Analyzing Heat Transfer and Flow Characteristics in Helical Coil Heat Exchangers: A Comprehensive Research Investigation

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ARTICLE DETAILS	ABSTRACT
	This research thinks about straight lines to helical and Helical coil heat exchangers to look at heat transfer and flow properties, particularly under laminar flow conditions. The undertaking explores completely created laminar flow in tube-in-tube heat exchangers utilizing both mathematical and exploratory examination. Key characteristics are inspected, for example, the cone point, pitch circle range, bend proportion, Reynolds number, Prandtl number, Dignitary number, and non-layered pitch. The discoveries show that Helical coil heat exchangers perform better with regards to heat transmission than straight cylinder and helical plans. Conical coils have the biggest grating element, while cone-moulded helical coils have heat transfer rates that are 1.12 to 1.34 times higher. The review stresses how significant twist impacts and mass flow rate proportions are to the viability of heat transmission. To all the more likely comprehend the plan and adequacy expectation of helical coil heat exchangers, connections are advanced to describe Nusselt number connections. In light of everything, this study propels our insight into the flow and heat transfer properties of helical coil heat exchangers.

1. INTRODUCTION

Heat exchangers are essential parts of many industrial operations because they transmit heat energy between fluids while keeping them apart. Helical coil heat exchangers, one of the many different designs that are possible, have attracted a lot of interest because of its small size and effective heat transfer [1]. Helical coils have been shown to exhibit higher heat transfer rates than straight pipes, particularly in laminar flow regimes. This is mainly because of the secondary flow that is created by curvature and the centrifugal forces that follow. Heat transfer is also made extremely variable by the torsion of helically coiled tubes, which complicates the temperature and velocity fields [2]. Optimising the performance and increasing energy efficiency of helical and Helical coil heat exchangers requires a thorough understanding of their complex flow and heat transfer properties.

Using a mix of numerical simulations and experimental studies, the current study aims to examine the heat transfer and flow properties of Helical coil heat exchangers in detail. The study concentrates on fully developed laminar flow conditions for both conical and helical coil designs in tube-in-tube heat exchangers. Through the examination of multiple parameters, including pitch circle radius, curvature ratio, Reynolds number, Prandtl number, Dean number, non-dimensional pitch, and cone angle, the study attempts to clarify the variables affecting heat transfer efficiency in these complex geometries[3].

Finite volume-based software, such ANSYS Fluent, can be used to do numerical simulations that shed light on the fluid dynamics and heat transfer mechanisms of Helical coil heat exchangers. Experiments are conducted in addition to these simulations to verify the numerical models and supply real-world data for comparison. The study covers a variety of geometric configurations and operating situations in order to provide a thorough evaluation of Helical coil heat exchanger performance.

The goal of the research is to determine the ideal design parameters and operating circumstances for maximising heat transfer efficiency while minimising pressure drop and energy consumption. This will be accomplished by calculating overall heat transfer coefficients and Nusselt numbers. The study also intends to suggest correlations that characterise the Nusselt number's dependence on important factors, which will aid in the design and optimisation of Helical coil heat exchangers for a range of industrial applications [4].

This research aims to promote advances in energy-efficient heat exchange systems and develop thermal management technologies by acquiring a greater understanding of the flow and heat transfer characteristics inherent in Helical coil heat exchangers. In the end, the results of this thorough analysis will be able to influence engineering procedures and direct the creation of more sustainable and effective heat transfer solutions across a range of industrial sectors [5].

1.1. Background of Heat Exchanger Technology

Heat exchanger technology is fundamental to many industrial domains, supporting operations that are essential for material processing, environmental control, and energy conversion. Fundamentally, a heat exchanger keeps fluids physically apart while facilitating the flow of thermal energy between them. Heat exchangers have a long history dating back to ancient civilizations, when they were first used for smelting metals, cooking food, and heating water. However, the growing demand for effective energy utilisation across industries did not spur the creation of modern heat exchangers until the Industrial Revolution [6].

