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CFD Analysis of Heat Transfer Characteristics & Performance Analysis of The Spiral Tube Heat Exchanger Using Alumina (Al_2O_3)-Based Nanofluid

Aniket Raj*, Prof.Animesh Singhai**,Prof. Rohit Soni***,
*(Mechanical Engg. Department, Trinity Institute of Technology and Research, Research Scholar, RGPV Bhopal)
**(Mechanical Engg. Department, Trinity Institute of Technology and Research, Professor, RGPV Bhopal)
***(Mechanical Engg. Department, Trinity Institute of Technology and Research, Professor, RGPV Bhopal)

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Abstract:

Due to its excellent heat exchange property and compact shape, a tube type heat exchanger is commonly utilized in many industrial applications. Dean vortices arise as a result of turbulence in a curved segment of pipe, increasing the heat transfer coefficient. ANSYS Fluent is used to investigate heat transfer features such as average outlet temperature, heat transfer coefficient and heat rate for a spiral tube filled with alumina (Al_2O_3)-based nanofluid at various mass flow rate. This tube's pressure drops, temperature distribution, and velocity distribution are also depicted. A steady-state numerical simulation employing a Fluent solver is used to forecast the exit temperature of fluid flowing through tubes. All CFD studies use tubes with similar diameters and lengths. For spiral designs of tubes, the outlet temperature of heat transfer fluid varies with mass flow rate. For a 0.04 kg/s mass flow rate at 1% of alumina (Al_2O_3)-based nanoparticle, the spiral tube has a maximum average exit temperature of 352.3 K. By Prasad Gilbile(2022) research ANSYS Fluent is used to investigate heat transfer properties such as heat transfer coefficient and heat rate for spiral, helical, and conical tubes. Using water as the base fluid, maximum outlet temperature of 338.39 K is observed for the spiral tube for a 0.04 kg/s mass flow rate. For a 0.04 kg/s mass flow rate, the heat transfer coefficient of a spiral tube is 0.44 percent higher than that of a helical tube and 2.57 percent higher than that of a conical tube. Additionally, pressure drop through the spiral tube is 2 % greater than the helical and conical tube.

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

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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.

Spiral plate heat exchangers are ideal for handling fouling-prone fluids, fluids with high viscosities, fluids containing suspended solid fragments, and process streams with complex heat transfer objectives. The correlations utilised to describe thermal and hydraulic performance are influenced by the geometrical configuration of the equipment. The current research shows how to construct spiral plate heat exchangers depending on fluid configurations, government flow, and whether the thermal equipment is utilised for condensing, cooling, or heating. A further study is performed in order to identify the geometrical elements that allow for increased and improved thermal and hydraulic performance. Computational fluid dynamics is also utilised to analyse thermal and hydraulic approaches.

With study on tubes, which play an important role, many types of tubes, such as helical, spiral, and conical tubes, are examined, and their internal comparison is made to develop an efficient tube, and a computational fluid dynamics (CFD) technique employing ANSYS is employed here. Fluent was used to run analytical simulations to identify parameter changes, which were accounted for as variations in mass flow rate (i.e., 0.4-1.2 kg/sec). All simulations were examined to determine the heat transfer behaviour of each tube, and graphs were shown to show the results for each tube. [1]

II. LITERATURE REVIEW

Since alumina-based nanofluids may be used in a range of heat transfer and other applications, they are critical. As a result, research has concentrated on developing stable nanofluids by modifying the surface of the particles, using various surfactants, and regulating the pH and temperature of various nanofluids. Several research have shown uneven increases in thermal conductivity for Al_2O_3 nanofluid, and the literature that is currently available does not explain why these increases occurred.

