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EFFECT OF GEOMETRICAL FACTORS ON HEAT TRANSFER ANALYSIS UTILIZING LOBED CROSS SECTIONS IN HELICAL COIL HEAT EXCHANGERS USING COMPUTATIONAL FLUID DYNAMICS (CFD)

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ABSTRACT

In this investigation, a 3-dimensional numerical (3-D) simulation was used to examine the forced convection heat transfer of a copper (CuO)-based nanofluid in a helical tube. We investigate the effects on heat transfer and Nusselt number using internal helical tubes with changing Reynolds numbers (Re) at a constant wall heat flux. The spiral flow increases pressure drop and considerably improves heat transfer efficiency.

This research uses computational fluid dynamics (CFD) to investigate the flow properties and heat transfer applications of a helical coil with a lobed cross section. The wall of the helical coil has a constant temperature of 373 K in all simulations, the flow is laminar, and the Reynolds number varies from 1200 to 2400.According to the findings, a coil with n=6 exhibits the highest Nusselt number (Nu) and the lowest friction factor coefficient (f).

The impact of incorporating CuO nanoparticles into water is considered last but not least. It can be seen that the Nusselt number increased about 33% when CuO-Water nanofluid was used instead of water as the working fluid. However, it is clear that there is little change in the friction factor coefficient. Furthermore, it is clear that the larger volume concentrations lead to faster rates of heat transmission. The correlation for forecasting Nusselt number is then illustrated using the numerical data.

Keywords: Computational Fluid Dynamic, Copper (CUO)-Based Nanofluid, Nanoparticles, Nusselt Number, Lobbed Tubes Section.

I. INTRODUCTION

Curved tubes called "helical coil tube heat exchangers" are used in a wide range of applications, including heat storage, heat recovery processes, air conditioning, and chemical reactors, are mostly employed in industry [1]. Additionally, they are employed in petroleum units as shell and coil heat exchangers and double pipe heat exchangers to lower the temperature of the lubricating oil for the pumps. Centrifugal force is produced in this type of heat exchanger when fluid flows through curved tubes. The centrifugal force causes a secondary flow, which significantly affects the behavior of the primary flow.In curved tubes, secondary flow is a more complicated phenomena than it is in straight tubes. Additionally, for the same flow rate and tube length, the pressure drop for flow in a curved tube is greater than that of a straight tube. Pressure decrease and heat transfer rate are the two main effects of this phenomena. Numerous research has been conducted to improve the effectiveness of helical coil heat exchangers on the basis of earlier studies

II. LITERATURE REVIEW

Experimental research on the improvement of heat transport was done by Jamshidi et al. heat exchanger with helical coils and a casing. They looked at geometrical factors like coil pitch and diameter as well as flow characteristics. Water flowing in a laminar regime served as the working fluid in every experiment. The impact of flow and geometrical factors on forced convection in helical coils was experimentally examined by Maowed [6].

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 presents the 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.

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

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.

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.

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.

III. GEOMETRY SETUP AND MODELLING

The geometry for doing simulation analysis is borrowed from **Mohamad Omidi, Mousa Farhadi, et al. (2022)**. Fig. 5.1 shows a schematic representation of the Helical tube and its computational domain. A helical tube is used to introduce input fluid into the computational environment. The primary goal of the current paper is to examine how heat transmission and pressure drop in helical coils are impacted by lobed cross sections.

Additionally, the tube diameter, coil diameter, and pitch of the helical coil under consideration are 12, 110, and 21.4 mm, respectively. The velocity inlet, pressure outlet, and wall make up the three components that make up the boundary condition of the current coil. The temperature of the inflow fluid is (27 °C), and its axial velocity corresponds to certain Reynolds values. Zero fluid velocity on the wall indicates a no-slip boundary condition, and the fluid's temperature is constant at (100 °C). The pressure outlet value has also been taken into consideration as zero.

