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Heat Transfer and Thermal Performance Analysis of Different Al_2O_3 Nanoparticle Concentrations in Double Tube Heat Exchanger with Helical Insert

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ABSTRACT

The materials utilized, the energy produced, and cost savings are directly impacted by increasing heat exchanger thermal efficiency. Heat efficiency and the cost-effectiveness of design and operation in applications requiring thermal transfer processes will both be significantly improved by improvements in heat exchange. Double tube heat exchangers are best suited for situations involving high temperatures and high pressures due to their narrow diameters. Despite being cheap, they have a rather high distribution rate to other forms. To meet the required heat transfer rate within the confines of the heat exchanger's stipulated design and lifespan while maintaining an affordable pumping capacity, many solutions were developed. Helix inserts are one of the most widely used and effective methods for improving heat exchangers. An ANSYS CFX tool for twin tube heat exchangers with an aluminum helical insert with a 15 mm pitch will be the subject of this article's performance analysis.

Here we are using the 15 mm helical insert made of aluminum and applying different Al_2O_3 nanoparticle concentration than observed the average outlet temperature.

Keywords: *Computational fluid dynamic, alumina (Al_2O_3)-based nanofluid, nanoparticles, helical insert, average outlet temperature.*

I. INTRODUCTION

Heat transfer is also defined as a system that transfers energy and entropy from one location to another, and it has a variety of applications including heating, cooling, power plant condensers, and steam generators, among others. Heat transfer is vital in increasing thermal efficiency and power generation since waste saves energy. The process of increasing the efficiency of heat exchangers is known as heat transfer enhancements. These approaches are divided into two types: active and passive, and they are primarily used to increase the efficiency of heat exchangers or any system that uses tubes for heat transmission. Inactive heat transfer enhancement requires additional external energy to enter the process, such as well stirring mechanical aid, jet impingement, surface vibrations, spray, and electrostatic fields, whereas passive does not require an external power source, which is why it has been used more than active because it reduces power consumption, but active cooling systems are much better when it comes to better cooling effect. As compared to straight tubes, these active and passive techniques improve heat transfer rate; several research worldwide have proved that this tubbed/curved tube is used in a number of applications.

It is common knowledge that turbulent flow has a greater rate of heat exchange and pumping power than laminar flow, the former of which is desired and the latter undesired. So, the researchers had the notion to introduce equipment into the laminar flow and induce local turbulence. The concept was a huge hit and is still widely used in the market. This apparatus is known as a turbulator, and up to this point, numerous turbulator types have been developed and their performance has been experimentally and statistically examined. Additionally, nanostructures have been designed for usage in order to improve the effectiveness of engineering systems.

II. LITERATURE REVIEW

Alumina-based nanofluids are essential because they may be employed in several heat transfer and other applications. In order to create stable nanofluids, research has focused on altering the surface of the particles, utilizing a variety of surfactants, and controlling the pH and temperature of different nanofluids. The literature that is presently accessible does not provide an explanation for why the thermal conductivity of Al_2O_3 nanofluid increased unevenly in many studies.

In order to outline future technical demands and research initiatives, this report provides current experimental findings on convective heat transfer for alumina-based nanofluid eutectics.

S. Padmanabhan, Obulareddy Yuvatejeswar et al. (2022), Enhancing the thermal efficiency of heat exchangers directly impacts the materials utilized, the energy produced, and cost savings. In applications requiring thermal transfer processes, improving heat exchange will also significantly enhance heat efficiency and the cost-effectiveness of design and operation. Double tube heat exchangers are best suited for high temperature and high-pressure applications due to their narrow diameters. Despite being cheap, they distribute to other forms in a rather large number. Numerous methods were developed to accomplish the required heat transfer rate at an affordable pumping capacity within the confines of the heat exchanger's stated design and lifespan. Helical inserts are one of the most well-liked and effective ways to enhance heat exchangers. inserts with helices.

Inderjeet Singh, Sachit Vardhan et al. (2021) An Evacuated Tube Collector solar air heater with Helical Coiled Inserts (ETC-HI) has been evaluated for performance in this paper. At various mass flow rates between 0.003-0.015 kg/s, the performance was concurrently experimentally tested using a simple ETC solar air heater. Under normal and reversed system operation, the impact of the helically coiled evacuated tube on the outlet temperature, heat gain, thermal efficiency, and pressure losses has been investigated. While the average air temperature was measured at 95.5 °C and corresponded to a mass flow rate of 0.003 kg/s, the highest air temperature at the exit for ETC-HI was reported to be 112.6 °C. The ETC-HI solar air heater's highest thermal efficiency of 70.9% was attained at a mass flow rate of 0.015 kg/s, compared to the standard ETC solar air heater's thermal efficiency of 64.5%. ETC-HI's effective efficiency was higher than simple ETC's without suffering any financial consequences, despite the 2.45 times increase in pressure drop. It has been shown that the ETC-HI solar air heater is superior than the basic ETC solar air heater and produces greater air temperatures as a result of enhanced thermal and effective efficiency.

