence of thermal radiation and normal convection;
2) The average of fluid and solid properties is calculated
3) Flow is incompressible;
4) Heat transfer steady state;
5) Transitional fluid flow and turbulent regimes, and
6) The fluid is distributed uniformly between the channels and the inlet channels have a uniform velocity profile.

The numerical simulation was with a 3-Dimensional steady state turbulent flow system. In order to solve the problem, governing equations for the flow and conjugate transfer of heat were customized according to the conditions of the simulation setup.

Table 2. Thermodynamic Properties of base fluid (water) & Al_2O_3 nanoparticles

Input Parameters	***Symbols***	***Units***	***Al_2O_3***	***H_2O***
Specific heat capacity	c_p	*J/kg-K*	*780*	*4179*
Density	ρ	*(kg/m^3)*	*3590*	*998.2*
Thermal conductivity	k	*W/m-K*	*46*	*0.6*
Viscosity	μ	*Kg/m.s*	*0*	*0.001003*

Additionally, the proposed helical coil's pitch, coil diameter, and diameter are each 12, 110, and 21.4 mm, respectively. The velocity inlet, pressure outlet, and wall make up the three components of the current coil's boundary condition. The intake fluid has a temperature of (27 °C), and its axial velocity corresponds to specific Reynolds values. Its constant temperature of (100 °C) and zero fluid velocity on the wall indicate a no-slip boundary condition. Last but not least, the value for the pressure outlet has been set to zero. the diameter of all the Al_2O_3 nanoparticles (dp) is 28 nm.

Following are the assumptions in the numerical simulation calculations has been used:

a) Helical tube is used instead of straight tube.

b) 3D flow, turbulent flow, developed flow, and static flow.

c) When inserting the nanofluid in Helical tube, the temperature at the inlet is 300^0K.

d) Based on the Reynolds number and flow rate, the inlet tube velocity flow profiles for both tubes are fully produced.

e) The uniform heat flux is used as the wall boundary condition from the pipes outside diameter to its inner diameter.

Table 3. Details of boundary conditions.

Detail	***Value***
Aluminium (Al_2O_3)-based nanofluid flow rate	*At different Reynold's no. 1200, 1600, 2000 and 2400*
Fluid velocity & Temperature on the wall	*0 & 100^0C*
Aluminium (Al_2O_3))-based nanofluid inlet temp.	*27^0C*
Pressure outlet	*0*
Outer surfaces	*Heat flux=0*

IV. RESULTS AND DISCUSSIONS

This section uses aluminum based nanofluids to assess the thermal performance of the helical tube sections. To investigate the performance of the heat exchanger employing flowable nanofluids, the differences in the heat transfer rate and thermal conductance are studied at various Reynolds numbers.

4.1. Data reduction equations

The values of Nusselt number, and Heat transfer coefficient calculated from the CFD modeling on the basis of temperature of hot and cold fluid obtained were compared with the values obtained from the analysis performed by **Hu Chen et al. (2020)**.

The data reduction of the measured results is summarized in the following procedures:

The Reynolds number is given by,

$$\boldsymbol{Re = \frac{\rho V D}{\mu}}$$

The mass flow rate is calculated on the basis of below formula,

$$\boldsymbol{\dot{m} = {}^{\cdot}\rho A V}$$

Where, $\boldsymbol{\rho}$ is the density of fluid, $\boldsymbol{A}$ is the cross-sectional area of the pipe and$\boldsymbol{V}$ is the velocity of fluid.

Therefore, for fluid flows in a concentric tube heat exchanger, the heat transfer rate of the hot fluid in the outer tube can be expressed as:

$$\boldsymbol{q_h = \dot{m}_h c_{ph} (T_{hi} - T_{ho})}$$

Where $\dot{m}_h$ is the mass flow rate of hot fluid, c_{ph} is the specific heat of hot fluid, T_{hi} and T_{ho} are the inlet and outlet temperatures of hot fluid, respectively.

