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A Review on Thermal Performance Evaluation of the Spiral Tube Heat Exchanger using Alumina Based Nanofluid

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ABSTRACT:

This research investigates the thermal performance analysis of a water-alumina nanofluid-operated spiral tube heat exchanger. The heat exchanger has two sides, one of which is filled with hot water and the other with a cold nanofluid. On the convective heat transfer coefficient, total heat transfer coefficient, and heat exchanger efficacy, the impacts of different mass flow rates and nanoparticle concentration are assessed. Additionally, as mass flow rate and concentration rise, convective heat transfer coefficient and total heat transfer coefficient rise as well. ANSYS Fluent is used to study the average outflow temperature, heat transfer factor, and heat rate for an alumina-based small molecule fed into a spiral tube at different mass flow rates. For this study, an H_2O-Alumina base nanofluid with 1% and 2% and different mass flow rates (0.04, 0.08, and 0.12 kg/s) is employed.

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

INTRODUCTION

The exchange of heat is a crucial engineering activity. the mechanism for transferring heat between moving fluids. The method of transferring heat from one fluid to another fluid is called a heat exchanger. A device known as a heat exchanger is used to transmit internal thermal energy between two or more fluids that are at different temperatures. The fluids are often separated by a heat transfer surface in heat exchangers, and ideally, they shouldn't mix. Process, energy, petroleum, transportation, air conditioning, refrigeration, cryogenics, heat recovery, alternative fuels, and other sectors all employ heat exchangers.

Due to its extreme compactness and great heat transfer efficiency, spiral tube heat exchangers are outstanding heat exchangers. One or more spirally wrapped coils are connected to a header where fluid is being pumped through a spiral-tube heat exchanger in a circular manner. In order to transmit heat between the two fluids, this spiral coil is placed inside of a shell that another fluid is cycled around outside of.

In comparison to a straight tube, a spiral tube has a faster rate of heat transmission. Additionally, spiralling allows for the accommodation of a sizable quantity of surface in a certain region. Thermal expansion is not likely to be an issue with spiral tube heat exchangers, and self-cleaning is also a possibility. A coil arrangement enclosed in a small shell, known as a spiral tube heat exchanger, maximizes both space and heat transmission efficiency. As a minimum material requirement for strength and longevity, every spiral coil assembly includes welded tube to manifold connections.

Multiple parallel tubes linked to a pipe or header by a spiral tube heat exchanger provide a tube side flow. The shell side flow route is formed by the spaces or gaps between the coils of the spiral tube bundle when it is inserted into the shell. Various flow route configurations are possible thanks to connectors on the bottom or top of the assembly that are on the tube side and shell side. The fluids flowing in a spiral pattern through the tube and shell promote heat transmission on both sides in a true counterflow configuration thanks to centrifugal force and secondary circulation flow. There are no baffles built into the system, which results in lower speeds and heat transmission coefficients. Performance is improved. The Spiral heat exchanger is known for its compactness, different arrangements combination, and high efficiency.

LITERATURE REVIEW

Prasad Gilbile, Rushikesh Pisal et al. (2022), Because of its high heat exchange property and compact structure, tube type heat exchangers are frequently employed in various industrial applications. Turbulence creates dean vortices in a curved piece of pipe, increasing the heat transfer coefficient. ANSYS Fluent is used to examine heat transfer properties such as heat transfer coefficient and heat rate for spiral, helical, and conical tubes. Pressure drop, temperature distribution, and velocity distribution are also illustrated for three separate tubes. A steady-state numerical simulation using a Fluent solver is used to anticipate the exit temperature of fluid moving through tubes. All CFD experiments take into account similar tube diameter and length. For all tube shapes, the outlet temperature of heat transfer fluid changes 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 via the spiral tube is 2% greater than that through the helical and conical tubes.