These days, heat exchangers are used in a wide range of industries, including as chemical processing, power production, HVAC systems, refrigeration, and automotive engineering. Heat exchangers are extremely versatile and can be used in a variety of processes due to their capacity to handle a wide range of operating conditions and fluid types. There are numerous varieties of heat exchangers, each designed to meet certain needs in terms of functionality and uses [7].

For example, shell-and-tube heat exchangers are made up of a cylindrical shell that contains a bundle of tubes. Effective heat transfer across the interface is made possible by one fluid flowing through the tubes and the other circulating around the tubes in the shell. Plate-and-frame heat exchangers provide compactness and design flexibility by using a sequence of thin plates to form flow channels for the transfer of heat between fluids [8].

Extended surfaces, or fins, are fastened to the tubes in finned-tube heat exchangers, increasing the surface area that can be used for heat exchange and improving heat transfer rates. Heat recovery applications, refrigeration units, and air conditioning systems all frequently use these exchangers. Intricate flow patterns created by coil heat exchangers, such as those with helical and Helical coildesigns, improve heat transfer efficiency, especially in laminar flow regimes [9].

The need for increased cost-effectiveness, environmental sustainability, and energy efficiency is what propels heat exchanger technology forward. More dependable and efficient heat exchangers have been developed as a result of advancements in manufacturing procedures, materials science, and computer modelling. Heat exchangers continue to be at the forefront of efforts to optimise thermal management and improve process efficiency as industries work to minimise energy consumption and reduce environmental impact [10].

1.2. Advantages of Helical coil heat Exchangers

Helical coil heat exchangers are appealing options for a range of commercial and industrial applications because of their many benefits. Their small design, which enables effective utilisation of space in

confined spaces, is one of their main features. Since the Helical coildesign maximises the amount of surface area available for heat transfer in a comparatively small footprint, it is especially well-suited for spaces-constrained applications, like portable heat exchange units or small HVAC systems [11].

In addition, Helical coil heat exchangers provide better heat transfer qualities than conventional straight-pipe designs. More turbulence and mixing within the fluid streams are encouraged by the coil's curvature, which creates secondary flow patterns like swirls and vortices. This results in higher heat transfer rates, particularly in laminar flow regimes, which enhance thermal efficiency and lower energy consumption [12].

Helical coil heat exchangers also have the benefit of being adaptable to a variety of fluid types and operating environments. Conical coils require little adjustment to suit a wide range of fluid characteristics and temperatures, whether working with liquids, gases, or multiphase mixtures. Because of their adaptability, they can be used in a variety of sectors, such as the manufacture of food and drink, chemicals, and pharmaceuticals [13].

Helical coil heat exchangers have additional benefits in terms of cleaning and maintenance. Because of the coil's smooth, continuous surface, less debris and fouling agents accumulate, requiring less frequent maintenance and downtime. Helical coil heat exchangers' accessible design also makes cleaning and inspection simple, which improves their dependability and operational efficiency even further [14].

Helical coil heat exchangers can also be designed to fit particular space and performance needs. Engineers can maximise heat transfer efficiency while guaranteeing compatibility with current infrastructure and process requirements by modifying factors like coil diameter, pitch, and length.

Helical coil heat exchangers are valuable assets in a wide range of industrial and commercial applications, helping to improve efficiency, cost-effectiveness, and sustainability. These benefits include their compact design, enhanced heat transfer capabilities, versatility, ease of maintenance, and customisation options[15].

1.3. Objectives of the study

1. Examine how the Nusselt number is influenced by the Dean, Prandtl, and geometrical characteristics.
2. Examine how the Dean number affects the inner tube and annulus friction factor.
3. Determine how the heat exchanger's efficacy and NTU relate to one another.
4. Gain a deeper comprehension of the heat transfer performance and flow dynamics by examining the velocity and temperature distribution, contours, and velocity vectors.

5. Evaluate various geometric arrangements for critical performance measures, such as mass flow rate, pressure loss, and heat transfer.

6. Put out correlations to explain how the Nusselt number is influenced by the Dean, Prandtl, and geometrical factors.

1.4. Significance of the Study

The research's conclusions have a big impact on how Helical coil heat exchangers are designed, optimised, and used in different sectors. This work contributes to our understanding of flow phenomena and heat transfer mechanisms in Helical coilshapes, which will help engineers design thermal management systems that are more sustainable and effective. In the end, the study advances heat exchanger technology and aids in initiatives to lessen industrial processes' negative environmental effects and increase energy efficiency.

