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Thermal Performance Analysis of Heat Exchanger Due to Geometrical Parameter Changes in The Tube: A Review

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ABSTRACT:

Applying the fundamental ideas of heat transfer processes to increase the rate of heat removal or deposition on a surface is known as "heat transfer enhancement." The boundary layer theorem states that a laminar sublayer occurs where the fluid velocity is lowest in the flow of a clean fluid through a heat exchanger's tube. Thermal conduction is primarily responsible for heat transport through this stationary layer, acting as the principal heat transfer barrier. If this stagnant layer is abolished or reduced to a limited extent, heat transport may be improved from an engineering perspective. Three approaches are available to boost the heat transfer rate in single-phase heat transfer processes. Choosing a lower free flow sectional area for higher fluid velocity results in a decrease in the laminar sublayer's thickness. A secondary approach involves designing novel surfaces that intensify local turbulence, while a third method involves using mechanical inserts that facilitate local turbulence. The pressure drop restricts the applicability of these options. In this paper we have reviewed heat transfer enhancement by considering different types of geometry changes of the heat exchanger.

Keywords — Computational fluid dynamic, helical impression, pitch, water (working fluid), pressure drop, Temperature, velocity.

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.

Most heat exchangers are shell-and-tube heat exchangers, which not only have a solid structure, but also have high reliability and wide adaptability. Currently, the consumption of shell-and-tube heat exchanger accounts for about 70% of all heat exchangers.

There are two ways to enhance the heat transfer efficiency: one is to change the shell side structure and promote fluid turbulence; the other is to strengthen the heat exchange element, which is the heat exchange tube. The most common shell side structure of traditional heat exchanger is bowing baffle heat exchanger and modified the tube geometrical parameter, which is simple in structure and easy to process, but has high resistance and pressure drop and low heat transfer efficiency. There are many ways to increases the heat transfer of the heat exchanger. Geometrical change in the parameter of the heat exchanger is the common way to increase or decreases the thermal exchanges.

Changing fluid flow

Increase the flow rate is the one way to improve flow rate, process length, and disturbance is to divide the tube side and shell side of a shell and tube heat exchanger. Note that a number of things restrict the flow rate's ability to rise. The optimal flow rate or the flow rate permitted by the fluid conveying gear should thus be chosen after taking into account a number of criteria in the design or practical application.

Jet impinging technique involves directly heating or cooling a solid surface by spraying a fluid via a nozzle with a slit or circle shape. Convective heat transfer coefficient rises dramatically because of the short flow path and thin boundary layer caused by the fluid immediately impinging on the solid wall. Impingement heat transfer of two-phase jet occurs when a liquid jet impinges on a heated surface and the heat flux is strong enough to cause boiling.

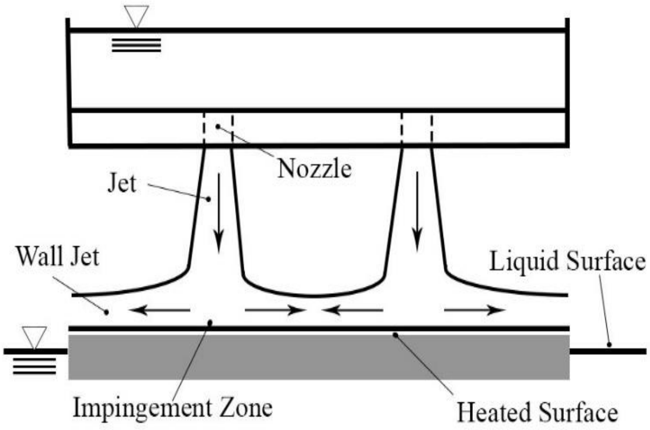

Fig.1.2 Jet impingement

Numerous insert types, including metal wire, metal spiral rings, disk-shaped parts, twist iron, and wing-shaped objects, may be inserted inside or outside of tubes to promote heat transmission, boost disturbance, and harm the flow boundary layer. To improve heat transmission and create a powerful rotating flow, for instance, a thin metal strip twisted in a helical pattern is introduced into the tube. It can still function as a fin and increase the heat transfer surface if it can make close contact with the tube wall.