N. Nwokolo, P. Mukumba et al. (2020) For heat recovery objectives, heat exchangers are often utilized in industrial applications like gasification systems. A large amount of thermal energy is wasted during syngas cooling in a biomass gasification system located in Melani village in South Africa's Eastern Cape. As a result, a heat exchanger was built and put into the gasification system for heat recovery. The purpose of this research is to assess the heat exchanger's performance in counterflow and parallel flow configurations under a variety of operating situations. The downdraft gasifier system's operating wood consumption rate was 180 kg/h, hence the experimental examination was conducted on a twin pipe heat exchanger. At the syngas' departure point from the gasifier, a heat exchanger was erected, with water acting as the cooling medium.

S. Padmanabhan a, S. Thiagarajan et al. (2020) Many studies on the fin's shape and material have been conducted recently to improve its use. Rectangular, triangular, and trapezoidal fin configurations were favored in many situations where fins are utilized to speed up the rate of heat transfer from the system. The enlarged surfaces that are purposefully placed in a location from which heat is to be removed are known as fins. The amount of conduction, convection, or radiation a component has affects how much heat it emits. Heat transmission rises when the ground surface area, thermal convection coefficient, and the temperature differential between the substance and the atmosphere all rise

III. GEOMETRY SETUP AND MODELLING

The heat exchanger and its computational domain are seen schematically in Fig. 1. The Double Tube Heat exchanger (DTHE) is one of the simplest forms of heat exchange in the piping system. It consists of mechanical lock isolated tubing. The main goal of the development of geometry is to create a solid that defines a field of fluid flow. This is the first step of the research process. In dimensions and geometry descriptions, current models were collected. Table 1 will model the heat exchanger to have helical dimensional inserts and then converted to a step file for further CFD study. Discretization is the process of converting a partial differential equation into a set of algebraic equations for discrete locations. ANSYS workbench 22 R1 and a grid system are used for discretization.

Table 1. STHE geometry design of casing heat exchanger

S.N.	parameters	Value & units (m)
1	Diameter of Inner Pipe	15 mm
2	Diameter of outer Pipe	30 mm
3	Length of a Heat exchanger	100 mm
4	Wire diameter of Helical Inserts	1.5 mm
5	Pitch distance of Helical Inserts	15 mm

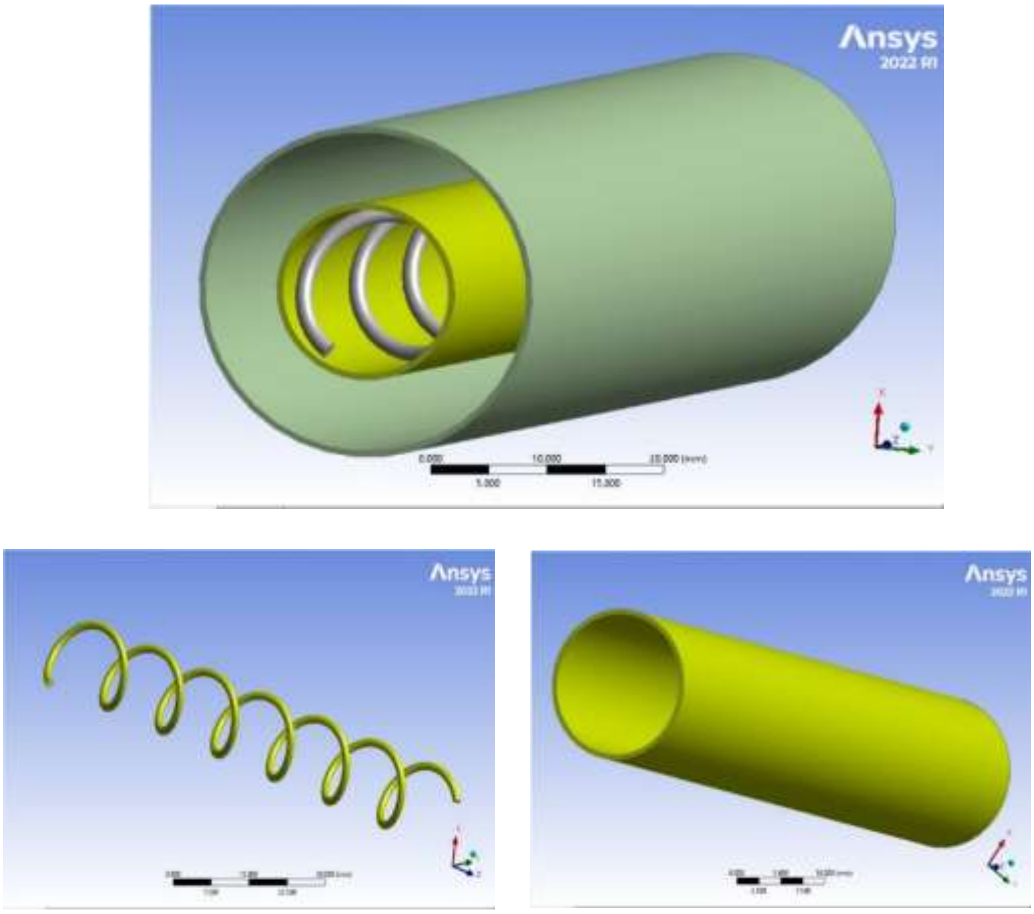

Figure 1. Computational model of heat exchanger.