While, the heat transfer rate of the cold fluid in the inner tube can be expressed as:

$$q_c = \dot{m}_c c_{pc}(T_{co} - T_{ci})$$

Average heat transfer rate is given by:

$$Q_{avg} = \frac{q_h + q_c}{2} = UA\theta_m$$

Where, $\theta_m = \frac{\theta_1 - \theta_2}{2}$

θ_m is the logarithmic mean temperature difference.

$U$is the overall heat transfer coefficient.

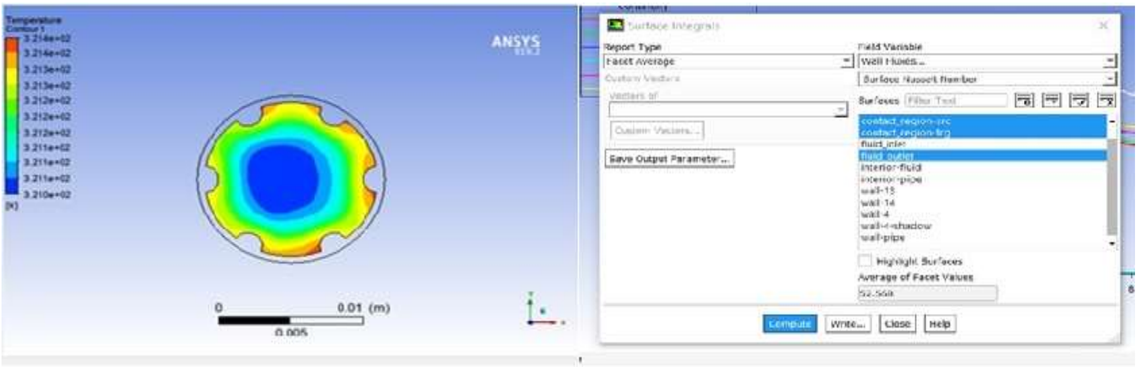
4.2. Validation of numerical computations

Comparison with the research published in **Mohamad Omidi, Mousa Farhadi, et al.** was done in order to verify the correctness of the established numerical technique (2022). The geometry of the helical tube sections utilised for the verification of the numerical calculations was taken into consideration. Here, we use Al_2O_3-water as the base fluid and use CFD to get the Nusselt number's value.

Then, using water as the base fluid and a copper (CuO)-based nanofluid at varying concentrations (1%, 2%, and 3% copper nanoparticles with base fluid), we calculate the Nusselt number.

- **For Re = 2400**

In this case, we are using Aluminum (Al_2O_3) based nanofluid in the base fluid (water) & find out the Nusselt number.



Report Type: Facet Average

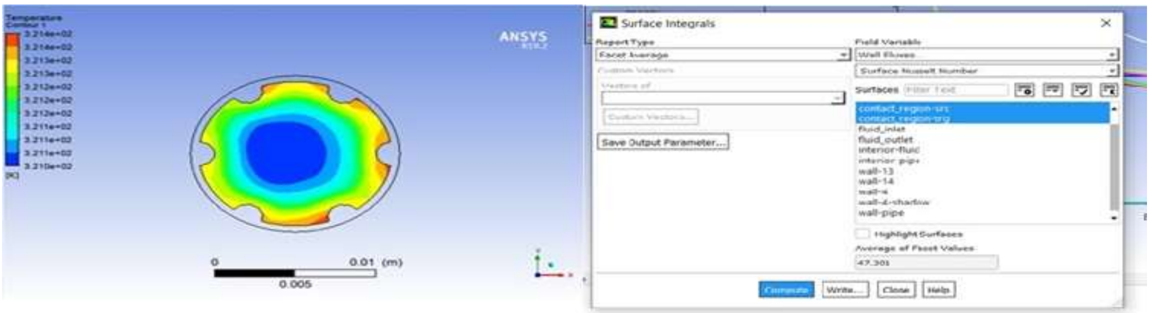
Field Variable: Wall Fluxes...

