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CFD Analysis of Spiral, Helical & Conical Tube

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Abstract: This research examines how coil design and other geometric aspects affect the characteristics of single phase flow and convective heat transfer. Copper tubes with internal diameters of 9.5mm, 1.5mm thickness, and 3000mm length were used in experiments on helical, conical, and spiral coil heat exchangers. According to the findings, helical coil heat exchangers had a convective heat transfer rate that was 9.54% greater than that of conical and spiral coil heat exchangers. As mass flow rate rose, Nusselt numbers climbed, demonstrating the efficiency of helical coil heat exchangers. The modeling of heat exchangers was carried out using computational fluid dynamics (CFD) software, and the CFD tool was utilized to confirm the experimental results of water outlet temperature. The results showed good agreement.

Keywords: spiral coil, flow rate, CFD, heat exchanger, geometry

I. INTRODUCTION

With uses in heating, cooling, power plants, and steam generators, heat transfer is an essential method for moving energy and entropy between sites. By preserving energy and lowering waste, it improves thermal efficiency and power generation. The goal of active and passive heat transfer improvements is to increase the efficiency of heat exchangers and systems that use coils for heat transfer. For the "Graetz problem," Kubair and Floor investigated spiral coils with an emphasis on curvature ratios. They discovered that spiral coils outperformed straight tubes in terms of efficiency. A novel spiral design was created by Drs. Madhkar and Joshi for a process industry where steam was produced utilizing recovered heat from waste. The effect of curvature ratio on heat transmission and flow creation in spirally horizontal tubing was investigated by Paisarn Naphon, who discovered that centrifugal force enhanced heat transfer and reduced pressure. In an effort to enhance convective heat transfer, Yang and Lau examined temperature, pressure, and route lines to illustrate their innovative heat exchanger. To improve thermal performance, Yakut and Sachin investigated the vibrational behavior of a conical ring. They discovered that the narrowest pitch ratio is when heat transmission occurs. In a comparison of cone-shaped helical coils, Digvijay D discovered that the cone-shaped coil had a heat transfer rate that was 1.18 to 1.38 times higher. According to Gosavi, perforated fins are more efficient and provide more homogeneous heat transmission than solid fins, which may disperse 50% to 60% of heat. Garcia discovered that wire coils outperformed twisted tapes in terms of heat transfer enhancement.

Compact Heat Exchangers:

Compact heat exchangers (CHEs) are heat exchangers that operate in liquid or two-phase streams and have an area density of more than 300m2/m3 for liquid or 700m2/m3 for gas. They are essential in many different sectors because of things like restrictions on packaging, demands for great performance, low cost, and the usage of air or gas as a fluid. In the past three decades, the design of heat exchangers has centered on lowering energy usage and lowering capital expenditure. Due to this, CHEs have become more used in process sectors where less compact heat exchangers were previously more prevalent. CHEs have benefits such smaller footprints, lower fluid inventories, and more precise process control with liquid and phase change working fluids.

Problem Statement:

Numerical analysis and comparison of helical, spiral, and conical coils.

Objectives

- Deciding on the coil's geometrical parameter.
- To use ANSYS Fluent to do CFD analysis on the spiral, helical, and conical coils.
- Comparing the numerical output to the data at hand to verify it.
- Forecasting the effective heat transfer coefficient over all coils.

Scope of Study:

- Identification of the heat transfer coefficient of the spiral, helical, and conical coils has received less research.
- Fluid flow properties and behavior in spiral, helical, and conical coils.

II. LITERATURE REVIEW

Naphon and Wongwises et al. (2005) investigated the wet-surface heat transfer properties of a small spiral coil heat exchanger. To calculate heat transfer rates and forecast performance, they carried out computational and experimental experiments. They discovered that the air and water temperatures at the output are influenced by the mass flow rate and air intake temperature. Enthalpy and humidity efficiency decline when water mass flow rate rises, and the outlet temperature drops. The Tube in Tube Helical Coil (TTHC) Heat Exchanger was computationally modeled by Vimal Kumar et al. to examine the properties of fluid flow and heat transfer at various flow rates in the inner and outer tubes. They created an empirical connection to predict heat and hydrodynamic transfer in the outer tube. The study discovered that, at constant wall temperatures, increasing inner coil tube flow rates enhances the total heat transfer coefficient. The total heat transfer coefficient rises when operating pressure in the inner tube rises as well. Both the inner and outer tubes have greater heat transmission.