Prasad Gilbile, RushikeshPisalet al. (2022), Because of its high heat exchange property and compact shape, tube type heat exchangers are commonly utilised in many industrial applications. Turbulence forms dean vortices in a curved segment of pipe, increasing the heat transmission coefficient. ANSYS Fluent is used to study heat transfer features such as heat transfer coefficient and heat rate for spiral, helical, and conical tubes. Pressure drop, temperature distribution, and velocity distribution are also presented for three distinct tubes. A steady-state numerical simulation with a Fluent solver is used to forecast the exit temperature of fluid passing through tubes. All CFD trials take into account same tube diameter and length. For all tube forms, the outlet temperature of heat transfer fluid varies with mass flow rate. The spiral tube has a maximum exit temperature of 338.39 K at a mass flow rate of 0.04 kg/s. With a mass flow rate of 0.04 kg/s, the heat transfer coefficient of a spiral tube is 0.44 percent higher than that of a helical tube and 2.57 percent higher than that of a conical tube. Also, the pressure loss through the spiral tube is 2% larger than that via the helical and conical tubes.

M. Vivekanandan et al. (2021) The thermal, hydraulic, and thermodynamic performances of a heat exchanger with spiral coils cascading over a cylinder-shaped shell inside the heat exchanger are investigated in this work. Hydraulic and thermo hydraulic performance are defined as tube side pressure drop and exergy efficiency, whilst thermal performance is defined as total heat transfer coefficient (U) and effectiveness. The flow rate on the tube side ranges from 2 to 6 lpm, while the flow rate on the shell is 4 lpm and 10 lpm. Flow parameters are adjusted and the experiment is carried out to determine the ideal flow rate inside the spiral heat exchanger.

Mangesh Shashikant Bidkaret al. (2021) When fluid moves via route curvature pipes, heat transfer efficiency improves. Heat transfer in a spiral coil is usually recognised to be higher than in a straight pipe. This report does not provide the exact characteristics of heat transfer and fluid movement. This paper includes a cfd study on how to improve heat transfer and reduce pressure. We will be able to forecast Transferring heat and pressure drop within a Spiral tube using this methodology. CFD simulation for spiral coils is performed by adjusting coil parameters such as I tube diameter and (ii) coil pitch (iii) The influence of the number of turns on heat transfer has been studied.Since there is no published numerical, analytical, or experimental information on spiral coil systems.The laminar of flow pressure drop and characteristics of transfer heat from spiral coil systems will be examined in this research using the widely available ANSYS FLUENT CFD programme. The effects of Newtonian fluid, Reynolds number, tube area or cross section, length to diameter ratio, coil pitch, and number of turns on fluid flow and heat transfer in spiral coils are explored and reported.

Vedant Irabatti et al. (2023) Energy conservation is a critical concern in today's environment, and heat exchangers may help. Heat exchanger selection is critical in process industries such as dissolution, fermentation, crystallisation, and so on. As compared to its traditional equivalents, spiral heat exchangers (SHE) are noted for their compact design and great heat transfer efficiency. For the same volume occupied, the surface area used for heat transfer in a spiral heat exchanger is substantially bigger than in traditional designs such as shell-type heat exchangers.Because of these benefits, SHEs are significantly more appropriate for a wide range of applications in the processing industries.

Lokesh Singh,et al. (2022) Spiral tubes are commonly utilised in engineering applications such as heat transfer between fluids, refrigeration, and many more. The best spiral tube can boost system efficiency. Many studies on spiral tube design and process parameters have been conducted in recent decades. The influence of friction factor on spiral tube is explored in this research by chaining its process and design parameters. The current study is based on CFD simulation. The "Taguchi Technique" is used to design experiments. The three process parameters specified for this study are surface wall temperature, fluid input temperature, and fluid mass flow rate. The inner diameter of the tube, the pitch of the tube, and the curvature ratio of the tube are the three design parameters used for this study.

III. RESEARCH OBJECTIVE

The convective heat transport of an alumina (Al_2O_3)-based nanofluid in a spiral tube was explored using a 3-dimensional numerical (3-D) simulation in this study. We investigate the impacts of using a spiral tube with variable mass flow rate at a constant wall heat temperature on the average outlet temperature, heat rate, and heat transfer coefficient. The performance of heat transport is greatly enhanced

Furthermore, various geometrical configurations such as spiral tube, helical tube, and conical tube are used to investigate the flow behaviour based on different mass flow rates using water as a base fluid corresponding to the analyse values such as average outlet temperature, heat rate, and heat transfer coefficient. The results show that the heat transfer coefficient tends to rise as the mass flow rate increases.