The pre-processor stage of ANSYS FLUENT 22 R1 produced a three-dimensional discretized model. Despite the fact that grid types and simulation outcomes are related, ANSYS creates a coarse mesh when it is configured. Due of this requirement, the overall structure is discontinuous in the final volume. Mesh is made up of ICEM Tetrahedral cells that are unit-sized and have triangular border faces. This inquiry employs a medium fluid curvature as well as a mesh metric.

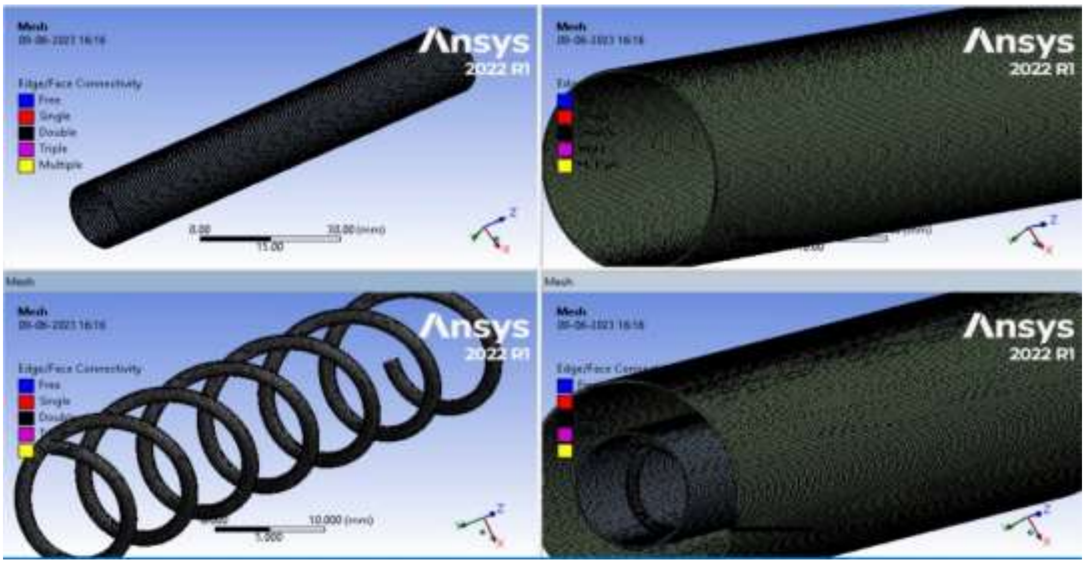

Figure 2. Meshing of Spiral tube Model.

Table 2. Meshing detail of model

S. No.	*Parameters*	*Value*
1	*Curvature*	*On*
2	*Smooth*	*Medium*
3	*Number of nodes*	*7511786*
4	*Number of elements*	*2670531*
5	*Mesh metric*	*None*
6	*Meshing type*	*Quadrilateral*

The Fluent 22 was used for computation. A finite element approach was used in investigations to discriminate between the governing equations. The researchers adopted a less difficult strategy for this convective component, and they combined pressure and velocity estimates using the second order upwind method. 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 transfers 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.

Table 3. Thermodynamic Properties of alumina (Al_2O_3)-based nanofluid (1%, 2%, 3% & 4% nanoparticle).

Input Parameters	*Symbols*	*Units*	*(Al_2O_3)-based nanofluid (1% nanoparticle)*	*(Al_2O_3)-based nanofluid (2% nanoparticle)*	*(Al_2O_3)-based nanofluid (3% nanoparticle)*	*(Al_2O_3)-based nanofluid (4% nanoparticle)*
Specific heat capacity	*cp*	*J/kg-K*	*4061.8966*	*1050.236*	*1076.254*	*1102.272*
Density	*ρ*	*(kg/m3)*	*1024.218*	*3947.744*	*3839.1106*	*3735.6056*
Thermal conductivity	*k*	*W/m-K*	*0.685862*	*0.7668688*	*0.843021037*	*0.91438896*
Viscosity	*μ*	*Kg/m.s*	*0.001132*	*0.0013085*	*0.001553838*	*0.001916924*

When it comes to improving heat transmission, the provision of inserts for heat exchanger tubes has become considerably more prevalent. As a result, a rectangular cross-section helical insert in a straight pipe in the heat exchanger tube is investigated. The investigation is carried out with insert heights and widths of 15 mm pitch held constant. Helical inserts are employed in this research to increase turbulence, resulting in improved heat transfer efficiency. The k- e turbulence model would be used to examine the heat transfer and flow characteristics caused by inserts in the fluid.

