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Thermal Performance of the Spiral Shape Tube with Al2o3 Nano Fluid Using CFD

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ABSTRACT

The tube style thermal exchanger is often used in multiple industrial uses because of its great heat exchange capability and small size. When instability occurs in a curvy pipe section, Dean vortices form, which raises the heat transfer factor. The average outflow temperature, heat transfer factor, and warmth rate for an alumina based small-molecule loaded into a spiral tube at varied mass flow rates are investigated using ANSYS Fluent as a tool. The range of temperatures distribution, velocity distribution, as well as pressure fluctuations in this tube are also shown. The final temperature of fluid passing through tubes is predicted using a constant-state numerical model using a Fluent solver. Tubes with equal sizes and lengths are used in all CFD investigations. The final temperature of the heat transfer fluid changes with mass flow rate for spiral tube configurations. The spiral tube's highest average output temperature is 352.3 K for a mass flow rate of 0.04 kg/s and 1% alumina-based nanoparticles.

Keywords: *Computational fluid dynamic, alumina (Al2O3)-based nanofluid, nanoparticles, Heat transfer coefficient, spiral tubes section.*

1. Introduction

Heat exchanger is used for heat transfer from hot fluid to cold fluid. The performance of heat exchanger is analysed by of the heat transfer rate and heat transfer coefficient. The addition of Nano particles in the fluids is improves the performance of the heat exchanger and overall performance of the system. Ferrous oxide Nano fluids improved the heat transfer and friction factor characteristics of a circular tube heat exchanger [1]. Al2O3/water-based Nano-fluid improves the thermo-hydraulic performance of serpentine tube heat exchanger (STHX) [2]. MWCNT/water Nano fluids improves the heat transfer about 30% as compare to plain fluids and pressure drop enhanced about 11% [3]. The nano particle suspension in three-phase system including the solid phase (nano particles), the liquid phase (fluid media), and the interfacial phase, which contributes significantly to the system properties because of its extremely high surface-to-volume ratio in Nano fluids [4]. Nano fluids used in micro channels its latter properties considerably increased the heat transfer enhancement relative to “conventional” properties and heat transfer enhancement is comparable to the enhanced skin friction rise [5]. Nano fluids improve both thermal and optical properties of current solar conversion systems. Direct solar thermal absorption collectors incorporating a Nano fluid offers the opportunity to achieve significant improvements in both optical and thermal performance. Since Nano fluids offer much greater heat absorbing and heat transfer properties compared to traditional working fluids [6]. Nano fluids increase the rate of heat transfer without affecting much the overall performance of the system, it is very useful in evaporators, air-conditioning equipment, thermal power plants, space vehicle, and automobile [7]. Nano fluid mixture with low concentration of solid particles are provided qualitative results regarding the heat transfer enhancement and provided heat transfer mechanisms [8]. Nano fluids showing the good result with Reynolds number of 20,000 and expansion ratio of 2.86, with methane [9]. Nano fluids improves the heat transfer of turbulent heat exchanger and separation flow in a symmetric expansion plane channel with the 5000 to 35,000 Reynolds number [10]. Standard k-ε model is very useful for calculated turbulent kinetic energy and velocity. This model presented the new trend for calculating the different parameter which is very useful for evaluating the performance of the turbulent flow heat exchanger [11]. Nano fluids have been used because of its higher thermal conductivity compared to traditional fluids. A new modified low- Reynolds number k-ϵ turbulence model showing the high wall heat transfer with Reynolds numbers ranging from 200 to 600 and different Nano fluids such as Cu, Ag, Al2O3, CuO, and TiO2 [12]. Al2O3, CuO, SiO2, and ZnO, with volume fraction that varied from 1% to 4% and the expansion ratio was 2, improves the heat transfer. Their results indicated that increasing Reynolds number and volume fraction augment Nusselt number; the highest Nusselt number value was associated with SiO2 [13]. Nano fluid flow and heat transfer over a backward-facing step, the results showed that the maximum heat transfer enhancement was about 26% and 36% for turbulent and laminar range, respectively, compared with pure water [14]. Al2O3-water Nano fluid flowing through a circular pipe showing the enhancement of heat transfer rate as compare to plain fluids [15]. The shape and size of Nano particles greatly affected the performance of Nano fluids. The smaller sizes of nanoparticles with spherical shape showing the higher heat transfer and enhanced the efficiency of the system [16]. The single phase dispersion model showed good performance compared to the other models [17]. Laminar TiO2-H2O Nano fluid flow in a horizontal circular pipe increase the heat transfer rate [18]. Al2O3– water Nano fluid flowing through a horizontal tube increase the heat transfer rate [19]. Cu-water Nano fluid flow in a circular tube under both the laminar and turbulent flow had increased the heat transfer coefficient [20]. The addition Al2O3 nanoparticles in the base fluids had helped to enhance the heat transfer rate. The maximum enhancement was observed to be 15% and 20% respectively at 3% under both the laminar and turbulent flow conditions [21]. Nanostructured ceramic materials have used for as promising heat transfer fluid additives owing to their outstanding heat storage capacities [22]. Nano particles based nano fluids improves the heat transfer rate in both laminar and turbulent flow condition [23]. Copper oxide nanoparticles dispersed in ethylene glycol improves the heat transfer rate as compare to water mixture [24]. Al2O3 Nano fluid improves the heat transfer coefficient and reduced the friction factor [25].