The above situation was observed by **Prasad Gilbile**, who utilised water as the base fluid and obtained a maximum output temperature of 338.39 K for the spiral tube at a mass flow rate of 0.04 kg/s. With a mass flow rate of 0.04 kg/s, the heat transfer coefficient of a spiral tube is 0.44 percent higher than that of a helical tube and 2.57 percent higher than that of a conical tube. Also, the pressure loss through the spiral tube is 2% larger than that via the helical and conical tubes. In that case, we use an alumina (Al_2O_3)-based nanofluid for the same arrangement and evaluate the varied heat transmission characteristics.

IV. GEOMETRY SETUP AND MODELLING

A. Geometry of membrane

The CFD model is used in this part to investigate the heat transfer physiognomies of an alumina (Al2O3)-based nanofluid in spiral tubes. CFD analysis is divided into three stages: (a) pre-processing, (b) solver execution, and (c) post-processing. The first phase involves creating the geometry and mesh of the intended model, while the last step displays the expected results. The boundary conditions are given into the model during the solver (medium) stage execution.

The geometry used for simulation study is based on the work of research scholar Prasad Gilbile (2022) [1]. The Spiral tube and its computational domain are seen schematically in Fig. 5.1. To inject input fluid into the computational environment, a spiral tube is employed. The spiral tube type heat exchanger is modelled in CATIA V5, and then converted to a step file for further CFD study.

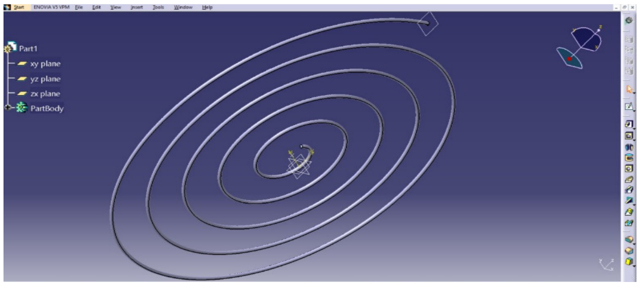

Figure 1.1 Modelling of the spiral tube type heat exchanger.

TABLE I
GEOMETRY PARAMETERS

S.N.	Parameters	Value & units (m)
1	Inlet tube diameter	0.00487 m
2	Outlet tube diameter	0.00487 m
3	Length of the tube	8.48 m
4	Surface area of tube	0.26 m^2

TABLE III
PROPERTY OF COPPER WALL

S.N.	Properties	Value & units
1	Density	8978 Kg/m3
2	Specific heat	381 J/Kg*K
3	Thermal conductivity	387.6 W/m*K

B. Meshing

The pre-processor stage of ANSYS FLUENT 22 R1 produced a three-dimensional discretised 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, theoverall structure is discontinuous in the final volume. Mesh is made up of ICEM Tetrahedral cells that are unit-sized and have triangular border faces.Thisinquiry employs a medium fluid curvature as well as a mesh metric.

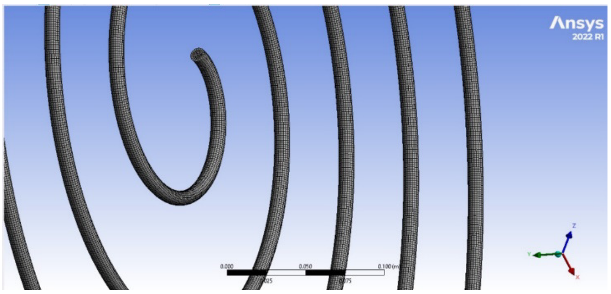

Figure 1.2. Meshing of Spiral tube Model.

TABLE IIIII
MASHING DETAIL OF MODAL

S.N.	Parameters	Value
1	Curvature	On
2	Smooth	Medium
3	Number of nodes	377262
4	Number of elements	327273
5	Mesh metric	None
6	Meshing type	Quadrilateral

C. Boundary Condition

The inlet conditions are the mass flow rate at the inlet and the severity of the turbulence (I_{in} = 5%) at a constant temperature (300 K). The pressure outlet condition with turbulence intensity (I_{out} = 5%) is outlet vent and Temperature (300 K) for backflow turbulence make up the output condition. The outer wall boundary condition is based on constant temperature (353 K) with made of copper metal. The Energy equation is used in the solver. For all mass, momentum, and energy equations, the convergence requirements are 10^{-3}. The following are the Fluent's boundary conditions:

i. Inlet boundary condition: The inlet is a mass flow inlet having a mass flow rate varying from 0.04 kg/sec to 0.12 kg/sec with a constant inlet temp of 300 K.
ii. Exit boundary condition: The outlet is a vent with a pressure equal to atmospheric pressure.
iii. The stationary wall at 353 K temperature serves as the wall boundary condition.