Mahmoud Abdelmagied et al. (2020) The triple spirally coiled tube heat exchanger (TSCTHE), a novel design, is experimentally studied in this paper, and its thermal and hydrodynamic properties are compared with those of a double spirally coiled tube heat exchanger (DSCTHE), which is used as a specific benchmark. A third tube was added to a DSCTHE to produce the new design. The investigation was conducted with turbulent fluid-to-fluid heat transfer in mind. The purpose of the study is to show the thermo-hydraulic properties of the TSCTHE with various operating and design parameters. Four water intake temperatures—50°C to 80°C—four flow arrangements—parallel, counter, counter-parallel, and parallel-counter—and three coil inclination angles—from 0° to 90°—were used in the studies. The experimental runs conducted varied from 500 to 6,500 for Dean numbers and from 3000 to 37,000 for Reynolds numbers. The findings show that for both counterflow and parallel flow patterns, the TSCTHE significantly improves the Nusselt number as compared to DSCTHE by 94.8% and 82.8%, respectively.

Ali Mostafazade Abolmaali et al. (2019) This study looks at the thermo-hydraulic properties of flow in spiral-wound heat exchangers with constant shell geometry on the shell side. Three-dimensional computational fluid dynamics is used to do this. Six fundamental characteristics, including start factor, tube outer diameter, number of tubes in the first layer, number of layers, longitudinal pitch, and radial pitch, may be used to establish the geometrical configuration of spiral-wound heat exchangers. The six main geometrical parameters are reduced to five non-dimensional characteristics by dividing the longitudinal and radial pitches by the tube outer diameter. 64 different geometries are modelled numerically to examine the effects of the four main non-dimensional parameters on flow and heat transfer: the number of tubes in the first layer, the number of layers, the ratio of the longitudinal pitch to the tube outside diameter, and the ratio of the radial pitch to the tube outside diameter.

Erfan Khodabandeh et al. (2018) Spiral pipe systems are one of the most popular ways to collect heat from solar ponds nowadays. This work uses numerical analysis to evaluate the effects of nanofluid concentrations and various tube cross sections on the thermal performance of a horizontal spiral coil in a laminar fluid flow. As a working fluid, water-graphene nanoplatelet/platinum hybrid nanofluids with volume concentrations of 0.02, 0.06, and 0.10% have been employed. Different mass flow rates between 0.0005 and 0.005 kg/s are simulated. As tube cross-sections, various forms such as rectangles, ellipses, trapezoids, and circles are used. As boundary conditions, uniform temperature and velocity distributions with a range of mass flow rates are applied to the geometry at the intake. The findings demonstrate that fluctuations in the average Nusselt number at lower mass flow rates are independent of the cross-sectional form of the flow. The tube with an oval cross-section has the largest Nusselt number as the nanoparticle concentration rises.

Jinxing Wu et al. (2018) The spiral coil heat exchanger's shell side condensation calculations have a shaky theoretical foundation. The theoretical model of the homogeneous flow was constructed to address the issue of pure steam film condensation heat transfer on the shell side of the spiral coil heat exchanger. Two alternative mathematical models were created and the features of heat transport were examined while accounting for centrifugal force. In the meanwhile, the first layer liquid film thickness solution formula was discovered. Based on a calculation model for the heat transfer coefficient of a one-component working fluid outside the tube bundle, taking the influence of the tube bundle into account, the theoretical formula for the heat exchanger's membrane-like condensation heat transfer was developed. The theoretical findings of Bays and McAdams as well as the two computed results from this study were each compared against experimental values in turn.

Xinyi Tang et al. (2015) In this study, experimental comparisons of the turbulent flow properties and heat transfer capabilities of twisted trilobed tubes (TTT) and twisted oval tubes (TOT) with Reynolds numbers of 8000–21,000 show that TTT has higher friction factor and better heat transfer capabilities than TOT. Furthermore, using computational fluid dynamics and a verified SST k- turbulence model, it is investigated numerically how different geometrical factors affect heat transfer efficiency and flow characteristics for various twisted spiral tubes. Different cross section forms, twisted pitches, twisted directions, and lobed numbers are some of these geometrical characteristics. The numerical result shows that the out-scribed circle (D2) tubes with bigger diameters give higher Nusselt numbers and friction factors. It is shown that decreasing the twisted pitch length P improves heat transmission efficiency and friction factor. Additionally, it has been discovered that twisted tubes with a right-to-left hand rotation perform better in terms of heat transmission than tubes with a right-hand rotation.