2. LITERATURE REVIEW

Kareem (2017) carried out research on the performance comparison between straight double tube heat exchangers and double pipe helical tube heat exchangers, with an emphasis on optimisation. By delving into the complexities of heat transfer mechanisms in helical tube designs, this research advanced the subject and provided useful insights on how to improve heat exchange efficiency through design changes and optimisation strategies [16].

Mahmoudi et al. (2017) utilized a TiO2/water nanofluid in an exploratory and mathematical investigation of constrained convection heat transfer and tension decline in helically coiled pipes. The target of this study was to further develop the heat transfer effectiveness of helical coil heat exchangers by applying modern liquid innovation. The review widened the scope of imaginative techniques for heat trade advancement by offering smart data about the potential benefits of nanofluids in improving warm conductivity and heat transfer productivity [17].

Sheeba et al. (2020) made a significant contribution to our understanding of innovative coil topologies by studying the heat transfer and flow characteristics of a Helical coil heat exchanger. The study clarified Helical coilperformance through extensive experimental analysis, revealing possible benefits in fluid flow dynamics and heat transfer efficiency. Through examining the distinct features of Helical coil heat exchangers, this study yielded important information for streamlining heat transfer procedures and creating effective heat exchange systems [18].

Sheeba, Abhijith, and Prakash (2019) studied the heat transfer and flow properties of a helical coil heat exchanger by experimental and numerical methods. Their research constitutes a noteworthy effort towards comprehending helical coil arrangement performance. Through the combination of numerical

simulations and experimental data, the study shed light on the complex dynamics of fluid flow and heat transmission in helical coil heat exchangers. By providing insights that can guide design optimisations and operational strategies for enhanced performance in a range of industrial applications, the study's findings deepen our understanding of the underlying mechanisms governing heat transfer efficiency and fluid dynamics in helical coil configurations [19].

Li et al. in (2022) A thorough analysis of flow parameters and heat transfer enhancement in concentric pipe heat exchangers. Their paper provides a thorough overview of flow dynamics and heat transfer enhancement approaches within concentric pipe designs by synthesising and consolidating the body of previous literature. Through a methodical analysis of numerous techniques for improving heat transfer and fluid flow characteristics, the review offers important insights into the basic ideas and optimisation approaches for concentric pipe heat exchangers. This review's thoroughness makes it an invaluable tool for practitioners and researchers studying thermal engineering and heat exchanger design. It helps them gain a better understanding of the flow characteristics and heat transfer mechanisms in concentric pipe configurations and provides recommendations for creating more sustainable and effective heat exchange systems in a variety of industrial sectors [20].

3. EXPERIMENTAL SETUP AND PROCEDURE

Concentrates on the flow properties and heat transfer of the Helical coiltube in tube heat exchangers have been brought out through tests.

3.1. Details about the heat exchanger's geometry

Figure 1 shows the basic computation for a Helical coilpipe, while Figure 2 shows the finer points of a cylinder cross-segment. The mathematical details of the cylinder in tube Helical coil heat exchanger used for this trial investigation are displayed in Table 1.