TABLE IVV
DETAILS OF BOUNDARY CONDITION

S.N.	Properties	Value & units
1	alumina (Al_2O_3)-based nanofluid flow rate	At different mass flow rate 0.04,0.08,0.12
2	turbulence intensity	(Iout = 5%) at pressure outlet condition
3	alumina (Al_2O_3)-based nanofluid inlet temp.	300 K
4	Copper outer wall temp.	353 K

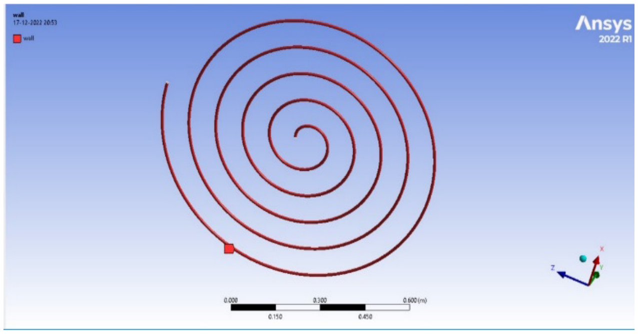

Figure 1.3. Name selection for applying boundary condition at different section

A three-dimensional CFD model is used to analyse spiral tubes. We are using these following parametersfor calculate the various characteristic of heat transfer.

TABLE V
PROPERTY OF (AL_2O_3)-BASED NANOFLUID

Input Parameters	Units	Alumina(Al_2O_3)-based nanofluid (1% nanoparticle)	Alumina (Al_2O_3) based nanofluid (2% nanoparticle)
Specific heat capacity	J/kg-K	4061.8966	1050.236
Density	(kg/m3)	1024.218	3947.744
Thermal conductivity	W/m-K	0.685862	0.7668688
Viscosity	Kg/m.s	0.001132	0.0013085

V. RESULTS AND DISCUSSIONS

The purpose of this section is to evaluate the thermal performance of the spiral tube sections utilising 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% and 2% subject to flow).

A. *Effect of suspension of alumina (Al_2O_3)-basednanofluid (1% & 2% of alumina nano particles)*

we use a volume concentration of 1% and 2% to analyse the impact of the suspension of alumina (Al_2O_3)-based nanofluid particles in the base fluid to promote thermal augmentation.

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

- **At 0.04 kg/s mass flow rate**

Hare, we are using the 1% alumina (Al_2O_3)-based nanoparticles with 0.04 kg/s mass flow rate & find out the result (contour) of outlet temperature, heat transfer coefficient and heat rate with the help of CFD

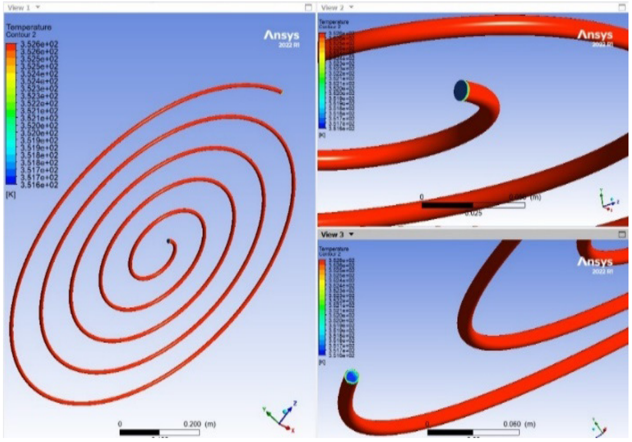

Figure 1.4. Temperature contour for the 0.04 kg/s mass flow rate with 1% (Al_2O_3) nanoparticle

- **At 0.08 kg/s mass flow rate**

Now, we are using the 1% alumina (Al_2O_3)-based nanoparticles with 0.08 kg/s mass flow rate & find out the result (contour) of outlettemperature, heat transfer coefficient and heat rate with the help of CFD.