Surface Nusselt Number

Average of Facet Values: 52.568

Figure 5. Temperature contour &Nusselt no. at Re = 2400 for Helical tube sections using Aluminum (Al_2O_3) based nanofluid.

- **For Re = 2000**



Report Type: Facet Average

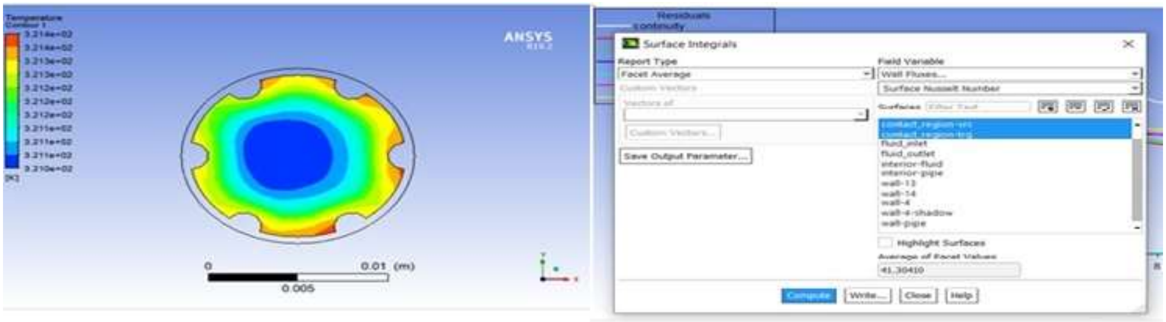
Field Variable: Wall Fluxes

Surface Nusselt Number

Average of Facet Values: 47.301

Figure 6. Temperature contour &Nusselt no. at Re = 2000 for Helical tube sections using Aluminum (Al_2O_3) based nanofluid.

- **For Re = 1600**



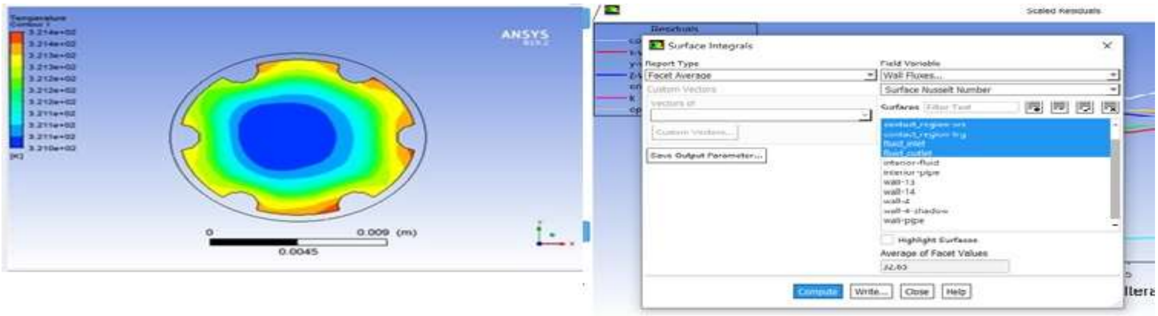
Report Type: Facet Average

Field Variable: Wall Fluxes... / Surface Nusselt Number

Average of Facet Values: 41.30410

Figure 7. Temperature contour &Nusselt no. at Re = 1600 for Helical tube sections using Aluminum (Al_2O_3) based nanofluid.

- **For Re = 1200**



Report Type: Facet Average

Field Variable: Wall Fluxes... / Surface Nusselt Number

Average of Facet Values: 32.63

Figure 8. Temperature contour &Nusselt no. at Re = 1200 for Helical tube sections using Aluminum (Al_2O_3) based nanofluid.

In Above analysis, validate the result of the base paper, taking the same configuration for lobbed section (n=6) using the Al_2O_3-water as a nano fluid. Following graph shown the Nusselt number variation at different Reynold number of base paper.