1.1. Experimental setup

Figure 4.3 shows the schematic outline of the trial configuration. Helical coil heat exchangers, or the test area, were constructed using copper tubing and conventional copper connections. The cone plot for the coil in the Helical coil heat exchanger example is completed by directing mathematical analyses. The cone point's optimal value of 75 degrees is determined through math. The Helical coil heat exchanger used in the investigation uses a coil with a base curve, pitch, and length comparable to those of the helical coil. A Helical coil heat exchanger with 2.5 turns has a length of 2.865 metres and a cone point of 75°. Concentrates on the flow properties and heat transfer of the Helical coiltube in tube heat exchangers have been brought out through tests.
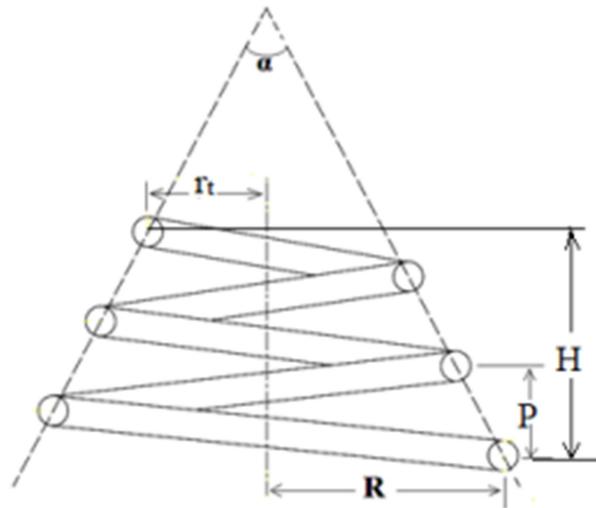
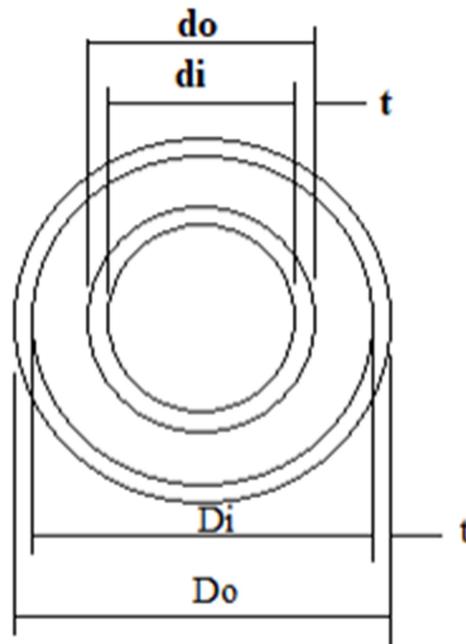**Figure1:** Basic geometry of a Helical coilpipe

Figure 2: Tube cross-section

The hot and cold liquids are separated by divergent syphons, and valves control the flow rate. Hot water is supplied by an electric heater that has a 15-liter capacity.

Table 1: Coil Dimensions Utilised in This Study

Symbols	Parameter	Dimensions
d_o	Outside diameter of inner tube	8.5 mm
di	Inside diameter of inner tube	6.8 mm
T	Wall thickness	0.5 mm
D_o	Outside diameter of outer tube	14.8 mm
D_i	Inside diameter of outer tube	15.5 mm
R	Base Radius of coil	236.9 mm
H	Height of the coil	120.6mm
r_t	Top radius of coil	150 mm
P	Axial pitch of coil	49 mm
α	Cone angle	75°
L	Total length of coil	2.865 m

the chamber inside. To appraise the temperature at critical areas inside the heat exchanger, changed T type thermocouples are utilized. The thermocouples utilized have a precision of ± 0.5 °C. To gauge the flow rates, flow meters with an exactness of ± 1% of full scale are utilized. With an accuracy of 0.6% of the perusing, the strain drops in the inward and repeal tubes are assessed utilizing differential pressure checks. Temperature information is gotten utilizing a data gathering engineering. 6.85% is the most elevated weakness as indicated by the Nusselt number appraisal.

Figure 4 shows the various stages of the trial contraption's production. The cylinder is wound on a metallic example with a conical profile to create the double cylinder helical cone coil. The incredibly fine salt powder was nicely packed and compressed into the inward and annular area before the cylinder was wound into a tube shape. After bowing, water was used to remove the salt particles. During the bowing framework, care was made to protect the coil's indirect cross piece, limiting the gamble of mutilation.

