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CFD Analysis of the Convective Heat Transmission on an Involute Finned Tube with Different Al_2O_3 Nanoparticle Concentrations.

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ABSTRACT

The main goal of this work is to research and analyse heat transfer via an involute finned duct with various concentrations of nanofluids. Utilizing commercial software, fluent performs dynamics and simulations for fluid flow in a circular duct with involute fins at the beginning of fully developed laminar flow with nanofluids under circumstances of constant wall temperature. For oxides of nanofluid, heat transport behavior's in the duct are examined under conditions of constant wall temperature. From the literature, the thermal characteristics of nanofluid are taken into account. The thermal analysis and velocity calculations between the tube's intake and outflow were performed using the commercial software ANSYS 2019. The entire domain will be discretized into quadratic components and taken into account with the turbulence model using the finite volume approach. Heat convection and turbulence differential equations system. Calculations will be made based on the starting circumstances at the duct's entry to determine the flow, pressure, and temperature at the exit.

Researcher by this research water and Al_2O_3 and Cu nanoparticles with different concentration used as the base fluid, he was able to achieve the highest Nusselt number and heat transfer coefficient with fin is better than without fin. Here we are using the involute fin instead of straight fin and applying different Al_2O_3 nanoparticle concentration than observed the heat transfer coefficient and outlet temperature.

Keywords*: Computational fluid dynamic, alumina (Al_2O_3)-based nanofluid, nanoparticles, Heat transfer coefficient, involute tubes section.*

I. INTRODUCTION

Exchangers are typically used when heat needs to be transferred between two systems. Systems for the transport of heat can take on a variety of shapes depending on where they are placed. In practice, a significant portion of how these devices are sized involves computing heat balances and pressure drops. The goal of improving the thermal performance of these systems and enhancing heat transfer is to comprehend the thermal and hydrodynamic characteristics that give excellent transfer coefficients without significant losses, leading to high thermal efficiency and high heat exchange. It is suggested that configurations be created to balance the maximum energy transfers with the least amount of energy losses. Fins are surfaces that extend from an item to speed up heat transmission to or from the environment by boosting convection, according to the study of heat transfer. The quantity of heat that an object conduct depends on its conduction, convection, and radiation rates. Heat transfer is accelerated by increasing the temperature differential between the object and its surroundings, the convective heat transfer coefficient, or the object's surface area. Sometimes changing the first two alternatives is neither practical or cost-effective. As a result, adding a fin to an object improves its surface area and sometimes solves heat transfer issues economically.

II. LITERATURE REVIEW

Alumina-based nanofluids are essential because they may be used for numerous heat transfer and other applications. The process used to create the bulk of Al_2O_3-based nanofluids involves an ultrasonic vibrator, which becomes unstable with time. As a result, research has concentrated on developing stable nanofluids by modifying the surface of the particles, using a variety of surfactants, and regulating pH and temperature for different nanofluids. The literature that is currently available offers no justification for the uneven gains in thermal conductivity for Al_2O_3 nanofluid that have been reported by various investigations

Srinivasa Rao G.(**2022)**, The major idea of this effort is to study and analyse heat transfer through a straight finned duct with different nanofluids. Dynamics and simulations for fluid flow at the start of fully developed laminar flow with nanofluids in a circular duct with and without fins under constant wall temperature conditions are performed by using fluent commercial software. Heat transfer behaviours of the duct are investigated for constant wall temperature conditions for oxides of nanofluid. The thermal properties of nanofluid are considered from the literature. Commercial software ANSYS 2018 was used to compute the velocity and thermal analysis between the inlet and outlet of the tube.

W. H. Azmi et al. (2016) It was crucial to determine the thermophysical parameters, particularly thermal conductivity and viscosity, in order to assess heat transfer coefficients for either a single phase flow or a two phase flow. Most of the studies and observations of heat transport and thermo-physical characteristics were made with nanoparticles larger than 10 nm. For the purpose of determining the thermal conductivity and viscosity of nanofluids, several studies measured and simulated. The majority of researchers created equations that are valid for their experimental range and allow for the calculation of thermal conductivity and viscosity as functions of temperature, % volume concentration, and occasionally particle size.