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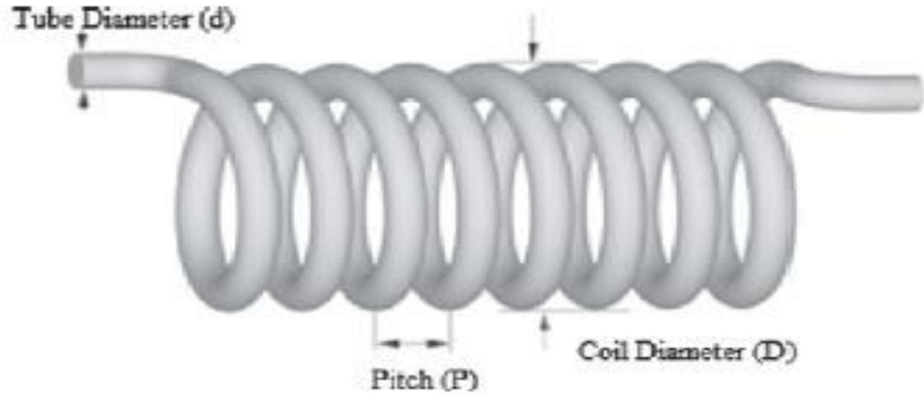

Figure 1. Geometry model of helical tube section

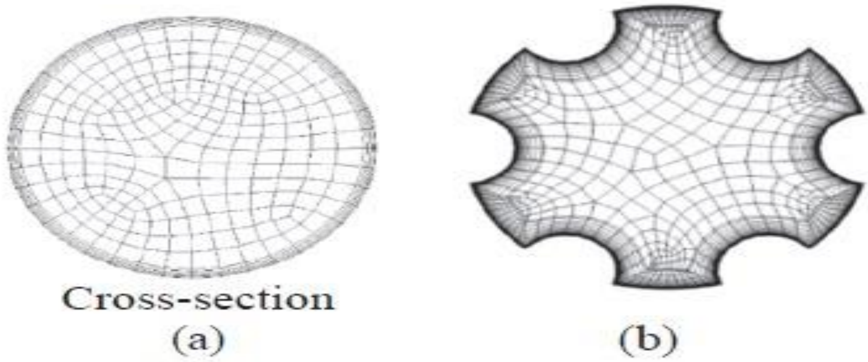

Figure 2. (a) circular cross section (b) lobed cross sections.

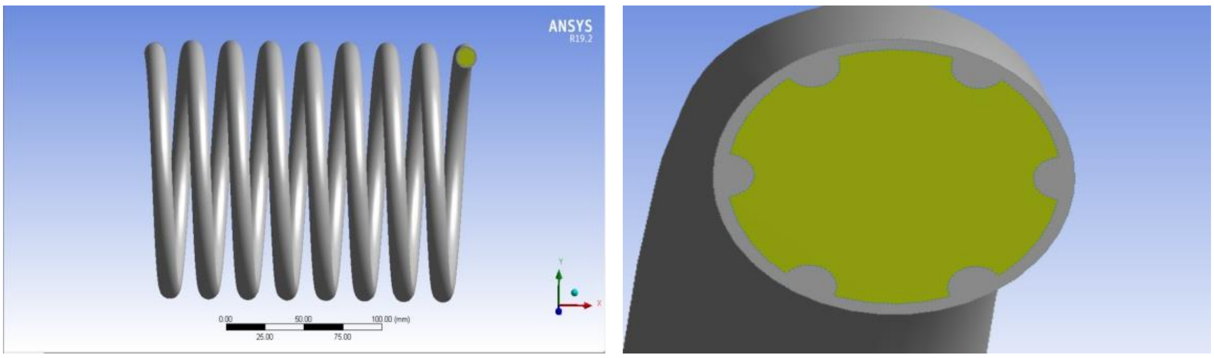

Figure 3. Lobbed section (n=6) in helical tube.