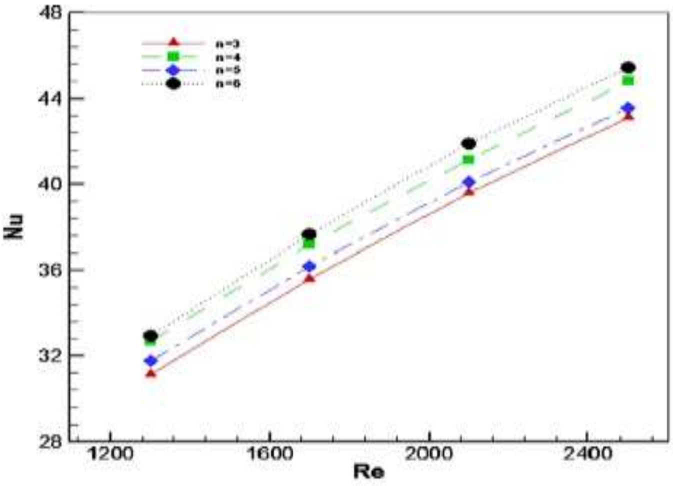
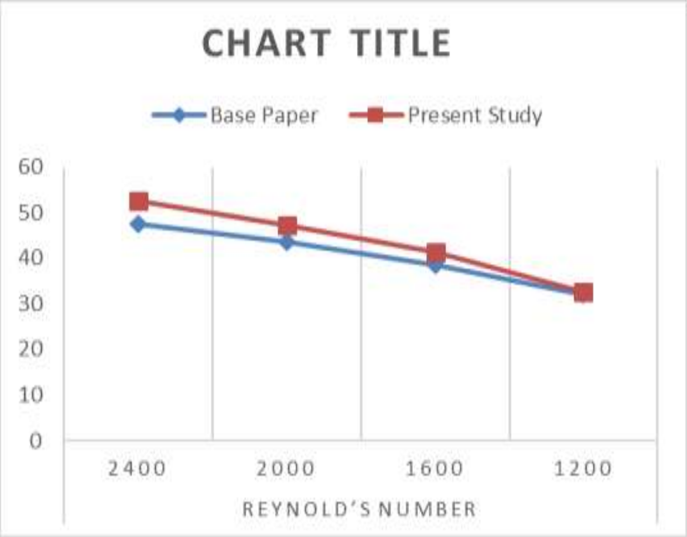


Figure 9. Nusselt number form the base paper [1] using Al_2O_3 - water nanofluid.

Table 4. Shows the values of Nusselt number calculated from the CFD modeling compared with the values obtained from the analysis performed by Mohamad Omidia, Mousa Farhadia, et al. (2022) using Al_2O_3-water as a nano fluid

S.No.	**Reynold’s number**	**Nusselt Number**	
		Base Paper	**Present Study**
1.	2400	47.52	52.568
2.	2000	43.621	47.301
3.	1600	38.559	41.304
4.	1200	32.0	32.65



V. CONCLUSIONS

According to the graph above, the numerical model of the Helical tube section utilizing Base fluid is accurate since the value of the Nu number acquired through numerical analysis is closer to the value of the Nu number derived from the base paper. The disparity between experimental and numerical results is significantly less.

Now, the copper (CuO)-based nanofluid was also used in the helical coil. By illustrating the swirl behavior induced by velocity and temperature distributions, which is the main characteristic in tubes with lobbed cross sections, the results of several of the aforementioned simulations were made apparent.

The following possible conclusions can be drawn from the simulation, which are:

- According to the foundation study, it was found that the helical coil with n=6 had the highest Nusselt number and the lowest friction factor when compared to the other lobed cross sections.
- How many percentages the rate of heat transfer will be increase or decrease while using Copper (CuO)-based nanofluid instead of alumina (Al_2O_3)-based nanofluid.
- Rate of heat transfer variation, while using Copper (CuO)-based nanofluid with 1%,2% and 3% volume concentration.
- What will be the impact of coil pitch and coil height, when we are using Copper (CuO)-based nanofluid instead of alumina (Al_2O_3)-based nanofluid.

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