Few research, however, have examined the behavior of the fluid flow and heat transfer in helical coil tubes when the curvature ratio changes for any boundary condition. Using experimental data and CFD simulations, Jayakumar et al. (2008) estimated temperature-dependent characteristics and conjugate heat transport. The analysis of heat transfer characteristics for situations of constant wall heat flux and temperature is based on the assumption that fluid properties are constant. The effectiveness of a residual heat removal system utilizing a helically coiled heat exchanger was examined by Jayakumar and Grover (1997) for a range of process parameters. When the barge is moving, Jayakumar et al. (2002) expanded on their research to ascertain the stability of the system. Following Shah and Joshi (1987), Berger et al. (1983) examined heat transfer and flow through a curved tube. (2006) Naphan and Wongwises studied the properties of flow and heat transmission in curved pipes. Prabhanjan et al. (2004), Berger et al. (1983), Nansen and Hoogendoorn (1978), and Ruthven (1971) are only a few researchers who have reported on the heat transfer and flow characteristics of helical pipes. They also reported on the increase of heat transfer in helical coil systems. An experimental study on the condensing heat transfer and pressure drop of the refrigerant R 134a in helical double pipes was done by Kang et al. in 2000. For Reynolds numbers ranging from 500 to 20,000, Yamamoto et al. (1995) investigated the impact of torsion on flow in a circular cross-section helical tube.

Constant wall temperature or constant heat flow circumstances are the main focus of most studies on heat transfer coefficients. My study, however, has examined both scenarios of constant heat flux and constant wall temperature. While constant heat flow is used in electrically heated tubes and nuclear fuel components, constant wall temperature is the ideal in heat exchangers with phase change. While Kumar et al. (2006) looked at heat transmission in a helical tube heat exchanger, Rennie and Raghavan did an experimental research on a double-pipe heat exchanger in 2005. A new analysis is required because the flow pattern in a helically coiled tube heat exchanger is very different from that in a twin pipe heat exchanger.

ANSYS Fluent (version 13.0) is used in this study to examine the heat transfer properties of a helical coil tube under various boundary and flow conditions. The analysis is based on earlier research on flow and heat transfer in helical tubes, such as the 1974 analysis by Patankar et al., the 1995 study by Yang et al., and the 1996 application of the k-model for turbulent convective heat transfer in a helical pipe with significant pitch by Yang et al. The numerical study offers insightful information on how heat transport behaves in helically coiled tubes. Performance of heat exchangers, in particular helically coiled double-pipe heat exchangers, has been examined using CFD. In order to study the features of heat transfer, Rennie and Raghavan (2005) computationally modeled a heat exchanger for laminar fluid flow. They calculated the total heat transfer coefficient for countercurrent and parallel flows by modeling the transmission of heat from hot fluid to cool fluid using PHOENICS 3.3. With a maximum error of 5%, the Dittus-Boelter equation predicted heat transfer coefficients similar to those obtained by Fluent. This implies that heat transfer coefficients may be accurately predicted using CFD modeling.

III. SOFTWARE ANALYSIS

Introduction

By using a solid edge, the modeling of the spiral coil heat exchanger is done and then conversion is done by step file for further CFD analysis. The process of discretization involves the transformation of a partial differential equation into a set of algebraic equations for discrete points. ANSYS workbench 20.2 with a grid system is used to do discretization. The boundary condition specifies the flow variation and it allows the governing equation to differentiate between different flow fields and produce a unique solution for a given geometry.

- Spiral coil - 134044, 100305, 237820, 3125770 and 3034980
- Helical coil - 113025, 100120, 234675, 2545395 and 2475925

- Conical coil - 205024, 180245, 302624, 3987210 and 3894750

From this grid distribution, it is observed that 5 grid distributions give the acceptable solution. The outlet temperature of the water is calculated at different grid distributions, it is found that the grid finer than 237820, 234675, and 302624 for spiral, helical, and conical coil gives an acceptable solution at outlet temperature and its variation within 1%.