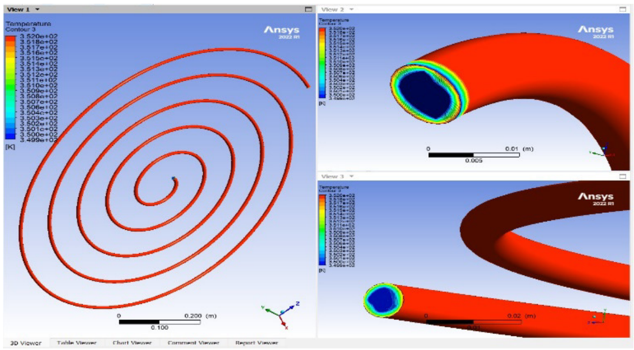

Figure 1.5. Temperature contour for the 0.08 kg/s mass flow rate with 1% (Al_2O_3) nanoparticle

- **At 0.12 kg/s mass flow rate**

And finally, we are using the 1% alumina (Al2O3)-based nanoparticles with 0.12 kg/s mass flow rate & find out the result (contour) of outlet temperature, heat transfer coefficient and heat rate with the help of CFD.

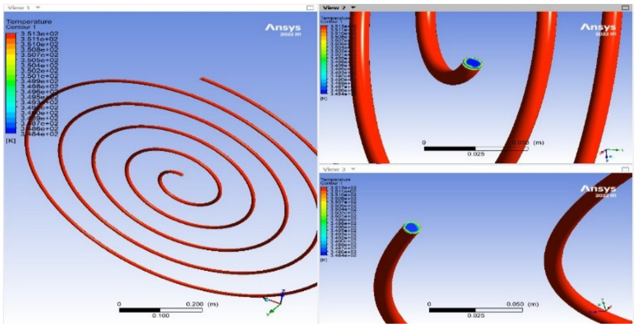

Figure 1.6. Temperature contour for the 0.12 kg/s mass flow rate with 1% (Al_2O_3) nanoparticle.

TABLE VI

VARIOUS HEAT TRANSFER CHARACTERISTIC USING ALUMINA (AL_2O_3)-BASED NANOFLUID (1% NANO PARTICLE).

Mass flow rate (kg/s)	Average Outlet temperature (K)	Heat transfer coefficient (W/m^2K)	Total heat transfer rate (kW)
0.04	352.1	886.144	8.601
0.08	350.95	1355.024	16.648
0.12	349.85	1737.389	24.245

- **Use 2% of alumina (Al2O3)-based nanofluid particles**

- **At 0.04 kg/s mass flow rate**

In the second case, we are using the 2% alumina (Al_2O_3)-based nanoparticles with 0.04 kg/s mass flow rate & find out the result (contour) of outlet temperature, heat transfer coefficient and heat rate with the help of CFD.

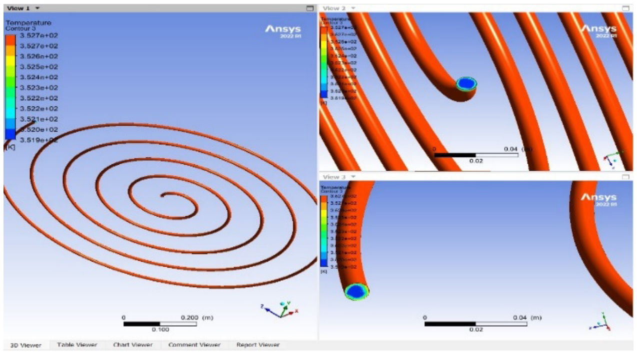

Figure 1.7. Temperature contour for the 0.04 kg/s mass flow rate with 2% (Al_2O_3) nanoparticle

- **At 0.08 kg/s mass flow rate**

Now, we are using the 2% alumina (Al_2O_3)-based nanoparticles with 0.08 kg/s mass flow rate & find out the result (contour) of outlet temperature, heat transfer coefficient and heat rate with the help of CFD.