Table 4. Details of boundary conditions.

Domain Specifications	***Data***
Flow type	*Counterflow*
Fluid	*Water*
Fluid domain	*Double tube*
Solid domain	*Turbulator and tube surface*
Turbulator material	*Aluminum*
Tube material	*Copper*
Heat transfer Model	*Thermal Energy*
Inlet Boundary Conditions	*Cold fluid 28 ^{0}C with 0.2 m/s*
Inlet Boundary Conditions	*Hot Fluid 90 ^{0}C with 0.2 m/s*

IV. RESULTS AND DISCUSSIONS

The purpose of this section is to evaluate the thermal performance of the spiral tube sections utilizing nanofluids. Variations in heat transfer rate and thermal conductance are studied at various mass flow rates to investigate the performance of a heat exchanger utilizing nanofluids (1%, 2%, 3% and 4% 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 **S. Padmanabhan et al. (2020).**

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

The Reynolds number is given by,

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

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

$$\dot{m} = \rho A V$$

Where, ρ 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:

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

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. Effect of suspension of alumina (Al_2O_3)-based nanofluid (1%, 2%,3% and 4% of alumina nano particles)

It is evident from the numerical findings and experimental evidence that the Average fluid temperature changing tendencies are qualitatively consistent. As a result, we use a volume concentration of 1%,2%,3% and 4% to analyze the impact of the suspension of alumina (Al_2O_3)-based nanofluid particles in the cold fluid to promote thermal augmentation. The boundary conditions used in the study of the helical insert heat exchanger were the same. Chapter 5 makes reference to the thermal characteristics of nanofluids for determining the impact of various nanoparticles on the Average outlet temperature, pressure and heat rate.

- **Use 1% of alumina (Al_2O_3)-based nanofluid particles**

Hare, we are using the 1% alumina (Al_2O_3)-based nanoparticles with 0.2 m/s flow velocity & find out the result (contour) of outlet temperature of hot fluid & cold fluid, temperature of adjacent layer of copper shell tube and velocity with the help of CFD.

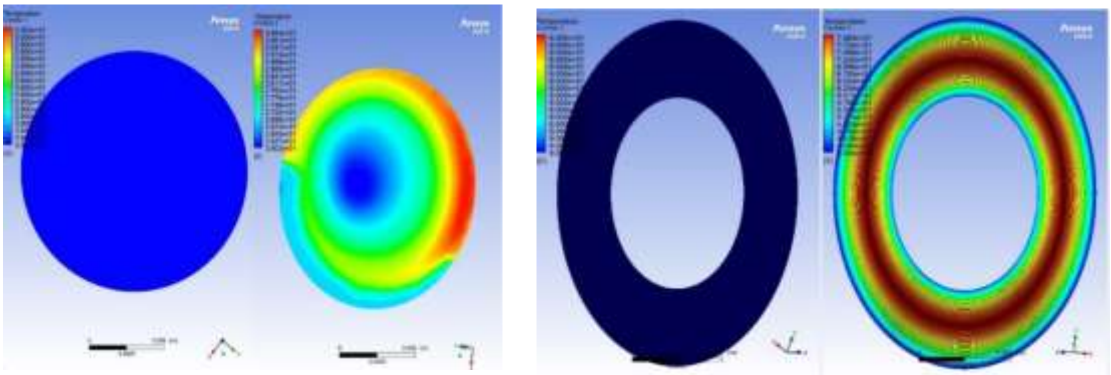

Figure 3. Temperature contour of inlet & outlet of cold fluid & hot fluid with 1% (Al_2O_3) nanoparticle.

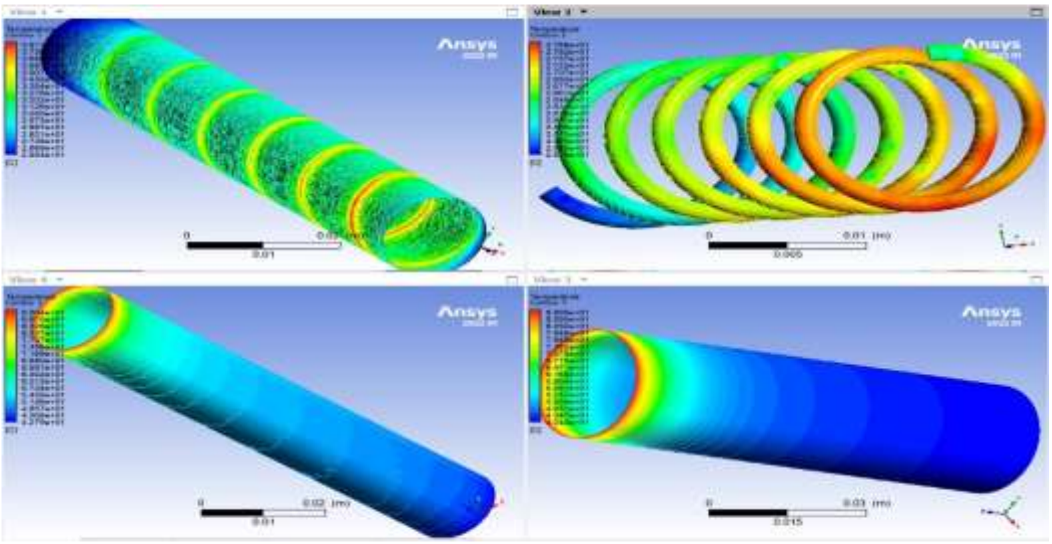

Figure 4. Temperature contour of various adjacent layer of inner & outer shell of copper tube & helical insert with 1% of nanoparticle.