The ANSYS FLUENT R 19.2 pre-processor stage resulted in the construction of a three-dimensional discretized model. The programmed ANSYS creates a coarse mesh, despite the fact that grid types and simulation results are connected. The structure as a whole is discrete in the final volume due to this need. Mesh is made up of ICEM Tetrahedral cells of unit size with triangular frontier faces. In this analysis, a medium fluid curvature is utilized with a mesh metric

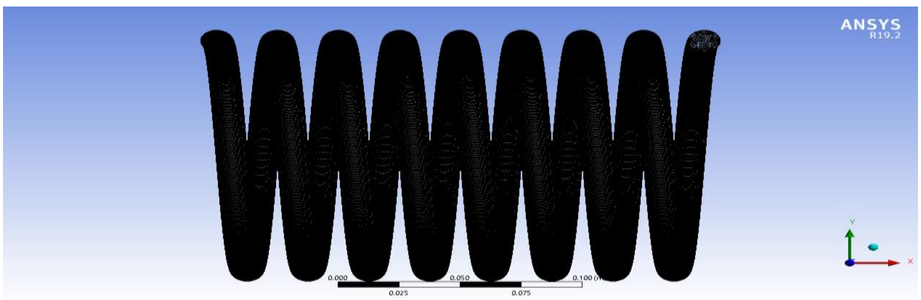

Figure 4. Meshing of helical pipe structure.

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

The Fluent 19.1 was used to calculate computationally. In research, the approach used to differentiate the governing equations was a finite element. A standard k-epsilon equation was used with flow and energy equations to solve turbulence. Which implies the following hypotheses:

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) & Cu nanoparticles

Input Parameters	Symbols	Units	Al_2O_3	Cu
Specific heat capacity	c_p	J/kg-K	780	383.1
Density	ρ	(kg/m^3)	3590	8930
Thermal conductivity	k	W/m-K	46	386
Viscosity	μ	Kg/m.s	0	-

Table 3. Thermodynamic Properties of copper (CuO)-based nanofluid
(1%, 2%, 3% nanoparticle) nanoparticles.

Input Parameters	Symbols	Units	Cu-Water (1%)	Cu-Water (2%)	Cu-Water (3%)
Specific heat capacity	c_p	J/kg-K	4150.9	4112.8	4074.8
Density	ρ	(kg/m^3)	1061	1140.7	1220.4
Thermal conductivity	k	W/m-K	0.662	0.682	0.702
Viscosity	μ	Kg/m.s	0.00061	0.00062	0.00064

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.

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 4. Details of boundary conditions.

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

Table 5. Inlet Velocity for different Reynold number of copper (CuO) based Nanofluid and Base fluid (water)

Reynold number	Velocity m/s for water	Velocity m/s for 3% Cu nanoparticles	Velocity m/s for 2% Cu nanoparticles	Velocity m/s for 1% Cu nanoparticles
1200	0.0365	0.0315	0.0329	0.0346
1600	0.0482	0.04208	0.0439	0.0461
2000	0.0609	0.0526	0.0549	0.0576
2400	0.0731	0.06312	0.0659	0.0692

IV. RESULTS AND DISCUSSIONS

This section is aimed at evaluating the helical tube sections thermal performance using nanofluids. The variations in the Heat transfer rate and Thermal conductance are measured at different Reynold's number in order to research the performance of the heat exchanger using nanofluids subject to flow.

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,

$$\mathbf{Re} = \frac{\boldsymbol{\rho} \mathbf{VD}}{\boldsymbol{\mu}}$$

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

$$\dot{\mathbf{m}} = \dot{}\boldsymbol{\rho}\mathbf{AV}$$

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

$$\mathbf{q_h} = \dot{\mathbf{m}}_\mathbf{h} \mathbf{c_{ph}} (\mathbf{T_{hi}} - \mathbf{T_{ho}})$$

Where $\dot{\mathbf{m}}_\mathbf{h}$ is the mass flow rate of hot fluid, $\mathbf{c_{ph}}$ is the specific heat of hot fluid, $\mathbf{T_{hi}}$ and $\mathbf{T_{ho}}$ 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:

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

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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.
Uis the overall heat transfer coefficient.