Similarly, when bowing, care was taken to maintain a constant pitch. The end associations close when they are bound by the copper tube. Plans were prepared for both coils' straight sections and boiling water exits. Two layers of heated protections were applied to the heat exchanger's exterior to prevent heat-related environmental events. The first layer was protection constructed of polyurethane foam (PUF), and the second layer was asbestos rope.
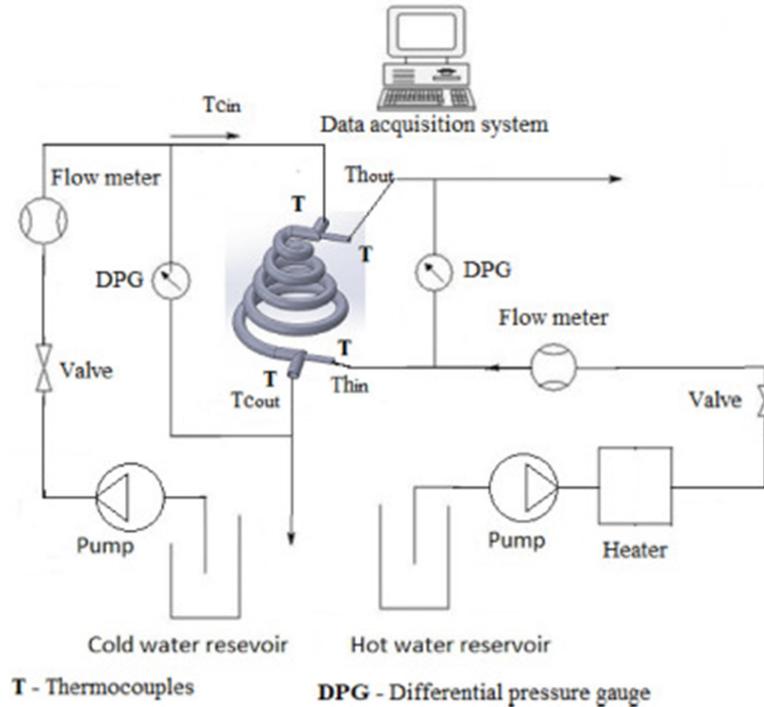
Figure 3: Experimental setup

Figure 4: Fabrication of Helical coil heat exchanger

1.2. Experimental Procedure

In the counterflow game plan, tests are led on a Helical coiltube in tube heat exchanger. Laminar flow for the two fluids came about because of contrasts in flow rates inside the limits of the inward chamber and the annulus. This limit is laid out utilizing associations that Ito recommends.

Critical Reynolds number for the helical coil is given by:

$$Re_{crit} = 20000 \left(\frac{r}{R}\right)^{0.32}$$

Based on the aforementioned relationship, the fundamental flow rates for this computation are 4.25 lpm for annular flows and 0.950 lpm for inward flows, respectively. At a time span of lpm, the flow rates were adjusted from 0.1 lpm to 1 lpm. We experimented with every possible combination of these flow rates in the annulus and the inward cylinder. As a result, the annular Senior member number in the scope of 25-251 (Reynolds number in the scope of 160-1595) and internal Dignitary number in the scope of 98-975 (Reynolds number in the scope of 478-4798) were created. The hot liquid's gulf temperature ranges from 45°C to 65°C, while the cool liquid's ranges from 25°C to 29°C. The hot liquid's power source temperature ranges from 25°C to 55°C, while the cool liquid's ranges from 30°C to 62°C. The temperatures, pressure drops, and flow rates were recorded once the framework reached a stable condition, which was used in the calculations.

1.3. Numerical Setup

The conical chamber heat exchanger's 3D estimation is shown utilizing ANSYS 14.5 Arrangement Modeler and AutoCAD 14.0. The ANSYS 14.5 workbench's cross segment module was utilized to make the grid. At first, a marginally more unpleasant cross segment was gotten. Mixed cells (Tetra and Hexahedral cells) with both three-sided and quadrilateral countenances at the limits are available in this cross segment. Furthest degree conceivable, coordinated hexahedral cells are used. The objective is to diminish numerical scattering however much as could be expected by orchestrating the cross segment sensibly, especially nearby the wall area. Later on, the solid fluid wall contacts are all obliged by extension layers, bringing about a fine cross segment.