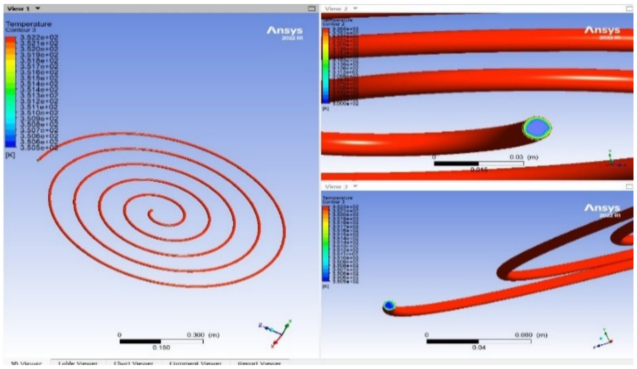

Figure 1.8. Temperature contour for the 0.08 kg/s mass flow rate with 2% (Al_2O_3) nanoparticle

- **At 0.12 kg/s mass flow rate**

	1% Al_2O_3 particle			**2% Al_2O_3 particle**		
MFR	**0.04**	**0.08**	**0.12**	**0.04**	**0.08**	**0.12**
A.O.T. (K)	352.1	350.95	349.85	352.3	351.35	350.35
H.T.C. (W/m^2 K)	886.1	1355	1737.38	948.65	1446.56	1851.69
H.R. (kW)	8.601	16.648	24.245	8.416	16.369	23.919

And finally, we are using the 2% alumina (Al_2O_3)-based nanoparticles with 0.12 kg/s mass flow rate & find out the result (contour) of outlet temperature, heat transfer coefficient and heat rate with the help of CFD.

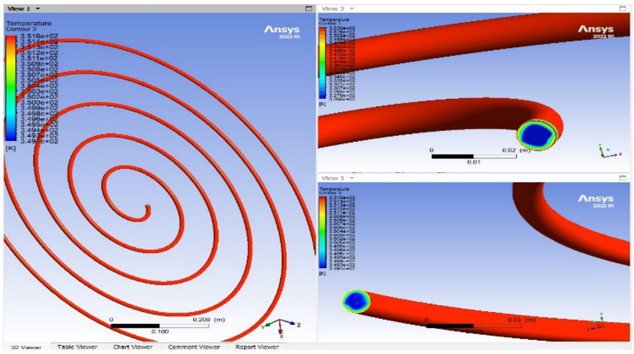

Figure 1.9. Temperature contour for the 0.12 kg/s mass flow rate with 2% (Al2O3) nanoparticle

TABLE VII

VARIOUS HEAT TRANSFER CHARACTERISTIC USING ALUMINA (AL_2O_3)-BASED NANOFLUID (2% NANO PARTICLE).

Mass flow rate (kg/s)	**Average Outlet temperature (K)**	**Heat transfer coefficient (W/m^2K)**	**Total heat transfer rate (kW)**
0.04	352.3	948.653	8.416
0.08	351.35	1446.564	16.369
0.12	350.35	1851.692	23.919

B. Comparison the various characteristic value of base fluid (water) and alumina (Al_2O_3)-based nanofluid at different Mass flow rate

After calculate the value of Average outlet temperature, heat transfer coefficient & total heat transfer rate for different mass flow rate (0.04, 0.08,0.12 kg/s) using alumina (Al_2O_3)-based nanofluid with 1% & 2% nanoparticle, we are comparing all of three cases.

TABLE VIII

COMPARISON THE VARIOUS HEAT TRANSFER CHARACTERISTIC USING ALUMINA (AL_2O_3)-BASED NANOFLUID WITH 1% AND 2% NANOPARTICLE AND WATER AS A FLUID.