Computational Domain

Pre-processing is the initial step in CFD analysis, involving model objective definition and computational domain identification. Over 50% of the time is spent on mesh generation. Geometries are done using Solid Edge software, and the 3-Dimensional geometrical model is imported into the ANSYS workbench. The domain meshes with quadratic mesh.

	Nodes	Elements
Spiral coil	1124393	237820
Helical coil	1090089	234675
Conical coil	1367399	302624

The main Solver

The Fluent Solver, which manages setup and solution, is the core element of CFD. It employs an absolute velocity formation, pressure-based solver, and steady time. The water-liquid fluid runs through the coil as the material parameters are set, preserving consistent fluid characteristics over the whole computational area.

- Density – 998.2 kg/m³
- Specific heat – 4182 J/ (kg K)
- Thermal conductivity - 0.6 W/ (m K)
- Viscosity - 0.001003 kg/ (m s)

The Solid material used is copper with constant properties are:

- Density – 8978 kg/m³
- Specific heat – 381 J/ (kg K)
- Thermal conductivity - 387.6 W/ (m K)

IV. RESULT AND DISCUSSION

Numerical Result for Spiral Coil:

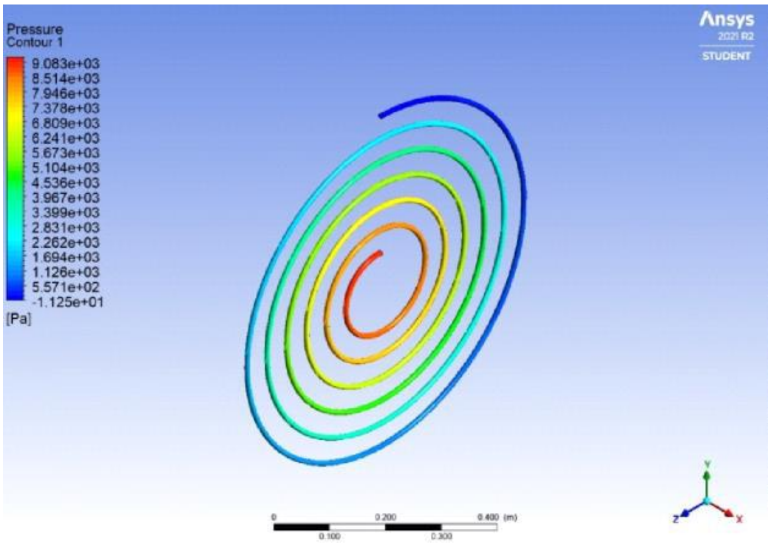

Figure 1: Pressure Contour of Spiral Coil

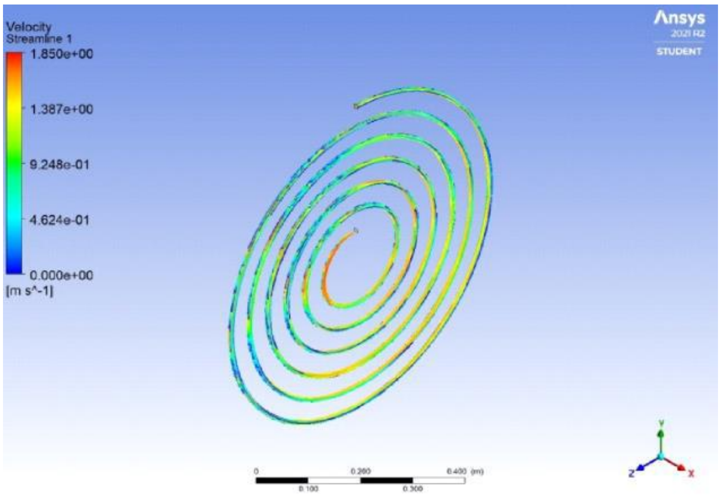

Figure 2: Velocity Streamline of Spiral Coil

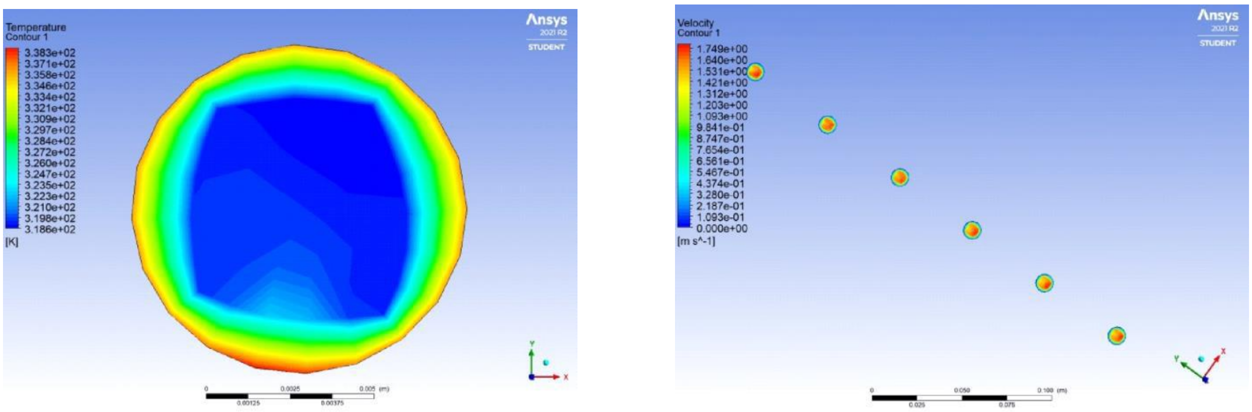

Figure 3: (a) Temperature Contour of Spiral Coil (b) Velocity Contour of Spiral Coil

Table 1: Numerical Calculations of Spiral Coil

Sr NO	Mass Flow Rate (kg/s)	Average Outlet Temp (k)	Pressure Drop (Kpa)	Heat Transfer Coefficient (W/m^2K)	Heat Rate (Kw)
1	0.04	338.39	2.63997	730.64	6.42187
2	0.06	330.71	4.18403	787.28	7.70575
3	0.08	325.23	5.79171	803.89	8.44094
4	0.10	321.46	7.52276	816.59	8.97457
5	0.12	318.57	9.27228	819.92	9.31916

Numerical Calculations for Helical Coil:

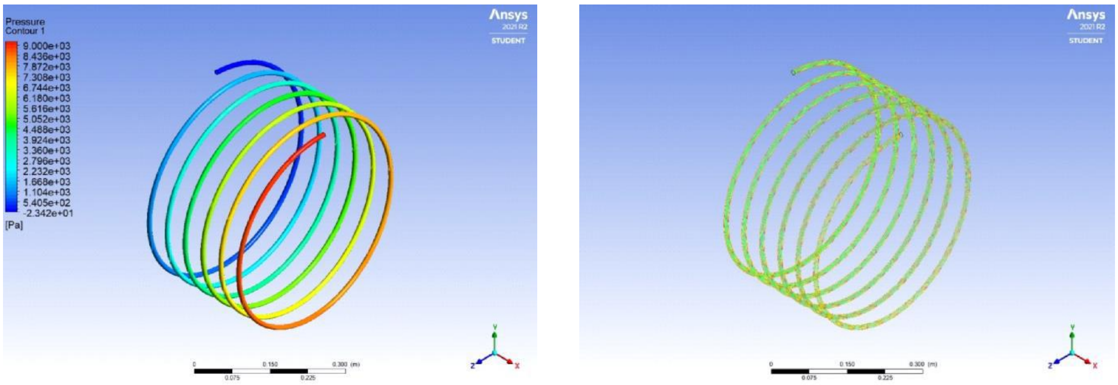

Figure 4: (a) Pressure Contour of Helical Coil (b) Temperature Volume Rendering

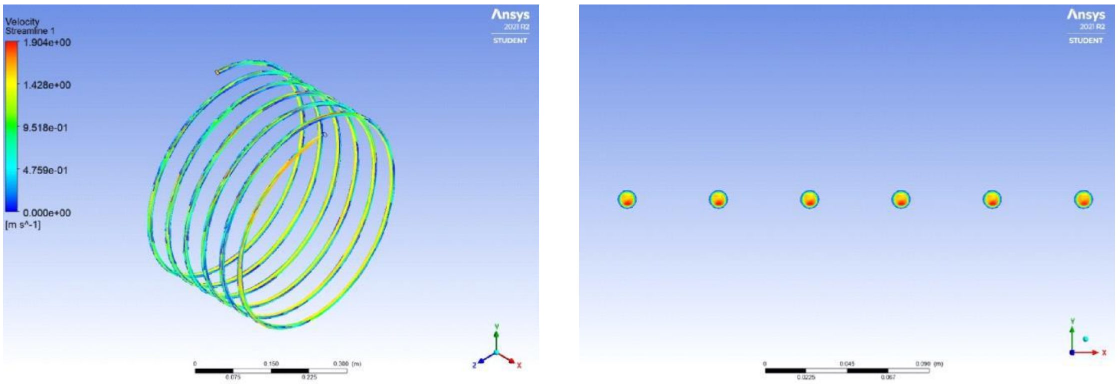

Figure 5: Velocity Streamline 2 of Spiral Coil

Table 2: Numerical Calculations of Helical Coil

Sr NO	Mass Flow Rate (kg/s)	Average Outlet Temp (k)	Pressure Drop (Kpa)	Heat Transfer Coefficient (W/m^2K)	Heat Rate (Kw)
1	0.04	338.28	2.58695	727.37	6.40347
2	0.06	330.60	4.08493	783.32	7.67815
3	0.08	325.20	5.66441	802.63	8.43091
4	0.10	321.40	7.24185	813.73	8.94948
5	0.12	318.56	9.18758	819.38	9.31415

Numerical Calculations for Conical Coil:

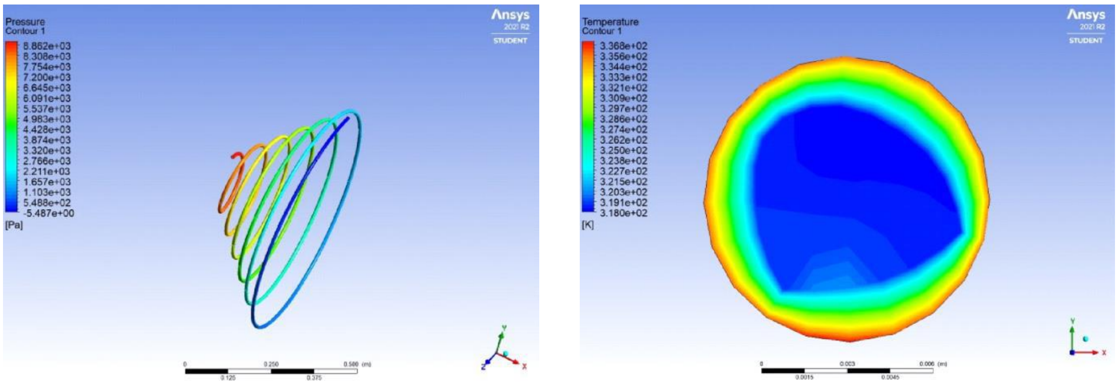

Figure 6: (a) Pressure Contour of Conical Coil (b) Temperature Volume Rendering

Table 3: Numerical Calculations of Conical Coil

Sr NO	Mass Flow Rate (kg/s)	Average Outlet Temp (k)	Pressure Drop (Kpa)	Heat Transfer Coefficient (W/m^2K)	Heat Rate (Kw)
1	0.04	337.77	2.57271	712.31	6.318166
2	0.06	329.83	4.04889	755.89	7.48494
3	0.08	324.41	5.69073	769.94	8.16661
4	0.10	320.80	7.41204	785.35	8.69856
5	0.12	317.96	9.04714	787.49	9.01304