In Figure 5, the calculation accomplished for endorsement is shown. Utilizing Recognizable 14.5, the heat transfer and flow examination of the chamber in the chamber heat exchanger is completed.
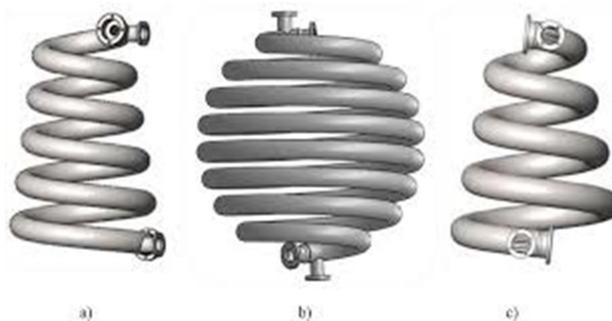
(a) Model of the Helical coil heat exchanger

(b) Meshed geometry

Figure 5: Helical coil heat exchanger

Table 2: Major and minor diameters of elliptical cross-section

Coil	a (mm)	b (mm)	a/b ratio
Coil 1	6	3.205	1.7023
Coil 2	5.5	3.45725	1.3078
Coil 3	5.2	3.75799	1.1506
Coil 4	3.90	3.99	2
Coil 5	3.1505	6	0.9945
Coil 6	3..5575	4.8	0.8806
Coil 7	3.8150	4.1	0.658

The heat transmission properties of a conical helical coil tube in a tube heat exchanger have been investigated numerically by adjusting geometric parameters, namely the inner tube's cross-section. By keeping the inner surface area of the elliptical tube constant, the inner pipe cross-section is made elliptical while the outside pipe cross-section remains round. By altering the inner elliptical tube's major diameter (a) to minor diameter (b) ratios, many geometries can be produced. With the exception of the inner tube properties, the helical coil heat exchanger with elliptical cross-section has the same dimensions as previously described. Table 2 lists the several main and minor diameter combinations that were employed.

2. RESULTS AND DISCUSSION

An analogous to what is seen below, a network free review was conducted prior to the itemised mathematical review.

2.1.Grid independent study

The lattice is gradually modified using edge measuring and expansion development rates as part of the matrix autonomy study (figure 6). This is repeated again until two successive modifications show a resilience of about 1% difference.
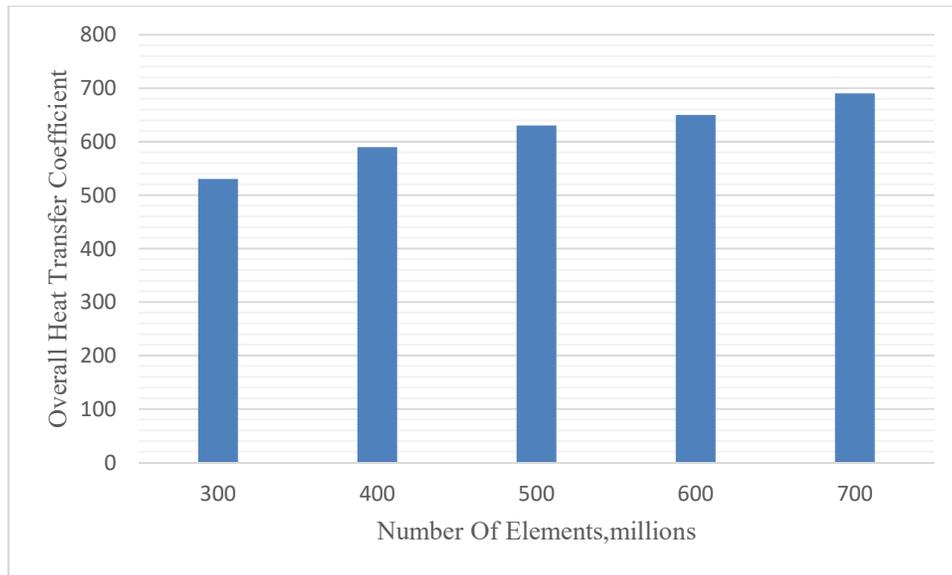