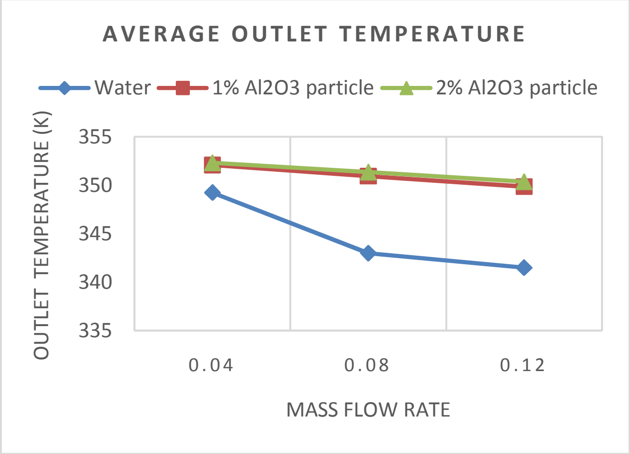

Figure 1.10 Mass flow rate vs outlet temperature

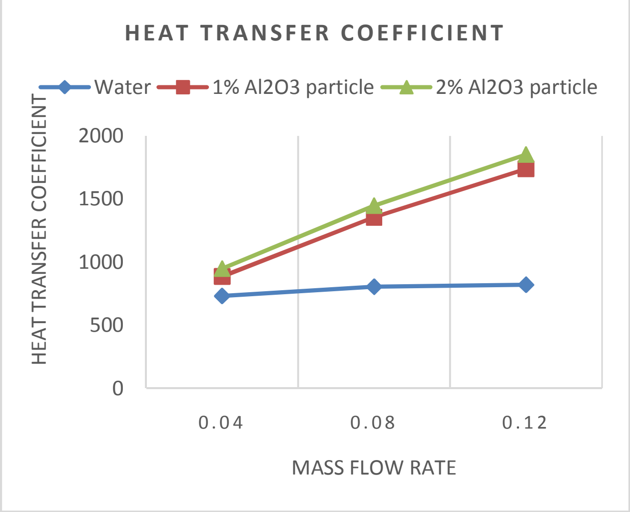

Figure 1.11 Mass flow rate vs heat transfer coefficient

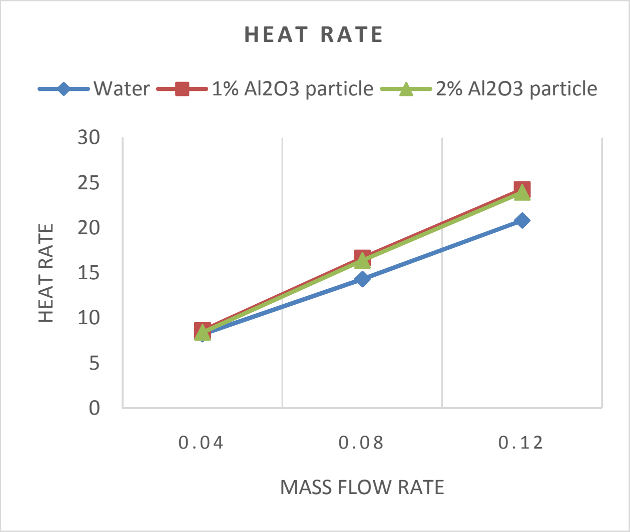

Figure 1.12 Mass flow rate vs Heat rate

VI. 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 average spiral tube outlet temperature with Al_2O_3 nano fluid (1%) is greater than 0.81 % for same spiral tube using water base fluid.
- The spiral tube with Al_2O_3 nano fluid (1%) has a higher heat transfer coefficient than using the water fluid in spiral tube. The heat transfer coefficient of the spiral tube with Al_2O_3 nano fluid (1%) is 0.212 % higher. But whenever we are using 2% nanoparticle, then it is increases in slightly less amount.
- When we talk about the heat rate, it increases only by the amount of 0.04 %, which is very less with comparison to water but as soon as we increase the concentration of Al_2O_3 in the fluid, then it increases by a good amount.

A standard design for a spiral tube heat exchanger may be created. The material, curvature of the coil, and inner diameter of the pipe and coil may all be changed throughout the experiment and analysis. By joining more than two spiral tube coils, they may be staggered. Employing a simple coil connection so that it may be quickly removed if the coil becomes broken. If the inner diameter of the coil is larger, internal core support can be provided. The spiral tube heat exchanger may be employed in small spaces as well as severe environments such as geo hot wells. Because heat performance is independent of the shell, this heat exchanger eliminates the complicated design of the shell.

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