Eric Duplain et al. (2009) In the context of steady, laminar, fully-developed forced convection in a straight duct with a circular cross-section using air as the fluid and non-twisted, uninterrupted, longitudinal internal fins made of steel, aluminum, and copper, a computational methodology for optimizing fin shapes is formulated and demonstrated. Finite volume techniques are used to solve the governing equations. Using non-uniform rational B-splines and the control points as design variables, the fins' forms are estimated. The optimization is carried out using a gradient-based methodology. Results for the constant pumping power per unit length maximization of appropriately defined thermal performance are given and discussed.

Hussein A. Mohammed et al. (2007) The local and average heat transfer for hydrodynamically fully formed and thermally developing laminar air flow in a horizontal circular cylinder is studied experimentally using combined (free and forced) convection. An aluminium cylinder with an interior diameter of 30 mm and a heated length of 900 mm (L/D = 30) serves as the test section in the experiment and is subject to a boundary condition requiring a constant wall heat flux. The examination includes the heat flux range of 60 W/m2 to 400 W/m2 and the Reynolds number range of 400 to 1600. Aluminum entry section pipes (calming sections) with the same internal diameter as the test section pipe but different lengths are used to create the fully matured state. Two lengthy soothing parts measuring 180 cm (L/D = 60) and 240 cm (L/D = 80) were incorporated in the entry sections, along with two shorter calming sections measuring 60 cm (L/D = 20) and 120 cm (L/D = 40). We reported the local and average Nusselt number distributions with dimensionless axial distance Z+ as well as the surface temperature distribution along the cylinder surface.

M. M. Aliet al. (2007) Convective heat transmission in the corrugated channels' entry region has been the subject of experiments. Two channel spacings were looked at for a single corrugation angle of 20° using water as the working fluid. The flow rate was adjusted between I50 and Re to 4000. While spanwise vortices were plainly visible at somewhat higher Reynolds numbers, flow visualisation under low-Reynolds-number flow conditions only hinted at their presence. For Re > 1500, the corrugated channels had Nusselt numbers that were around 140% and 240% higher than those of the parallel-plate channel, with corresponding increases in friction factor of 130% and 280%.

David R.Sawyerset al. (1998) Analytical and numerical methods are combined to study the impact of three-dimensional hydrodynamics on the improvement of steady, laminar heat transport in corrugated channels. To prevent unstable flow, Reynolds numbers in the range of 0 to Re 250 are taken into account. As a starting point, two-dimensional sinusoidal corrugations with flow parallel to the corrugations are used. Due to the existence of recirculation zones and greater advection close to each stagnation point, as well as the asymmetry of the flow in the downstream direction, the area-averaged heat transfer coefficient is higher than for flat plates. The corrugations in the three-dimensional instance are sinusoidal and run in two opposite directions.

III. GEOMETRY SETUP AND MODELLING

The geometry for doing simulation analysis is borrowed from research scholar **Srinivasa Rao G.et al. (2022)**. Figure shows a tube with internal fins that has a diameter of D and a length of L. At one end, the fluid enters the flow domain, and at the other, it leaves. The energy equations and the governing equations (2)-D axisymmetric model for a basic tube. The working fluids employed in nanofluids include water and water-based nanofluids, which enter at two distinct temperatures of 40^0C and 55^0C. A recent research found that traditional heat transfer fluids had lower thermal conductivity coefficients. In order to solve the issue, heat transfer fluids are swapped out with nanofluids. Whereas nanofluid is a combination of a base fluid (such as water, oil, etc.) and nanoparticles, which are defined as particles with a size between 1 and 100 nm. It is a concoction of liquid and solid particles (nanoparticles) (base fluid).