2. Methodology

Computational fluid dynamics (CFD) includes the use of PC-based re-enactment with systems such as liquid stream, warm motion, and related wonders to be analysed. First, using an arrangement of scientific conditions, which portrays the current, a numerical model is created. Using the end objective of a PC device to carry the stream factors in the stream space, those conditions are then overcome.

Since the introduction of the modern PC, CFD has been well recognized and is frequently used to analyse various fluid component parts. CFD's innovation and usage has undergone important advances and has become a major instrument in the design and analysis of different processes. In the mid-80s, PCs proved to be sufficiently strong for broadly functional CFD programming to end up available.

3. Geometry and Modeling and boundary conditions

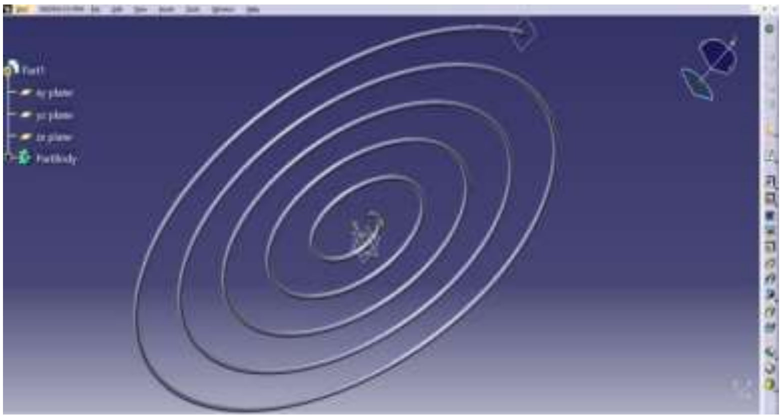

Figure 1 Modelling of the spiral tube type heat exchanger

Based on research by academic Prasad Gilbile et al. (2022) [1], the geometry employed for the modeling study. Fig. 1 depicts the Spiral tube and its computational domain schematically. A spiral tube is used to feed source fluid into the computing environment. In order to facilitate future CFD research, the spiral tube type heat exchanger is first modelled in CATIA V5 and then converted to a step file. A partial differential equation is discretized by creating a series of mathematical formulas for discrete places. For discretization, ANSYS Workbench 22 R1 and a grid system are used.

4. Meshing of geometry

An ANSYS FLUENT 22 R1 pre-processor stage created a 3-D reduced model. Although there is a correlation between grid types and simulation results, when ANSYS is setup, a coarse mesh is produced. This need results in a disjointed overall structure in the final volume. ICEM Tetrahedron cells with triangle border faces and unit size make up the mesh. Both a mesh metric and a medium flowing curvature are used in this investigation.

Figure 2 Meshing of Spiral tube Model.

Table 1 The parameters of the spiral tube structure

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 2 The properties of copper used as an outer 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

5. Boundary Conditions

A Velocity inlet, uniform mass flow inlets and a constant inlet temperature were assigned at the channel inlet. At the exit, pressure was specified.