4.2. Validation of numerical computations

To validate the accuracy of developed numerical approach, comparison was made with the work reported in **Mohamad Omidi, Mousa Farhadi, et al. (2022).** The Helical tube sections geometry that used for validation of numerical computations was considered as same. Here we are using Al_2O_3-water as a base fluid & find out the value of Nusselt number with the help of CFD. After that we are using water (Base fluid) + Copper (CuO)-based nanofluid with different concentration (1%, 2%, 3% of copper nano particles with base fluid) & find out the value of Nusselt number.

➢ **For Re = 2400**

In the case first, we are using copper (CuO) based nanofluid (3% copper nano particle) in the base fluid (water) & find out the Nusselt number.

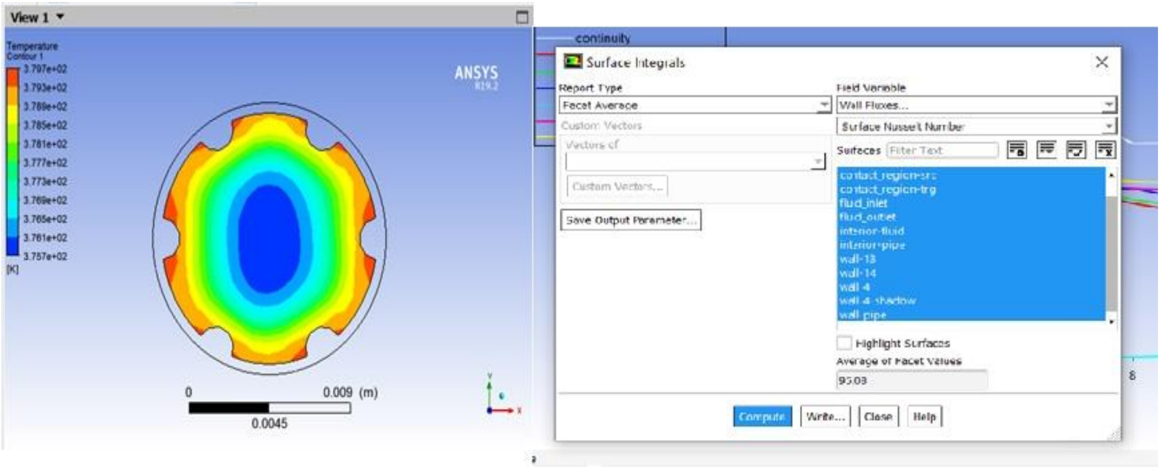

Figure 5. Temperature contour &Nusselt no. at Re = 2400 for Helical tube sections using copper (CuO)-based nanofluid (3% of copper nano particles).

In the case second, we are using copper (CuO) based nanofluid (2% copper nano particle) in the base fluid (water)