Table 1. The parameters of the Straight fin tube& involute fin tube

Parameters	Dimensions (in mm) (Straight fin)	Dimensions (in mm) (involute fin)
Length of tube	250	250
Outer Diameter	12.25	12.25
Inner Diameter	10.25	10.25
Fin Length	250	250
Fin Width	2	-
Fin Height	6	6
No. of Fins	8	8
Fin Width (Bottom)	-	4
Fin Width (Top)	-	2

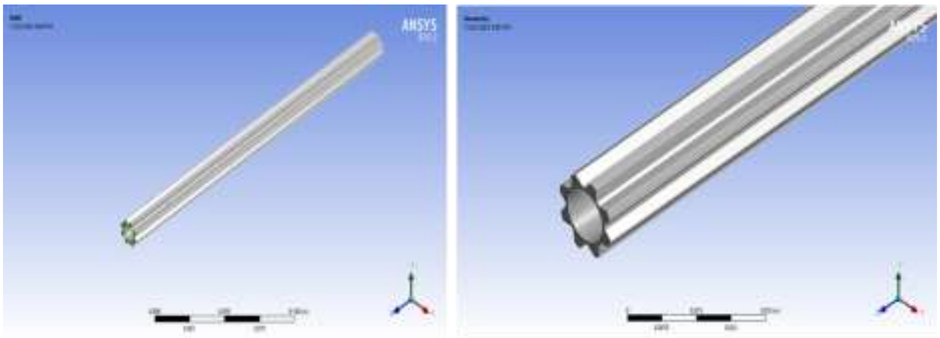

Figure 1. Computational model of heat exchanger.

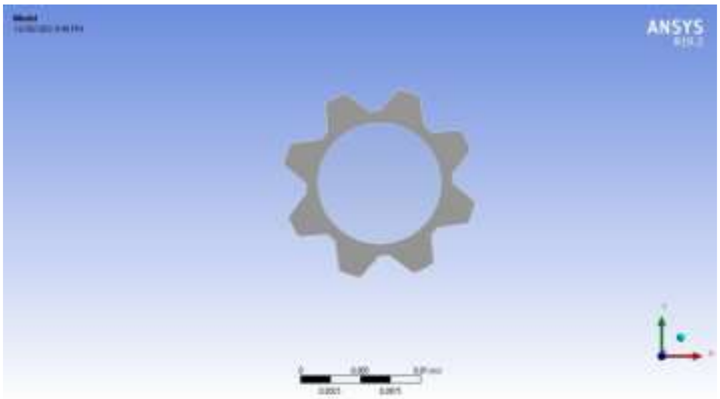

Figure 2. Side view of heat exchanger modal

In the pre-processor stage of ANSYS FLUENT R 19.2, a three-dimensional discretized model was created. The programmed ANSYS creates a coarse mesh, despite the fact that the grid types and simulation results are connected. The structure as a whole must be discrete in the final volume. Unit-size mixed cells (ICEM Tetrahedral cells) with triangular frontier faces make up the mesh. A mesh metric and a medium fluid curvature are employed in this investigation.

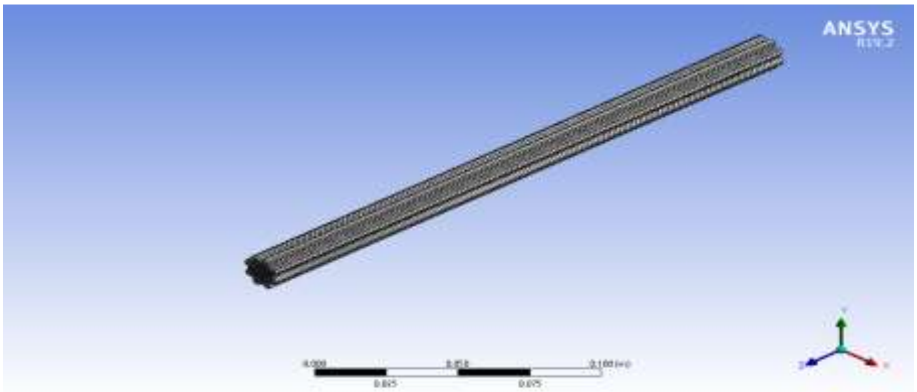

Figure 3. Meshing of heat exchanger.