Y. Wang et al. (2015) Using transmission electron microscopy (TEM), the interfaces between the -Fe_2O_3/-Al_2O_3 heterostructure have been investigated. The interface displayed coherent zones divided by misfit dislocations spaced uniformly. It was established that the misfit dislocations were edge dislocations with a dislocation spacing of 4 nm. High-resolution transmission electron microscopy pictures and geometric phase analysis were used to visualize the strain fields around the misfit dislocation core. The Peierls-Nabarro dislocation model and the Foreman dislocation model were contrasted with the strain measurement data. These analyses demonstrate that the Foreman model (a = 2) is the best theoretical representation of the dislocation core's strain fields.

Paisarn Naphon et al. (2011) The heat transmission and flow properties of the horizontal spiral-coil tube are examined in the current research using computational and experimental data. A copper tube with an 8.00 mm diameter that is straight is bent into a spiral-coil shape with five turns to create the spiral-coil tube. The spiral coil's inner and outermost diameters are 270.00 mm and 406.00 mm, respectively. Water is employed as the working fluid both hot and cold. The turbulent flow and heat transport properties are simulated using the k-standard two-equation turbulence model. Using a finite volume approach and an unstructured nonuniform grid system, the key governing equations are solved. In order to validate the numerical findings, experiments are carried out to get the heat transfer and flow parameters. The comparison of the experiment's outcomes with those predicted by the model yields a fair amount of agreement. Additionally, the spiral-coil tube's Nusselt number and pressure drop per unit length are 1.49 and 1.50 times, respectively, greater than those of the straight tube.

RESEARCH OBJECTIVE

This study looked at the convective heat transport of a nanofluid made of alumina (Al_2O_3) in a spiral tube using a 3-dimensional numerical simulation (3-D). We test the effects of a spiral tube with variable mass circulation rate at a fixed wall warming temperature on the average outlet temperature, heat rate, and heat transfer coefficient. There has been a noticeable improvement in heat transfer efficiency. This makes use of an ANSYS-based computational fluid dynamics (CFD) method. Utilizing Fluent, analytical simulations were run to identify typical changes that were taken into consideration as variations in mass flow velocity (i.e., 0.4–1.2 kg/sec).

GEOMETRY SETUP AND MODELLING

A. Geometry of membrane

The geometry used for the modeling investigation was derived from scholarly research by Prasad Gilbile et al. (2022) [1]. Fig.1 shows a schematic representation of the Spiral tube and its computational domain. To feed source fluid into the computer environment, a spiral tube is employed. The spiral tube type heat exchanger is first modelled in CATIA V5 and then converted to a step file in order to ease future CFD study. By developing a number of mathematical formulae for discrete locations, one discretizes a partial differential equation. ANSYS Workbench 22 R1 and a grid system are utilized for discretization.

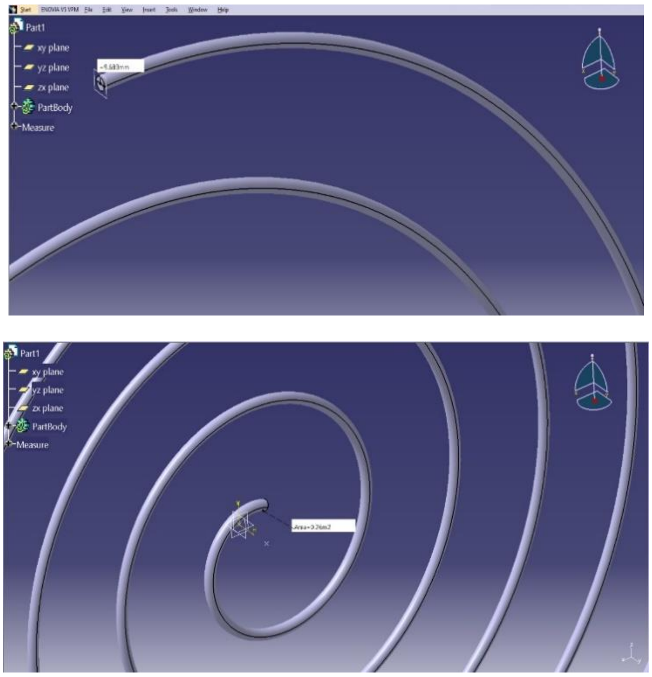

Figure 1. Modelling of the spiral tube type heat exchanger.