Table:-3 Boundary Conditions

Detail	***Value***
alumina (Al2O3)-based nanofluid flow rate	*At different mass flow rate 0.04,0.08,0.12*
turbulence intensity	*(Iout = 5%) at pressure outlet condition*
alumina (Al2O3)-based nanofluid inlet temp.	*300 K*
Copper outer wall temp	*353 K*
Outer surfaces	*Heat flux=0*

6. Results and Discussions

This section's goal is to assess the spiral tube sections' thermal performance using nanofluids. To examine the effectiveness of a heat exchanger using nanofluids (1% and 2% exposed to flow), variations in heat transfer rate and thermal conductance are evaluated at different mass flow rates.

Data reduction equations

The results obtained by Prasad Gilbile's research (2022) were contrasted with the values of exit temperature, heat transfer coefficient, and heat rate derived using CFD modeling on the basis of acquired intake fluid temperature.

- **For mass flow rate 0.04**

Here, we are determining the average exit temperature while utilizing water as a fluid flowing through an inlet at a mass flow rate of 0.04. 349.551 K is the average output temperature. These temperature contours show the fluid's (water) maximum and lowest output temperatures.

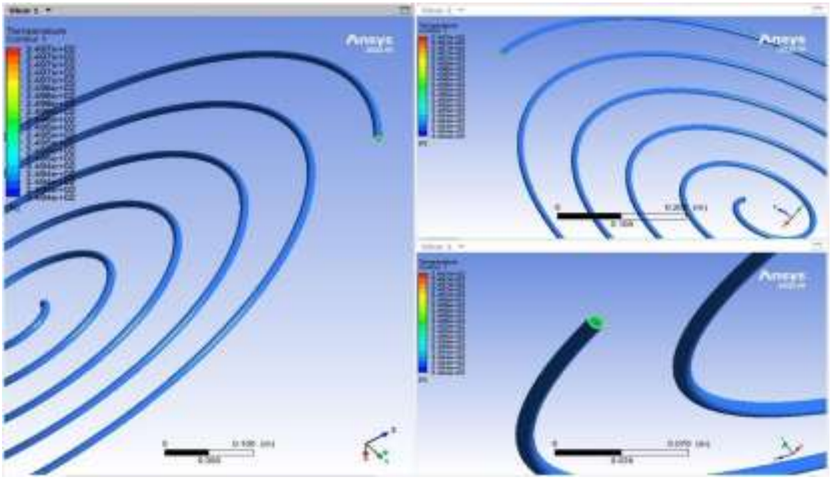

Figure 3. Temperature contour at 0.04 kg/s mass flow rate using water as a base fluid.

- For mass flow rate 0.08

Here, we are determining the average exit temperature while utilizing water as a fluid flowing through an inlet at an average velocity of 0.08. 342.476 K is the average output heat. These temperature contours show the liquid's (water) maximum and lowest output temperatures.