Table 2. Meshing detail of model

S. No.	*Parameters*	
1	*Curvature*	*On*
2	*Smooth*	*Medium*
3	*Number of nodes*	*22639*
4	*Number of elements*	*16751*
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 3. Thermodynamic Properties of alumina (Al_2O_3)-based nanofluid (4% & 5%nanoparticle) nanoparticles

Input Parameters	***Symbols***	***Units***	***alumina (Al_2O_3)-based nanofluid (4% nanoparticle)***	***alumina (Al_2O_3)-based nanofluid (5% nanoparticle)***
Specific heat capacity	c_p	*J/kg-K*	*3735.60*	*3635.606*
Density	ρ	*(kg/m^3)*	*1102.272*	*1112.161*
Thermal conductivity	*k*	*W/m-K*	*0.9143*	*1.152*
Viscosity	μ	*Kg/m.s*	*0.00191*	*0.0021*

The discrete flow domain has been defined under sufficient limits. Inlets were allocated the mass flow rate requirements, while pressure outlet limits were allocated for outlets. The surfaces of the heat exchanger are regarded as normal wall limits. The interior walls were fitted with couplings of thermal walls.

Table 4. Details of boundary conditions.

Detail	***Value***
alumina (Al_2O_3)-based mass flow rate	*0.01 kg/s*
Energy	*on*
alumina (Al_2O_3)-based inlet temp.	*300 K*
Outer surfaces	*Heat flux=100 W/m^2*

IV. RESULTS AND DISCUSSIONS

This section is aimed at evaluating the heat exchanger 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,

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

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. Analysis of the involute fin section

It is evident from the numerical findings and experimental evidence that the outlet temperature &Heat transfer coefficient changing tendencies are qualitatively consistent. As a result, we use a volume concentration of 4% & 5% to analyze the impact of the suspension of alumina (Al_2O_3)-based nanofluid particles in the base fluid to promote thermal augmentation. The boundary conditions used in the study of the Straight fin tube section were the same. Chapter 5 makes reference to the thermal characteristics of nanofluids for determining the impact of various nanoparticles on the outlet temperature &Heat transfer coefficient.

- **At 1% concentration of nanoparticle in base fluid**

Here on the first case, we are applying Al_2O_3 nanoparticle at 1% concentration on the modified geometrical section tube (involute section). We are finding that the outlet temperature and heat transfer coefficient at 40^0C

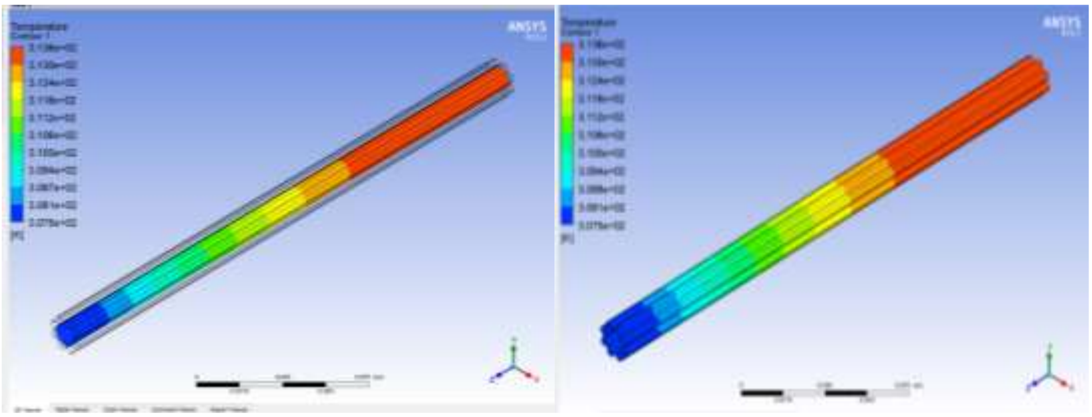

Figure 4. Temperature contour of Involute fin section tube applying Al_2O_3 nanofluid.