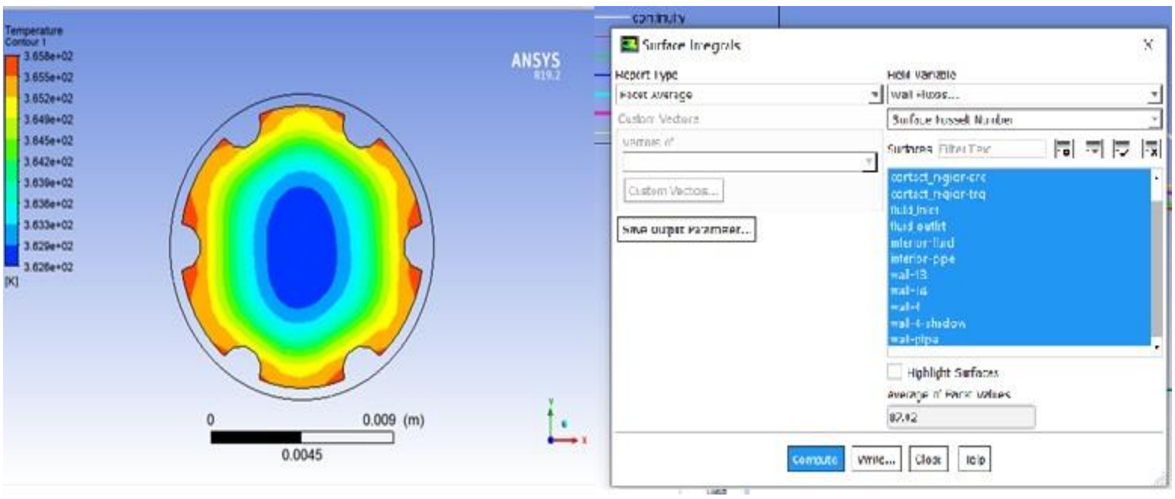

Figure 6. Temperature contour & Nusselt no. at Re = 2400 for Helical tube sections using copper (CuO)-based nanofluid (2% of copper nano particles).

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➢ **For Re = 2000**

In the case first, we are using copper (CuO) based nanofluid (3% copper nano particle) in the base fluid (water) & find out the Nusselt number.

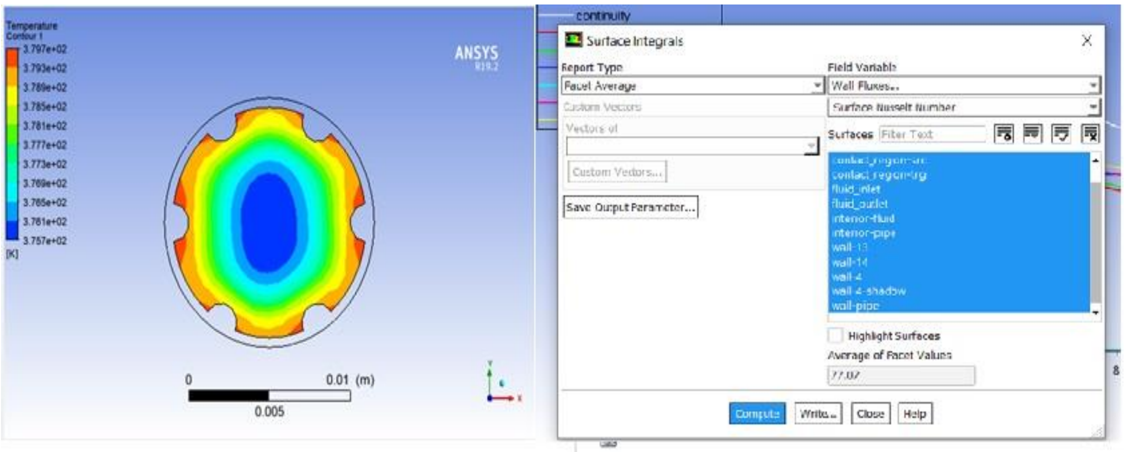

Figure 7. Temperature contour &Nusselt no. at Re = 2000 for Helical tube sections using copper (CuO)-based nanofluid (3% of copper nano particles).

In the case Second, we are using copper (CuO) based nanofluid (2% copper nano particle) in the base fluid (water).