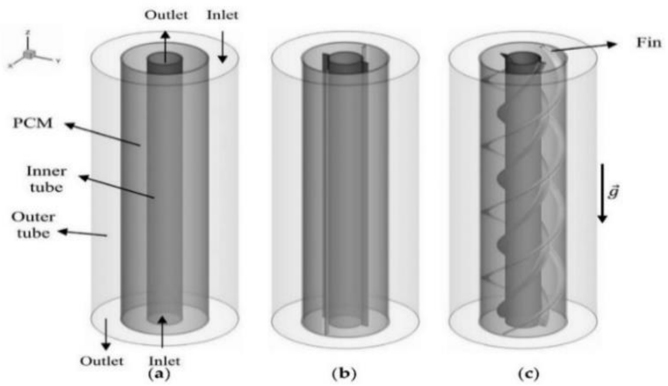

Fig.1.3. Twisted thin metal strip inserted into the tube

By the Adding of rotating device the fluid will create secondary circulation due to the centrifugal force of the spinning flow, increasing the heat transfer. Some of the aforementioned inserts, such twist iron and metal spiral wire, have other features in addition to the ability to create rotating flow. We would want to discuss a few unique parts or apparatuses that can generate rotational flow in this study. Vortex generators, for instance, have the ability to force a fluid at a certain pressure to flow violently in a tangent direction via a tube. The findings indicate a relationship between Reynolds number and the degree of heat transfer amplification.

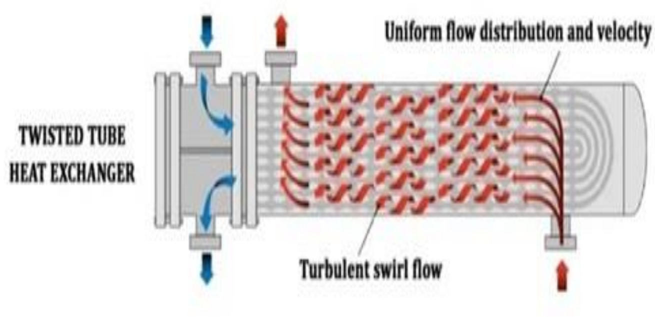

Fig. 1.4. metal spiral wire to produce rotational flow

Physical properties of alternating fluids

The convective heat transfer coefficient is significantly influenced by the fluid's physical characteristics. Larger heat transfer coefficients are often seen in fluids with higher thermal conductivity and volume specific heat. In cooling equipment, for instance, the volume of water cooling is much less than that of air cooling because the α value between the wall and air is between 1 and 60 W/(M^2·°C), while the α value between the wall and water is between 200 and 12000 W/(M^2·°C). Adding chemicals to the fluid is another approach to alter its characteristics.

Change the heat exchange surface condition

The property, shape and size of the heat transfer surface have great influence on the convective heat transfer coefficient.
Raising the wall roughness helps with forced flow heat transfer inside the tube as well as forced flow heat transfer outside the tube and during boiling and condensation. Under various flow and heat transfer circumstances, the same roughness has varying effects on heat transfer. It need to be taken into account for industrial use.

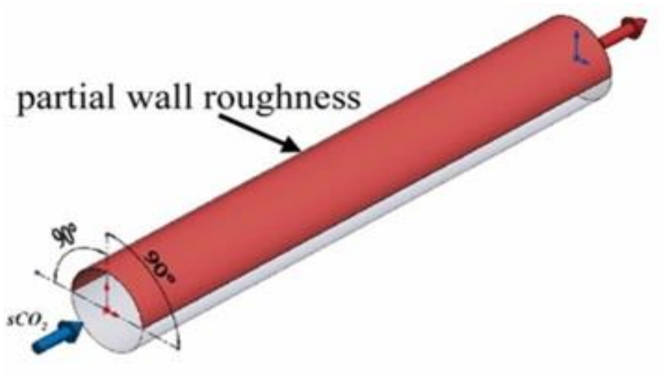

Figure 1.5. Increasing the wall roughness

A variety of unique pipe shapes and surface grooving, including elliptical, spiral, corrugated, variable cross-section, and longitudinal groove pipes, may also be utilised to raise the convective heat transfer coefficient. Since the elliptical tube's equivalent diameter is less than the circular tube's under the same cross-sectional area, the heat transfer coefficient is higher. The fluid's direction and velocity will fluctuate continually owing to the altered surface form, which will boost turbulence and decrease boundary layer thickness in addition to slightly increasing the heat transfer area of other specially designed tubes.

By sintering, EDMing, or cutting a thin, porous layer of metal onto the metal tube surface, the heat transmission from condensation and boiling may be improved. For example, the USA's high heat flow tube, Japan's E-tube, Germany's T-tube, China's DAE, etc. Furthermore, by placing a porous body on the heating surface in a boiling heat exchange liquid, the so-called "suction" technique of continually removing steam via the porous heating surface may enhance film boiling heat transmission

LITERATURE REVIEW :

An overview of the published research in a subject of study is called a literature review. This may serve as the main topic of a paper, or it may be a subsection of a longer work. Reviews of the literature demonstrate your analysis of the body of information and your ability to support your thesis or research questions
This article reviews recent experimental results on heat transfer for different geometry of heat exchanger with the goal of identifying future technical demands and research initiatives.