- **Use 2% of alumina (Al_2O_3)-based nanofluid particles**

In case Second, we are utilizing 2% alumina (Al2O3)-based nanoparticles with a flow velocity of 0.2 m/s and using CFD to determine the outcome (contour) of the outlet temperature of hot and cold fluid, temperature of the neighboring layer of copper shell tube, and velocity.

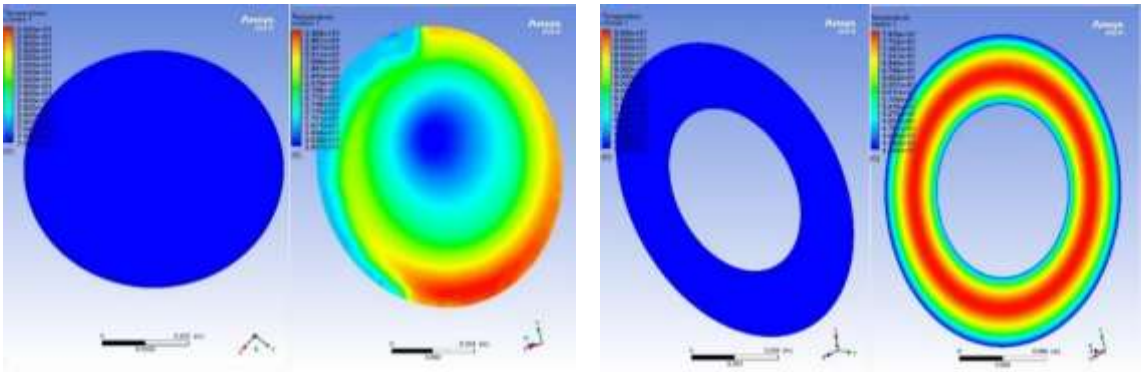

Figure 5. Temperature contour of inlet & outlet of cold fluid & hot fluid with 2% (Al_2O_3) nanoparticle.

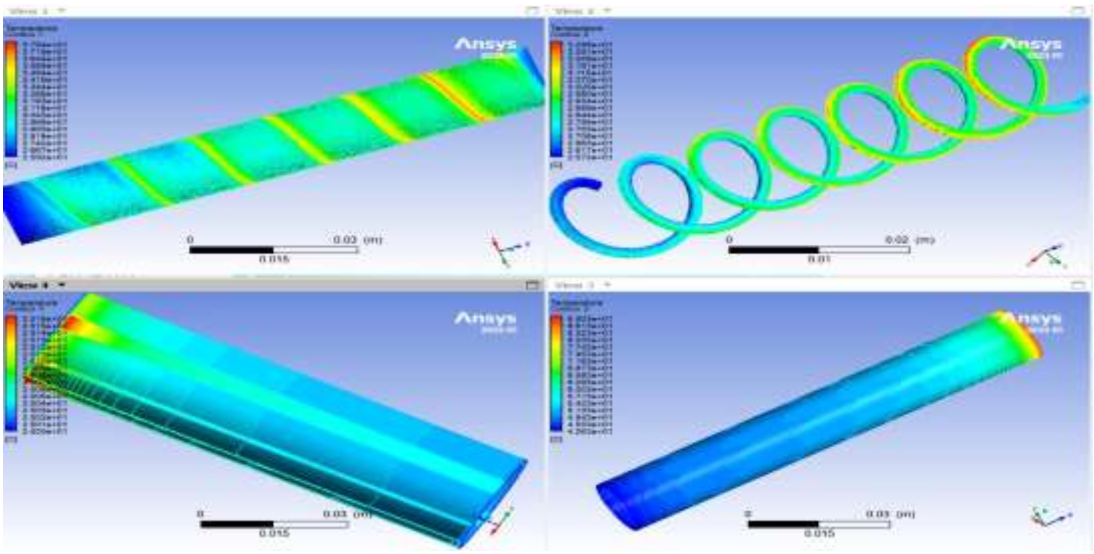

Figure 6. Temperature contour of various adjacent layer of inner & outer shell of copper tube & helical insert with 2% of nanoparticle.

- **Use 3% of alumina (Al_2O_3)-based nanofluid particles**

In the third scenario, we're employing 3% alumina (Al_2O_3)-based nanoparticles with a flow velocity of 0.2 m/s and CFD to figure out the result (contour) of the outlet temperature of hot and cold fluid, temperature of the neighboring layer of copper shell tube, and velocity.