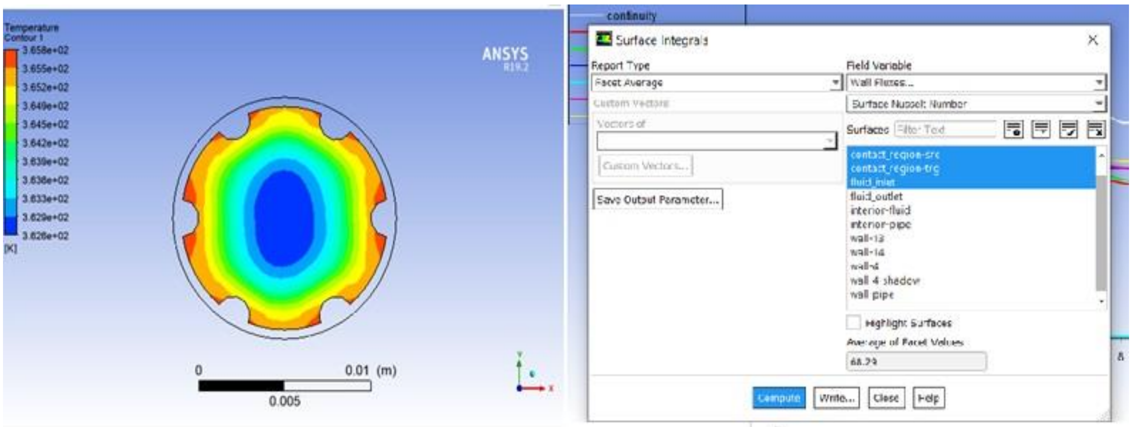

Figure 8. Temperature contour &Nusselt no. at Re = 2000 for Helical tube sections using copper (CuO)-based nanofluid (2% of copper nano particles).

➢ **For Re = 1600**

In the case first, we are using copper (CuO) based nanofluid (3% copper nano particle) in the base fluid (water) & find out the Nusselt number.

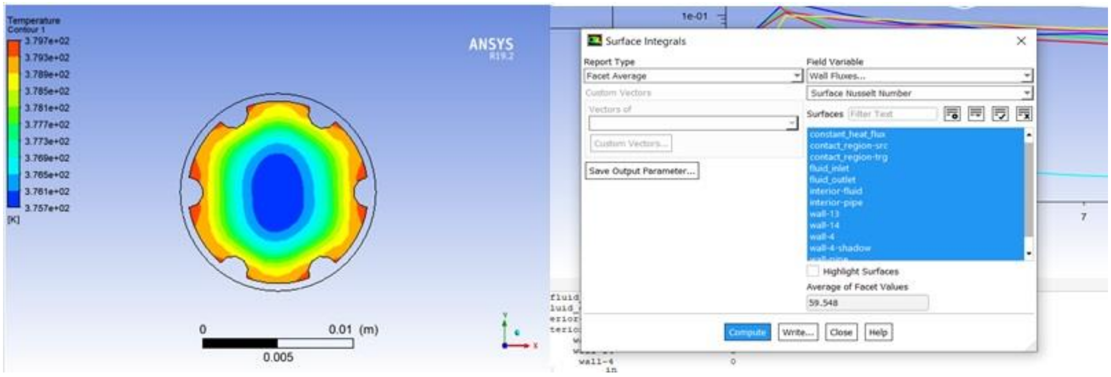

Figure 9. Temperature contour & Nusselt no. at Re = 1600 for Helical tube sections using copper (CuO)-based nanofluid (3% of copper nano particles).

In the case second, we are using copper (CuO) based nanofluid (2% copper nano particle) in the base fluid (water).

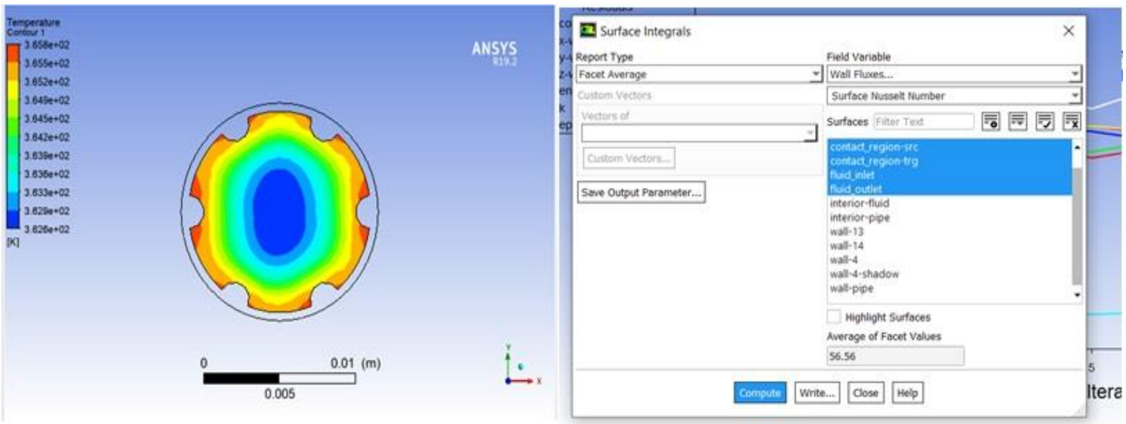

Figure 10. Temperature contour & Nusselt no at Re = 1600 for Helical tube sections using copper (CuO)-based nanofluid (2% of copper nano particles).