Figure 6: Grid independent study

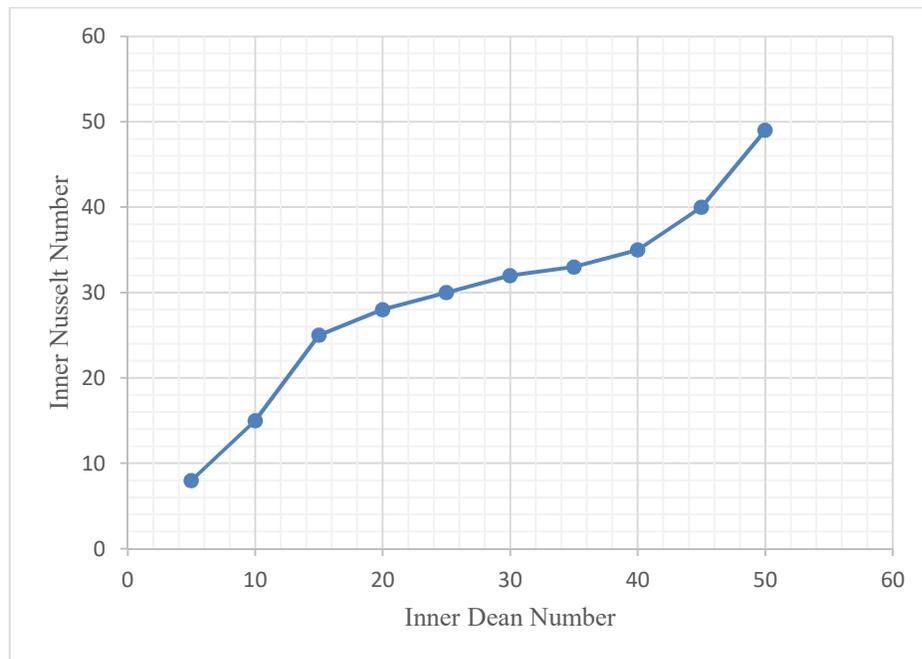### 2.2.Effect of Senior member number on inward Nusselt number

Figure 7: Impact of Dean number on inner Nusselt number

The range of exploratory upsides of the Senior member number and the inward Nusselt number are displayed in Figure 7. The attributes obtained through mathematical research are also presented for review. The greatest extreme divergence is only 8%, and the mathematical attributes agree with the exploratory features. Heat transfer coefficients are calculated using the Wilson plot technique using the exploratory data. When the Dignitary number varied between 95 and 975, the Inward Nusselt number increased by 86.5%. The auxiliary flow also increases as the cylinder side liquid speed rises. The expansion in helper flow guarantees that the fluid inside the chamber mixes authentically, expanding the heat transfer coefficient.

2.3.Effect of annulus Reynolds number on inner Nusselt number

Studies have focused on how the annulus Reynolds number affects the internal Nusselt number by altering the annulus flow rate. Figure 8 shows a variety of internal Nusselt numbers with inward Senior member numbers for various annulus Reynolds numbers. The annulus Reynolds number increases in response to an increase in the annulus mass flow rate, which lowers the temperature gradient across the liquids. The mean temperature of the hot liquid decreases because the cool liquid transfers more heat. A decrease in the inward Nusselt number follows an increase in the annular Reynolds number.
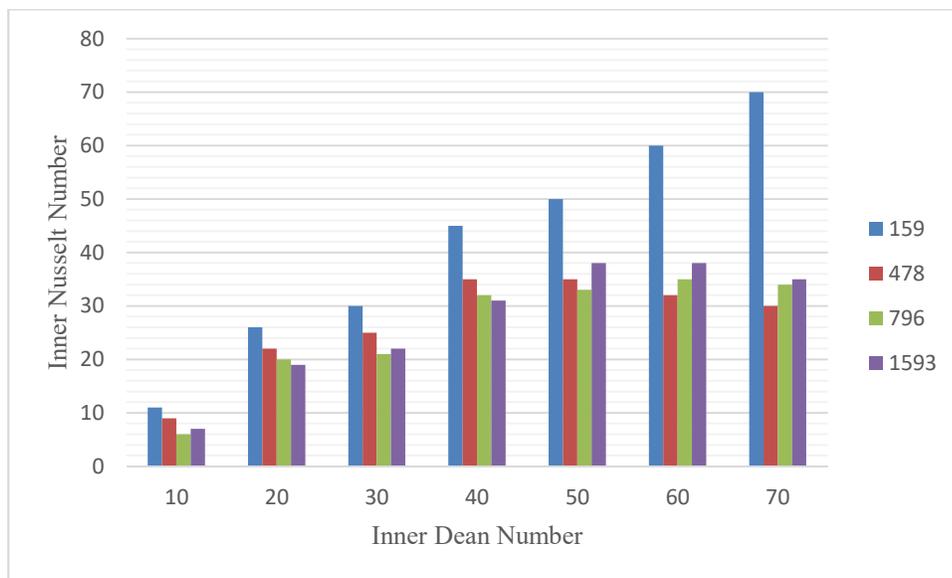