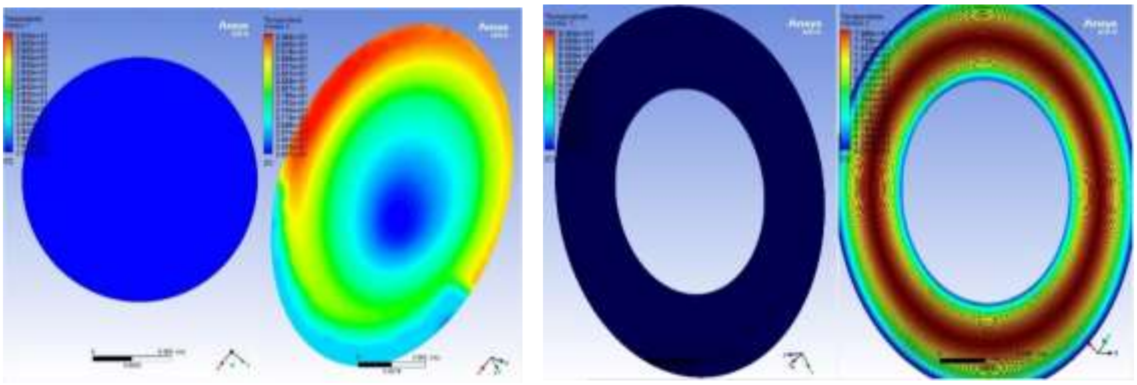

Figure 7. Temperature contour of inlet & outlet of cold fluid & hot fluid with 3% (Al_2O_3) nanoparticle.

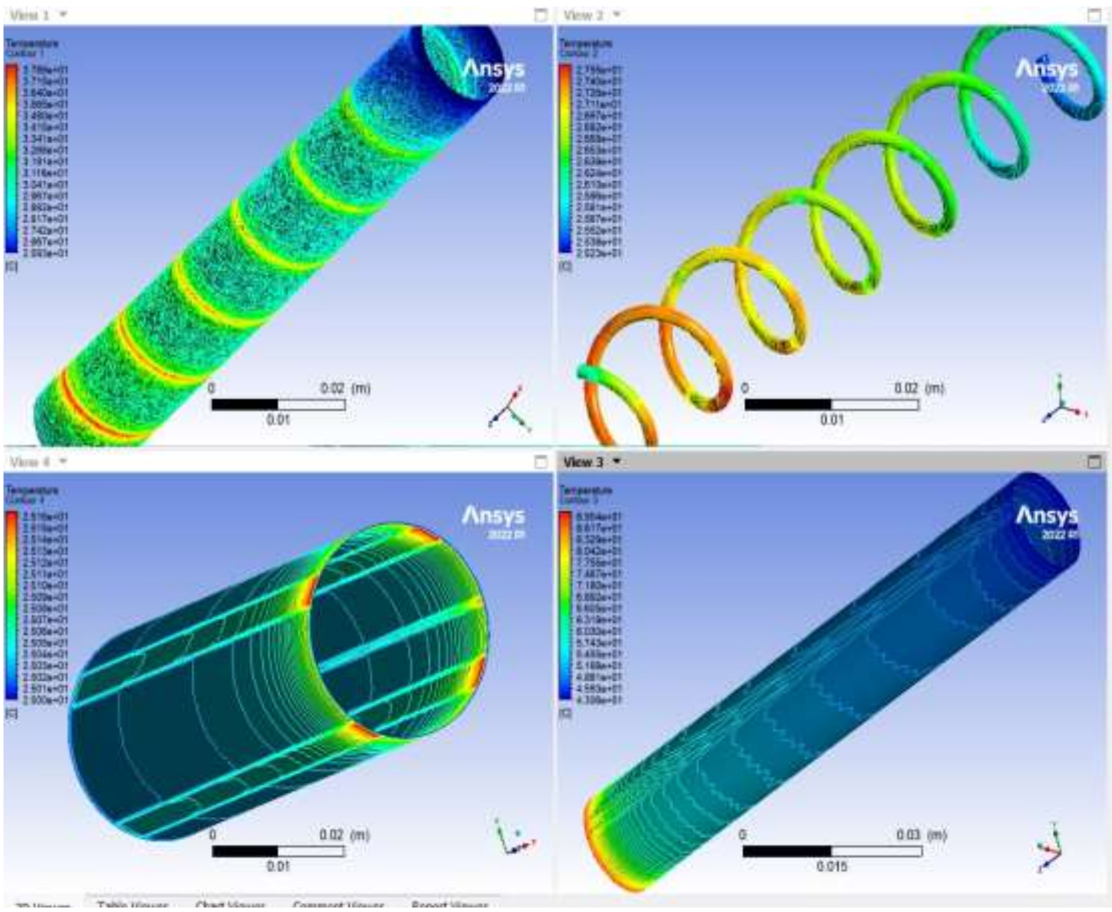

Figure 8. Temperature contour of various adjacent layer of inner & outer shell of copper tube & helical insert with 3% of nanoparticle.