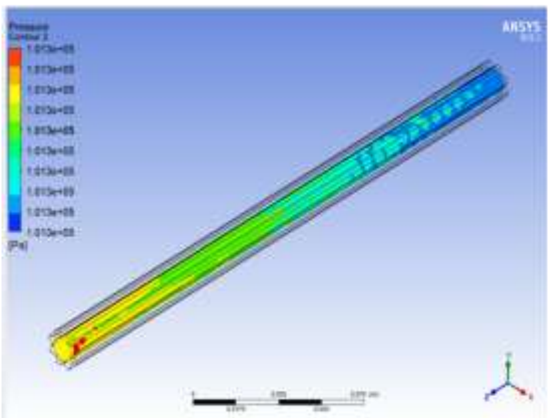

Figure 5. Pressure contour of Involute fin section tube applying Al_2O_3 nanofluid.

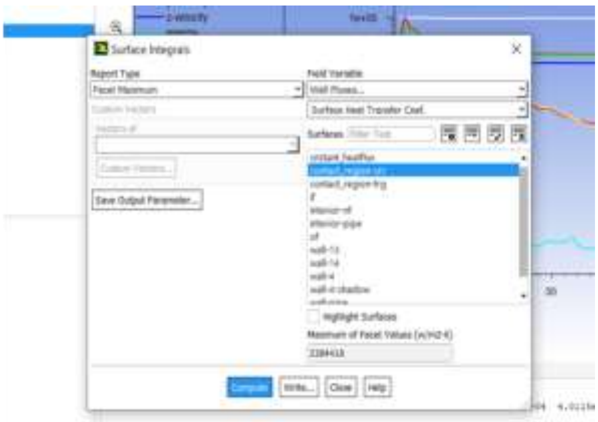

Figure 6. Heat transfer coefficient value of Involute fin section tube applying Al2O3 nanofluid.

- **At 4% concentration of nanoparticle in base fluid**

Here on the Second case, we are applying Al_2O_3 nanoparticle at 4% concentration on the modified geometrical section tube (involute section). We are finding that the outlet temperature and heat transfer coefficient at 40^0C.

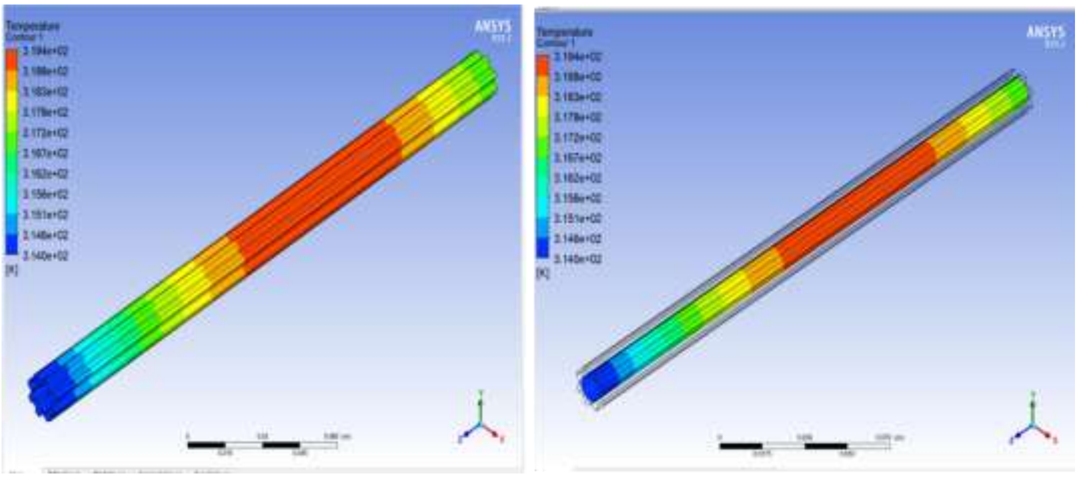

Figure 7. Temperature contour of Involute fin section tube applying Al2O3 nanofluid.