Figure 8: Impact of Dean number on inner Nusselt number

2.4.Effect of annulus Dignitary number on annulus Nusselt number

The impact of the annulus Nusselt number on the annulus Dignitary number is portrayed in Figure 9. The outcomes got from the numerical examinations are contrasted and the exploratory information. The most extreme variance is 8%, and there is strong agreement between the trial results and the

mathematical analysis. The annulus Nusselt number expands by 185% at the moment where the Senior Member number changes from 25 to 250. Radiating power increases as annular flow rate increases, enhancing both the basic and optional flows.
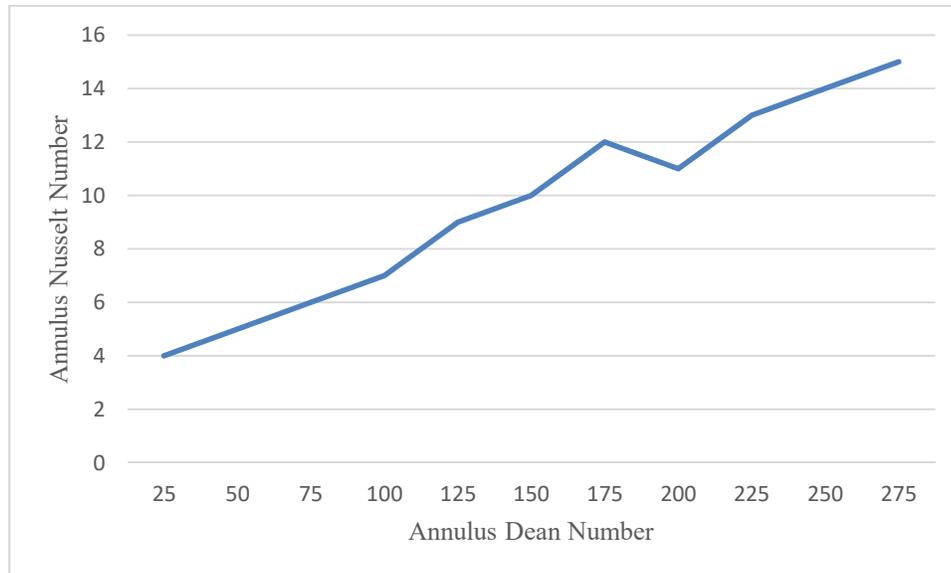

Figure 9: Impact of Dean number on annulus Nusselt number

3. CONCLUSION

In conclusion, under laminar flow conditions, this work offers a comprehensive investigation of heat transfer and flow dynamics in helical and Helical coil heat exchangers. Key factors, such as Reynolds number, Prandtl number, Dean number, and geometric dimensions, were carefully examined through a mix of experimental and numerical analyses, resulting in a sophisticated understanding of heat transfer mechanisms in such arrangements. Even though Helical coil heat exchangers have higher friction factors than helical and straight tube layouts, the results highlight their superior heat transfer capabilities. Furthermore, the research clarifies the complex interactions between variables like mass flow rate ratios and torsion effects, offering important information for the modelling and design of helical coil heat exchangers. In thermal engineering applications, the research leads to more precise and effective design techniques by putting forth correlations to characterise Nusselt number dependence. All things considered, this work is a substantial breakthrough in our knowledge of the flow and heat transfer properties of helical coil heat exchangers, opening the door for the future development of more environmentally friendly and effective heat exchange systems.

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