- **Use 4% of alumina (Al_2O_3)-based nanofluid particles**

In the fourth case, we use 4% alumina (Al_2O_3)-based nanoparticles with a flow velocity of 0.2 m/s and CFD to calculate the outcome (contour) of the outlet temperature of hot and cold fluid, temperature of the neighboring layer of copper shell tube, and velocity.

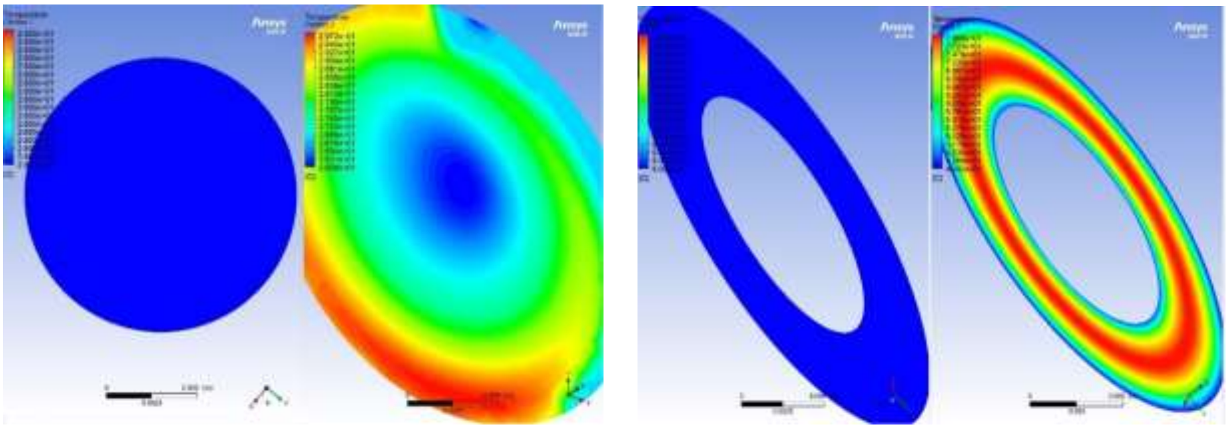

Figure 9. Temperature contour of inlet & outlet of cold fluid & hot fluid with 4% (Al_2O_3) nanoparticle.

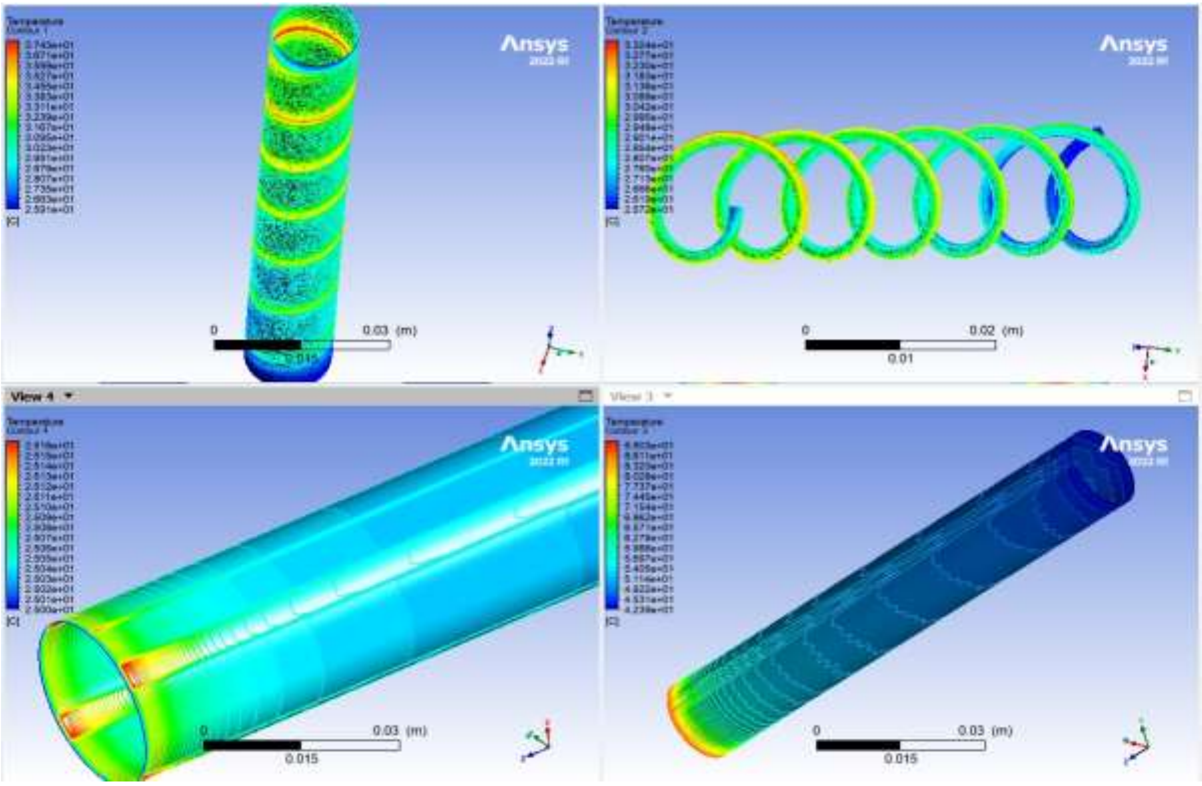

Figure 10. Temperature contour of various adjacent layer of inner & outer shell of copper tube & helical insert with 4% of nanoparticle.