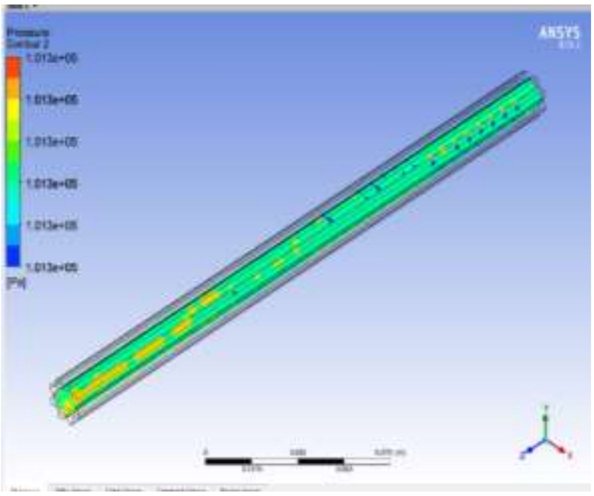

Figure 8. Pressure contour of Involute fin section tube applying Al2O3 nanofluid

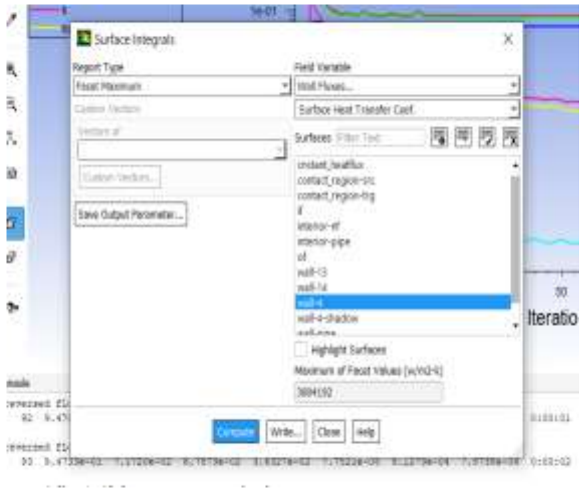

Figure 9. Heat transfer coefficient value of Involute fin section tube applying Al2O3 nanofluid.

- **At 5% concentration of nanoparticle in base fluid**

Here on the third case, we are applying Al_2O_3 nanoparticle at 5% concentration on the modified geometrical section tube (involute section). We are finding that the outlet temperature and heat transfer coefficient at 40^0C.

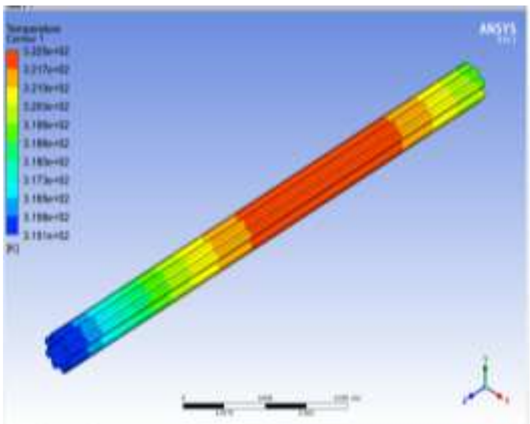

Figure 10. Temperature contour of Involute fin section tube applying Al2O3 nanofluid.

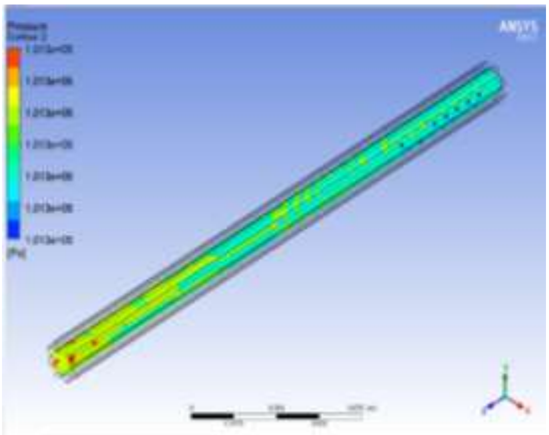

Figure 11. Pressure contour of involute fin section tube applying Al2O3 nanofluid