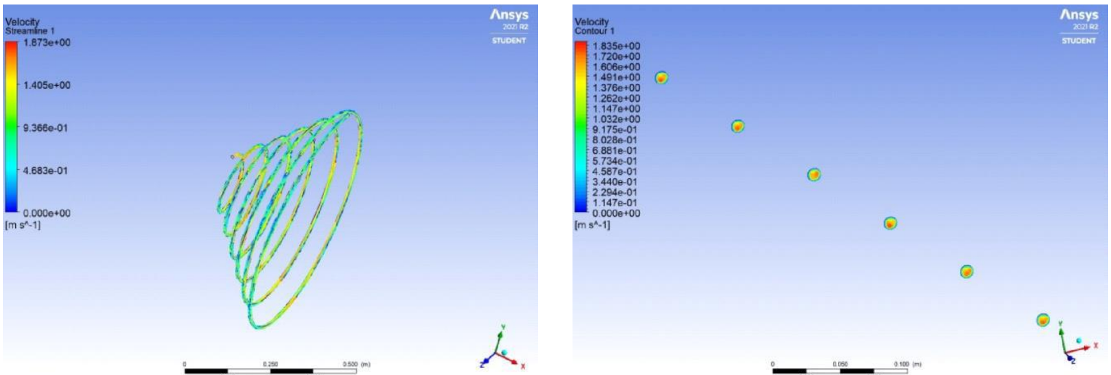

Figure 7: Velocity Streamline 1 of Conical Coil & Velocity Contour of Helical Coil

Graphical Analysis of result

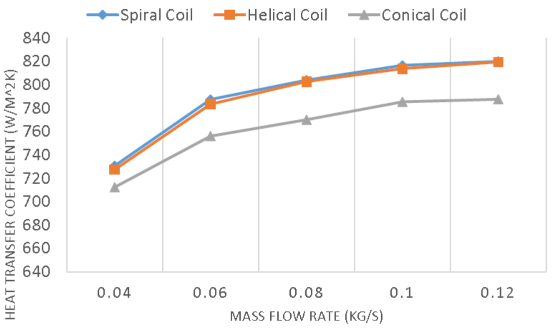

Figure 8: Mass Flow Rate Vs Pressure Drop

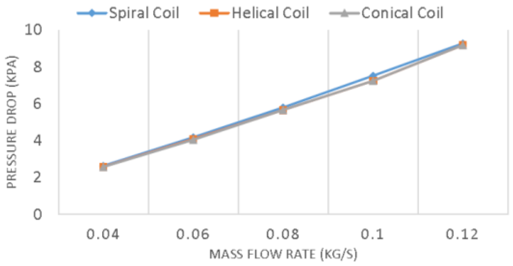

Figure 9: Mass Flow Rate vs Heat Transfer Coefficient

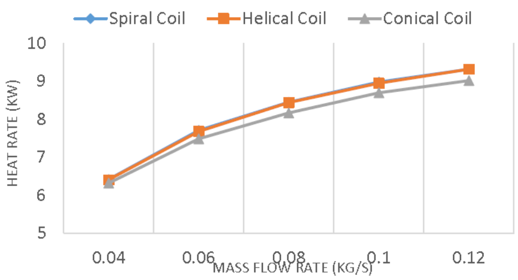

Figure 10: Mass Flow Rate vs Heat Rate

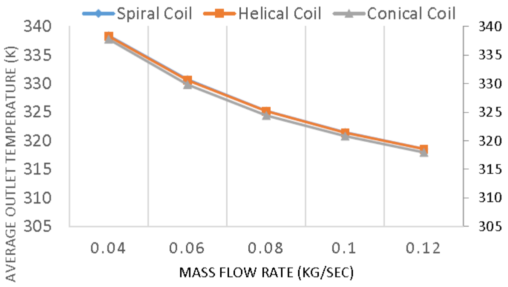

Figure 11: Mass Flow Rate VS Average Outlet Temperature

V. CONCLUSION

This work presents the numerical study on spiral, helical and conical coil, where the thermal and flow characteristics are resolved using ANSYS Fluent. After the experimental investigation following conclusions are derived out of the present numerical analysis work:

- The outcome makes clear that the relationship between heat rate and output temperature and pressure drop is valid.
- Experimentation has shown that it increases as the exit temperature and pressure drop decrease.
- The fact that Outlet temperature drops with rising pressure provides another illustration.
- As a result, mass flow rate and heat transfer coefficient both rise.
- As expected, the spiral coil has a higher heat transfer coefficient than the helical and conical coils.

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