TABLE I

Geometry Parameters

S.N.	Parameters	Value & units
1	Inlet tube diameter	4.87 mm
2	Outlet tube diameter	4.88 mm
3	Length of the tube	8480 mm
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 step of ANSYS FLUENT 22 R1 produced a 3-D reduced model. A coarse mesh is generated when ANSYS is set up, despite the fact that grid types and simulation outcomes are correlated. Because of this need, the finished book has a jumbled overall structure. The mesh is composed of unit-sized ICEM Tetrahedron cells with triangular border faces. The experiment employs both a mesh metric and a mild flowing curvature.

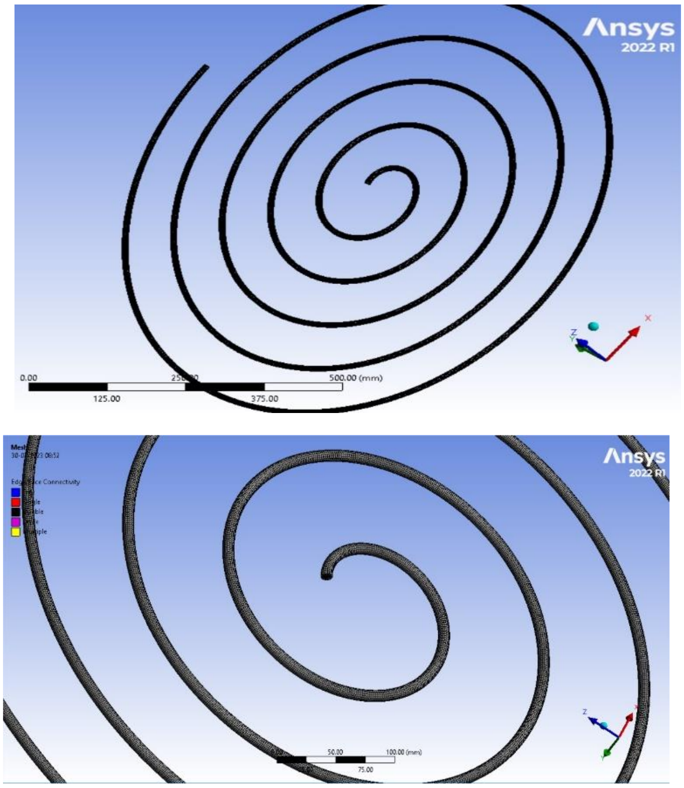

Figure 2. Meshing of Spiral tube Model.

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 intake conditions are determined by the mass flow rate and the amount of turbulence (Iin = 5%) at a certain temperature (300 K). The output condition consists of a pressure outlet condition with turbulence intensity (Iout = 5%) and a temperature of 300 K for downstream turbulence. This condition for the boundary is based on a copper metal outer wall produced at a constant temperature (353 K). The Energy equation is used in the solution. For all equations involving momentum, energy, and mass, the convergence requirements are 10-3. The Fluent's limitations are as follows:

i. With a constant inlet temperature of 300 K and a mass flow velocity varying from 0.04 kg/sec to 0.12 kg/sec, the intake boundary exists

ii. The vent's output has a pressure that is equivalent to that of the atmosphere.

iii. iii. The wall boundary condition is the stationary wall at 353 K temperature.