4.3 Comparison the various temperature value of alumina (Al_2O_3)-based nanofluid flow at various volume rate

After calculate the value of Average temperature of cold fluid, Temperature result of various adjacent layer of inner & outer shell of copper tube & helical insert with the variation of nanoparticle. After getting the result we are comparing all of four cases.

Table 5. Comparison the values of Average outlet temperature& various adjacent layer temperature result using alumina (Al_2O_3)-based nanofluid with 1%, 2%, 3% and 4% nanoparticle and water as a fluid.

S.N.	Different zone of heat exchanger	1% (Al_2O_3)-based nanoparticle	2% (Al_2O_3)-based nanoparticle	3% (Al_2O_3)-based nanoparticle	4% (Al_2O_3)-based nanoparticle
1	Cold fluid	27.935	27.960	27.845	27.900
2	Hot fluid	60.120	60.115	60.150	60.055
3	Inner shell layer temperature (cold fluid)	32.020	31.93.0	31.910	31.67
4	Helical insert temperature	26.465	29.340	26.390	29.480
5	Inner section of outer shell (hot fluid)	25.08	25.08	25.08	25.08
6	Outer section of inner shell	64.715	65.83	66.05	65.71

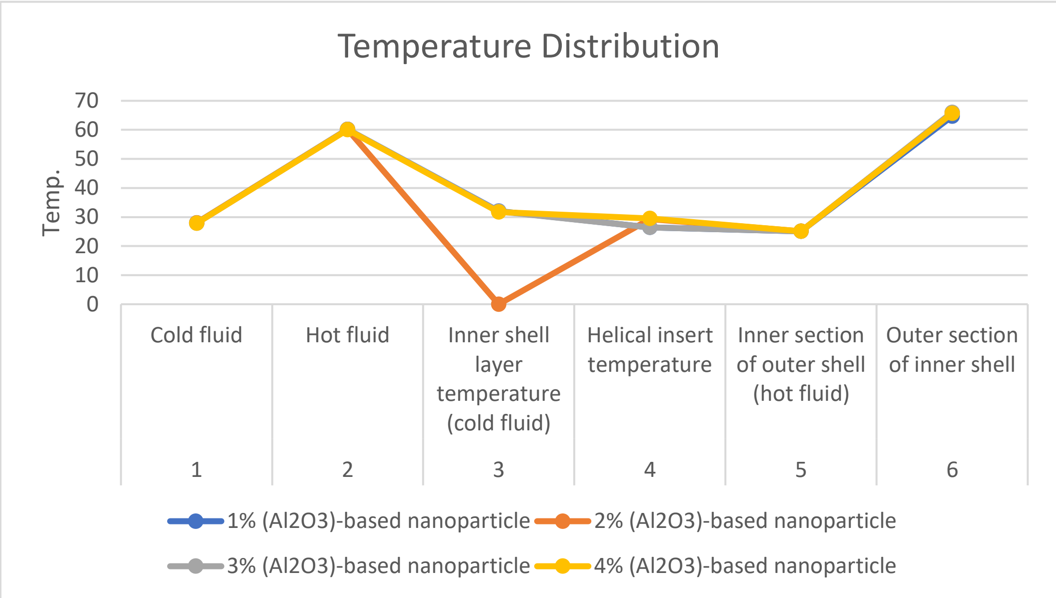

Figure 11. Comparison of different temperature zone of heat exchanger at various concentration of Al_2O_3 nanoparticle fluid

V. CONCLUSIONS

The numerical analysis on spiral tubes is presented in this work, where the thermal and flow properties are resolved using ANSYS Fluent. Following the experimental examination, the following findings may be drawn from the current numerical analytical work:

- The greatest average hot fluid temperature (60.150 ^{0}C) and the lowest average cold fluid temperature (27.845 ^{0}C) are for 3% Al_2O_3 nano fluid. When using water as a base fluid, the average cold fluid temperature is 28.165 ^{0}C. The ability of cold fluid to store heat is improved by around 1.15%.
- For all four circumstances, the heat exchanger's inner sections of the and outer sell are almost identical.
- According to the results table, the lowest average hot liquid temperature is 60.055 ^{0}C for 4% Al_2O_3 nanofluid, while the highest average cold liquid temperature is 27.960 ^{0}C for 2% Al_2O_3 nanofluid.

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