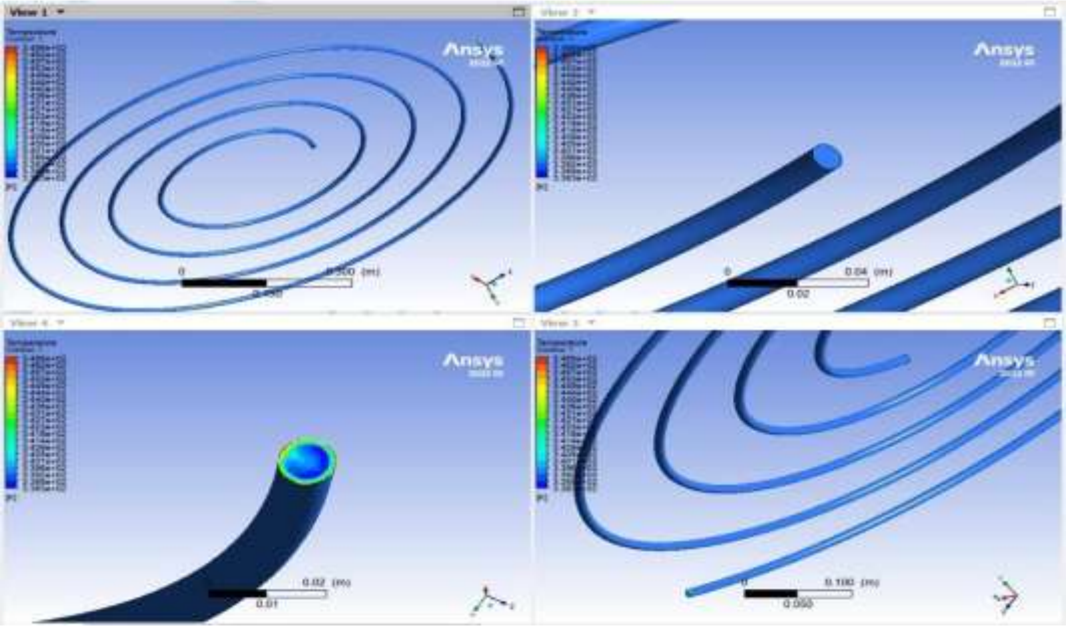

Figure 4. Temperature contour at 0.08 kg/s mass flow rate using water as a base fluid

Table 3. Compares the average outlet temperature figures derived from CFD modeling to figures from an investigation done in 2022 by Prasad Gilbile et al. using water as the basis fluid.

S. No.	**Mass flow rate (Kg/s)**	**Outlet Temperature (K)**	
		Base Paper	**Present Study**
1.	0.04	349.25	349.551
2.	0.08	343.0	342.746

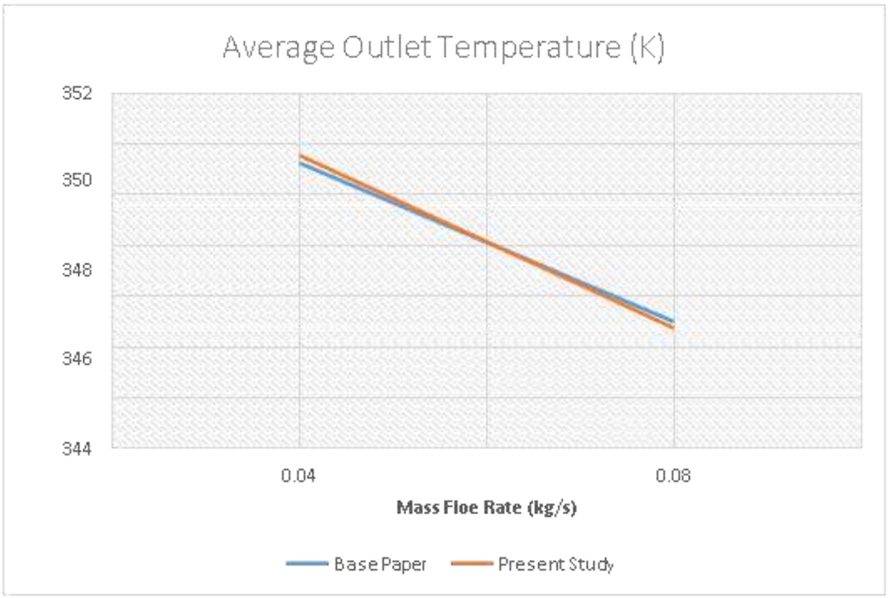

Figure 5. compare the values of average outlet temperature calculated from the CFD modeling with the values obtained from the analysis performed by Prasad Gilbile, et al. (2022)

Comparison the various characteristic value of base fluid (water) and alumina (Al2O3)-based nanofluid at different Mass flow rate

We are comparing each of the three examples after computing the values for Average outlet temperature, heat transfer coefficient, and total heat transfer rate for varied mass flow rates (0.04, 0.08, and 0.12 kg/s) using an aluminum (Al2O3)-based nanofluid technology with 1% and 2% nanoparticles.