➢ **For Re = 1200**

In the case first, we are using copper (CuO) based nanofluid (3% copper nano particle) in the base fluid (water) & find out the Nusselt number.

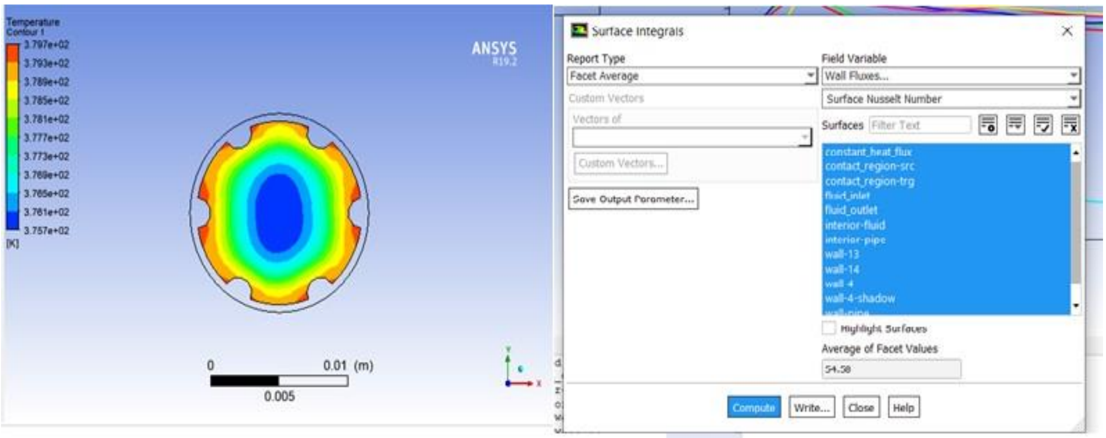

Figure 11. Temperature contour & Nusselt no at Re = 1200 for Helical tube sections using copper (CuO)-based nanofluid (3% of copper nano particles).

In the case second, we are using copper (CuO) based nanofluid (2% copper nano particle) in the base fluid (water).

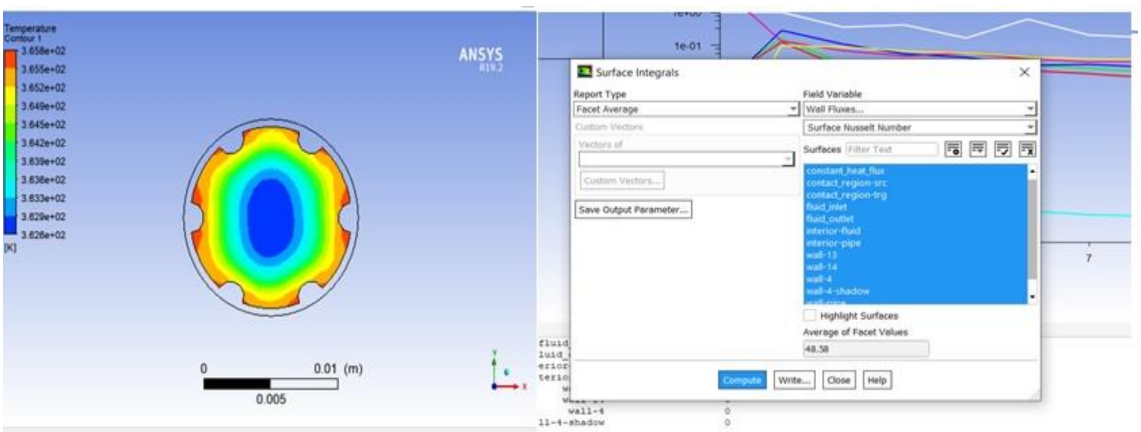

Figure 12. Temperature contour & Nusselt no at Re = 1200 for Helical tube sections using copper (CuO)-based nanofluid (2% of copper nano particles).