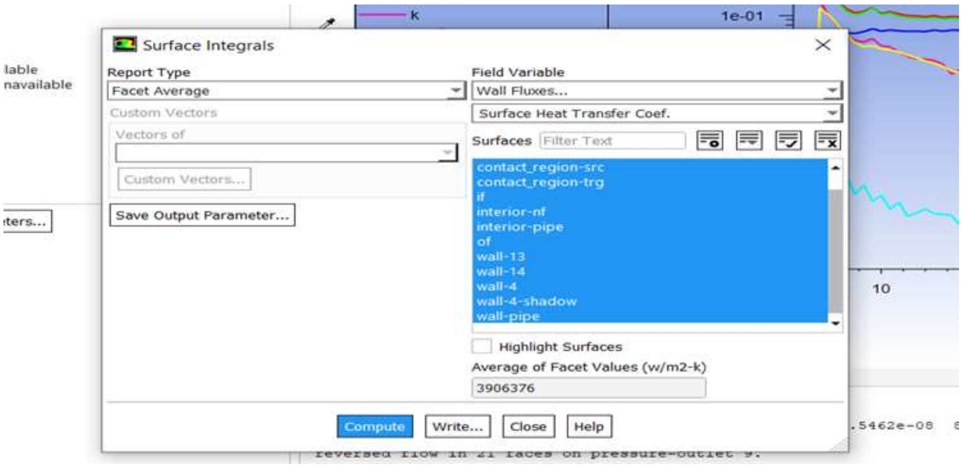

Figure 12. Heat transfer coefficient value of Involute fin section tube applying Al2O3 nanofluid.

Table 5. Shows the values of outlet temperature & heat transfer coefficient calculated from the CFD modeling using the alumina (Al_2O_3)-based nanofluid at different concentration of nanoparticle.

S. No.	**Concentration of nanoparticle**	**Involute fin section**	
		Outlet temperature	**Heat transfer coefficient**
1.	1%	313.6 K	3.384 e^{+6}
2.	4%	319.4 K	3.804 e^{+6}
3.	5%	322.5 K	3.906 e^{+6}

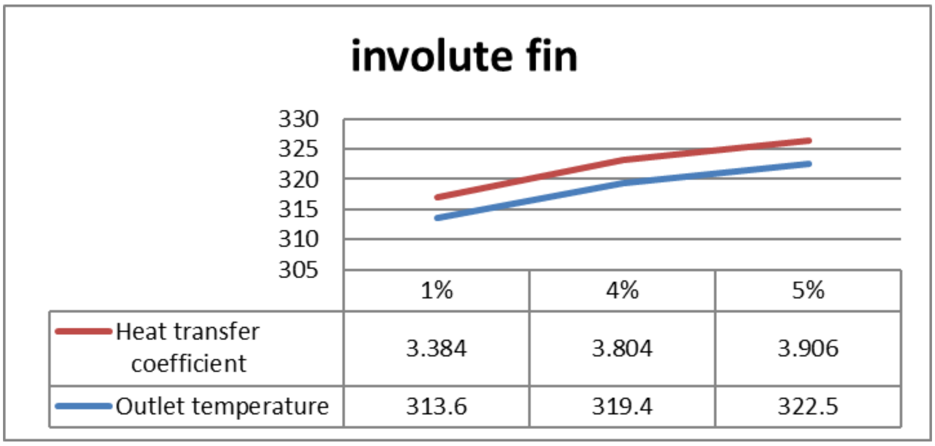

Figure 13. Shows the values of outlet temperature & heat transfer coefficient calculated from the CFD modeling using the alumina (Al_2O_3)-based nanofluid at different concentration of nanoparticle.

V. CONCLUSIONS

This CFD research examines the thermal properties of an alumina (Al_2O_3)-based nanofluid in a involute fin tube section. The results of this inquiry and the most current experimental results published in the literature showed significant agreement. The impact of nanofluid on fluid flow and heat transfer in a heat exchanger was investigated through testing and observation. These conclusions are possible based on the presented results.

- Compared to the results of fluid with involute fin and with straight fin shown that the rate of transfer of heat increases by modified fin. By checking the temperature contours and heat transfer coefficient the increase in the concentration of the nanoparticle increases the speed of transfer of heat and also increases the amount of heat release.
- If we are observed that the heat transfer coefficient of straight fin tube section at 0.5% and 3% concentration is 3.55e+04 and 2.25e+05 respectively. But at the modified section, we are observing that at 3% concentration, it gives the better heat transfer coefficient about 27.7%.
- So, we can say that on the basis of observation, the heat transfer is more with modified fins and same nanofluid also increases with increasing the concentration.

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