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

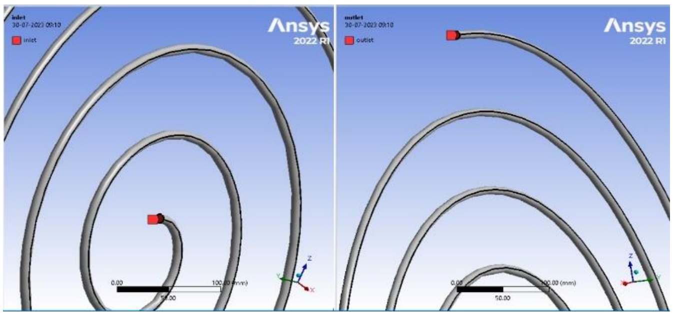

Figure 3. Name selection for applying boundary condition at different section

TABLE V

Thermodynamic Properties of alumina (Al_2O_3)-based nanofluid (1% & 2% nanoparticle) nanoparticles.

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	0.685	0.766
Viscosity	Kg/m.s	0.0011	0.0013

RESULTS AND DISCUSSIONS

This section's goal is to assess the spiral tube sections' thermal performance using nanofluids. It is evident from the numerical findings and experimental data that the average outlet temperature changing tendencies exhibit qualitative consistency. In order to boost thermal augmentation, we investigate the impacts of dispersing alumina (Al_2O_3)-based nanofluid particles in the base fluid utilizing volume concentrations of 1% and 2%. The same boundary criteria were used to the spiral tube investigation. 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.

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

We examine the effects of the suspension of alumina Al_2O_3 based nanofluid particles in the base fluid to support thermal augmentation using volume concentrations of 1% and 2%.

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

In the first case, we will be examining the heat rate, heat transfer coefficient and average outlet temperature using Al_2O_3 aluminum based nanofluid on the spiral tube shape. We will apply the different mass flow rate (0.04, 0.08, 0.12 kg/s) at the inlet condition. 1 % of alumina (Al_2O_3)-based nanofluid particles is used as a base fluid & find out the various result. After the CFD analysis we are compare these result data with the base paper, which is using the water as a base fluid. The geometric property of the spiral tube is shown in table I.

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

Using an Al_2O_3 aluminium-based nanofluid in a spiral-shaped tube, we will also investigate the heat rate, heat transfer coefficient, and average outlet temperature in the second instance. The varied mass flow rates (0.04, 0.08, and 0.12 kg/s) will be used at the inlet condition. As a base fluid, 2% of alumina Al_2O_3 based nanofluid particles are utilized to study the varied outcomes. Following the CFD study, we compare the obtained data to the basis paper, which uses water as its base fluid. The property of water & Al_2O_3 based nanofluid (1% and 2%) are shown in Table V.

B. Fluid (water) and Alumina (Al_2O_3)-based nanofluid at different Mass flow rate

After calculating the data for Average outlet temperature, heat transfer coefficient, and total heat transfer rate for different mass flow rates (0.04, 0.08, and 0.12 kg/s) utilizing a nanofluid technology based on aluminium (Al_2O_3) with 1% and 2% nanoparticles, we will be comparing each of the three cases.

CONCLUSIONS

This paper provides a numerical analysis of spiral tubes. For calculating the thermal and flow characteristics, ANSYS Fluent is employed. The following findings from the continuing numerical analytical study may be reached after the experimental investigation:

- When using Al_2O_3 nano fluid (1%) in spiral tubes, the effect on average output temperature can be greater than when using a water base fluid. And to what percentage it will increase, we will know from this result
- The heat transfer coefficient of spiral tube containing Al_2O_3 nano fluid (1%) can result in how much higher than that of spiral tube containing water fluid. What will be the effect on the heat transfer coefficient when we use 2% nanoparticles instead of 1% nanoparticles. In this way, when we increase the number of nanoparticles, then by what percentage the heat transfer coefficient may change, it will be seen from this result.
- The heating rate also plays an important role in the transfer of heat. From this analysis, we will also be able to know that as we increase the concentration of Al_2O_3 in the fluid, the percentage change in the heating rate.

A spiral tube heat exchanger standard design may be developed. It is possible to change the material, the coil's curvature, the inner diameter of the pipe, and the coil during the experiment and analysis. By connecting more than two spiral tube coils, they may be spaced apart. utilising an easy-to-remove coil connection in the case that the coil breaks.

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