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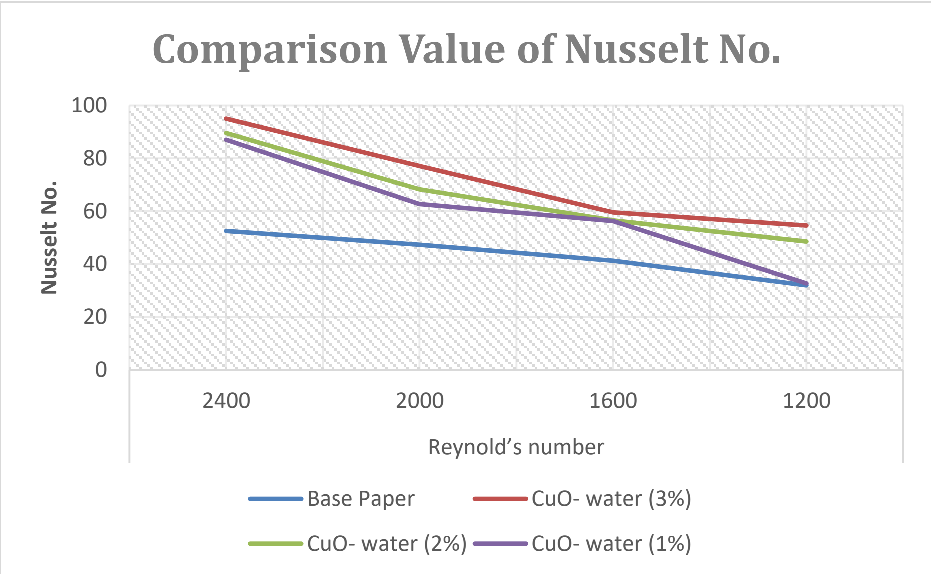
It is evident from the numerical findings and experimental evidence that the Nusselt number's changing tendencies are qualitatively consistent. As a result, we use a volume concentration of 1%, 2%, and 3% analyze the impact of the suspension of copper (CuO)-based nanofluid particles in the base fluid to promote thermal augmentation. The boundary conditions used in the study of the corrugated tube section were the same. Chapter 5 makes reference to the thermal characteristics of nanofluids for determining the impact of various nanoparticles on the Nusselt number.

Table 6. Shows the values of Nusselt number calculated from the CFD modeling using (Al_2O_3)-water as a base fluid compared with the values obtained by using the using Copper (CuO)based nanofluid (1%, 2% and 3% of copper nano particles) in helical tube Section.

S.No.	Reynold's number	Nusselt Number			
		Base Paper	CuO- water (3%)	CuO- water (2%)	CuO- water (1%)
1.	2400	52.568	95.08	89.54	87.02
2.	2000	47.301	77.07	68.29	62.65
3.	1600	41.304	59.548	56.56	56.295
4.	1200	32.0	54.58	48.58	32.65



V. CONCLUSION

The helical coil also made use of Copper (CuO)based nanofluid. The results of several of the aforementioned simulations were made clearer by displaying the swirl behavior caused by velocity and temperature distributions, which is the primary feature in tubes with lobed cross sections. The simulations produced the following findings, which were:

- As per the base paper, in comparison to the other lobed cross sections, it was discovered that the helical coil with n=6 had the highest Nusselt number and the lowest friction factor.
- Copper (CuO)-based nanofluid has a Nusselt number that is approximately 33.25% greater than base fluid utilized as alumina (Al_2O_3)-based nanofluid.
- The Nusselt number of the CuO nanofluid was found to be greater than that of the base fluid (alumina (Al_2O_3)-based nanofluid) and to rise along with the nanofluid volume concentration.
- We looked at the impact of coil pitch and coil height. The fully formed flow after a few coil rotations was seen to have no substantial impact on the flow characteristics.

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