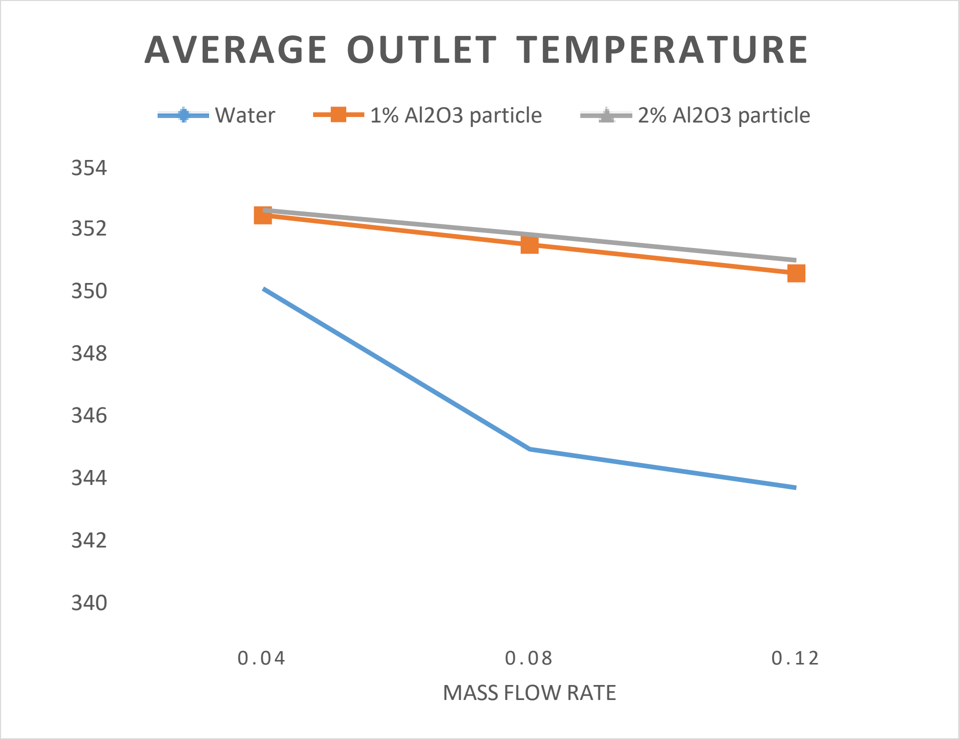

Figure 6 Mass flow rate vs outlet temperature

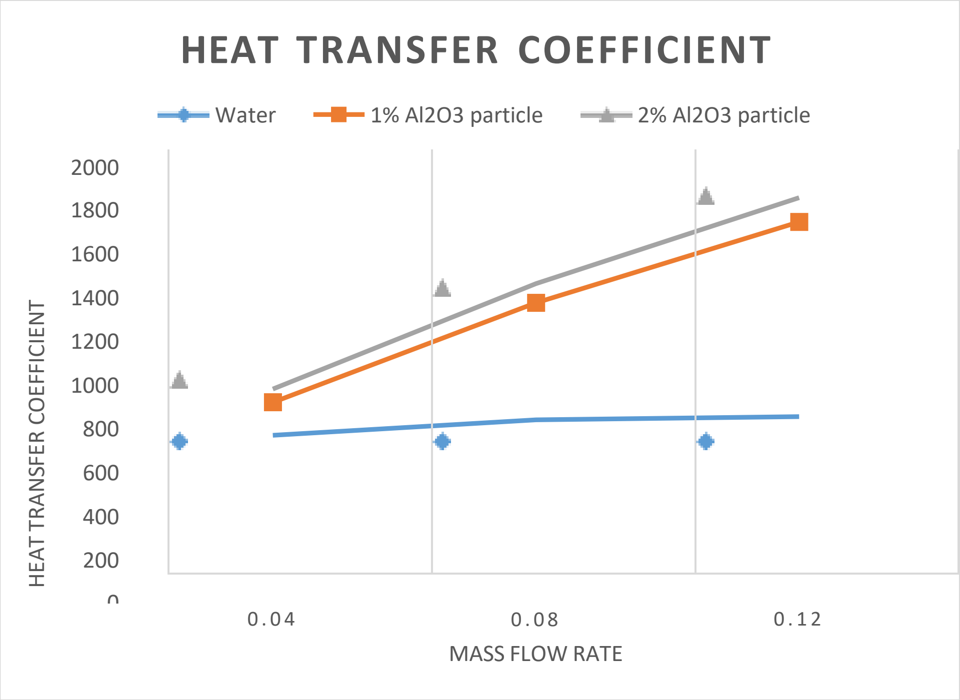

Figure 7 Mass flow rate vs heat transfer coefficient

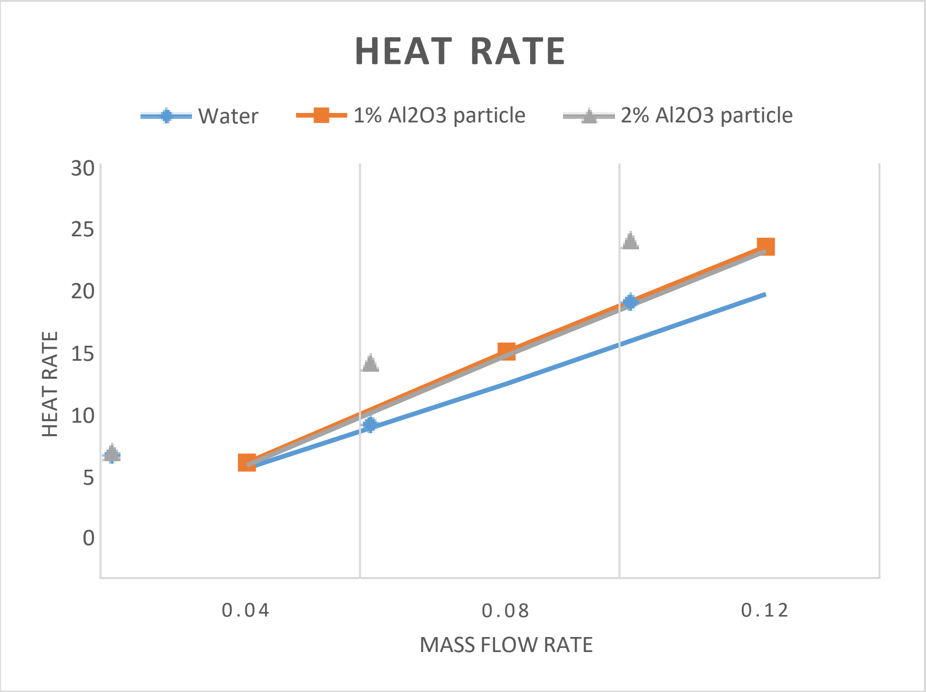

Figure 8 Mass flow rate vs Heat rate

7. Conclusions

In this study, the numerical analysis of spiral tubes is provided. ANSYS Fluent is used to determine the thermal and flow parameters. Following the experimental investigation, the following conclusions from the ongoing numerical analytical work may be drawn:

- When employing Al2O3 nano fluid (1%) in spiral tubes, the average output temperature is higher than when using water base fluid (0.81%).
- The heat transfer coefficient of the spiral tube containing Al2O3 nano fluid (1%) is greater than that of the spiral tube containing water fluid. The spiral tube with Al2O3 nano fluid (1%) has a 0.212% greater heat transfer coefficient. But when we use 2% nanoparticle, the gain is a little less noticeable.
- When it comes to heat rate, it just goes up by 0.04%, which is a very little amount when compared to water, but as soon as we raise the concentration of Al2O3 in the fluid, it goes up by a significant amount.

8. Future Scope

It could be possible to develop a spiral tube heat exchanger standard design. Throughout the experiment and analysis, it is possible to alter the material, the coil's curvature, and the inner diameter of the pipe and coil. They may be staggered by linking more than two spiral tube coils. using a simple coil connection that may be easily removed in the event that the coil breaks. Internal core support may be provided if the coil's inner diameter is bigger. Both cramped areas and harsh situations, as geo thermal wells, may use the spiral tube heat exchanger. This heat exchanger does away with the intricate shell design since heat performance is independent of the shell.

Alumina (Al2O3) is the most common nanoparticle that many researchers use in their experiments. There has been a lot of interest in the investigation of the thermal conductivity of nanofluids. The temperature, the Brownian motion of the particle, the interfacial layer, and the impact of additives on the thermal conductivity of small particles with smaller particle sizes are all influenced by the form of the particles. In general, the volume percentage of nanoscale rises with the thermal conductivity of nanofluids.

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