Harsh V. Malapur, Sanjay N. Havaldar, Gary A. Anderson (2022) [1], Earlier studies have looked at ways to improve heat transfer via the use of surfaces, pipes with circular dimples, and other methods. The size and placement of dimples, for example, have a major impact on the pipe's flow and thermal properties. This computer research looked at five different pipe topologies with internal dimples. Utilising water as the working fluid and steel pipes with internal dimples, ANSYS Fluent 16 was utilised to simulate the flow. A comparison was made between the thermal performance of a plain tube heat exchanger and the effects of dimple number and diameter on flow and thermal parameters using five different internal dimple designs. Tube heat exchangers with interior dimples or inner protrusions saw a larger pressure drop in the flow channel from the entry to the exit. The dimples increased the heat transfer coefficient when the pipe heat exchanger was compared to the plain tube heat exchanger. Heat exchangers (HE) with a greater pressure loss were found, even though they had superior thermal performance than straightforward pipes.

Table 1 Various Configuration models used for analysis.

Various Configuration models used for analysis.

Design Number	Design Details
1	Plain cylindrical pipe
2	Plain square pipe
3	Dimpled Pipe with zero pitch
4	Dimpled Pipe with 15° helical pattern
5	Dimpled Pipe with 30° helical pattern
6	Square Dimpled Pipe with zero pitch

In this analysis the fluid's temperature in the dimpled pipe Hot water (320 K) is contained in the inner segment, while the pipe (298 K) is located in the outside part. The distribution shows that the hot water cools as it gets closer to the outlet.

This experiment shows the tiny dimples that cause a spinning motion and pressure loss in the fluid streamline. The exit temperatures, pressure losses, and velocities of the different designs are shown in Table 2. It was found that when the dimples' skewing rises, so does the outflow velocity.

Table 2 Designs configuration and their results.

Designs configuration and their results.

Design Number	Outlet Velocity (m/s)	Pressure drop (Pa)	Outlet Temperature (K)
1	1.032	0.348	302.10
2	1.026	0.317	301.43
3	1.695	29.692	300.26
4	1.710	30.66	299.45
5	1.737	30.983	302.30
6	1.676	29.658	302.04

Plain pipes do not have as good heat transmission characteristics as dimpled pipes do, according to the CFD simulation. The arrangement also has a role; a better thermal efficiency is associated with a helical pattern with a lower pitch angle.

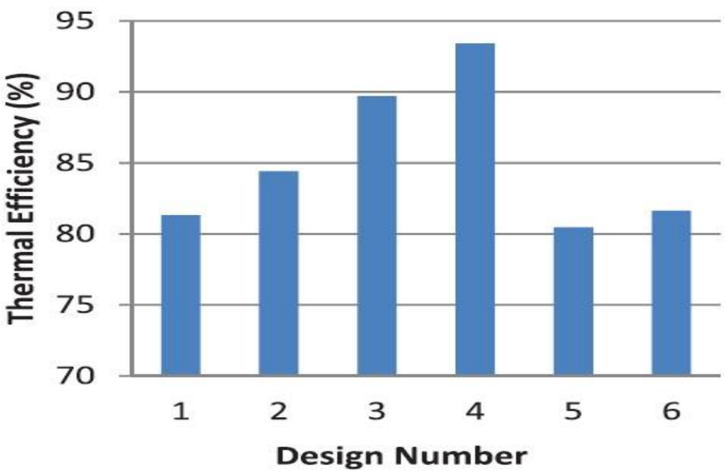

Figure 1.6

The flow has superior heat transfer qualities because of the higher-pressure loss over the length, which is made possible by the dimples. Moreover, it changes with the Reynolds number of the flow. The pipe's friction factor increases with a lower Reynolds number, improving heat dissipation. The relationship between the number of dimples and the thermal efficiency of the pipe was also seen; the pipe with more dimples had a better thermal efficiency. The thermal efficiency was found to be significantly influenced by the size of the dimples; a bigger dimple diameter yielded increased thermal efficiency. Based on the numerical analysis, it can be concluded that the presence of dimples in the tube HE enhances heat transfer between the hot and cold fluids through the tube HE walls by promoting flow mixing and the formation of a thermal boundary layer.

S. Padmanabhan, Obulareddy Yuvatejeswar Reddy et al. (2022) [2] Increasing the heat exchanger's thermal efficiency immediately reduces costs and increases the amount of energy and materials consumed. Enhancing heat exchange will also significantly raise heat efficiency as well as the cost-effectiveness of design and operation in applications where thermal transfer activities are necessary. Double tube heat exchangers are best suited for high temperature and high-pressure applications due to their narrow diameters. Although they are cheap, they do spread to the other kinds in a very large manner. Various methods were devised to get the required rate of heat transfer at a cost-effective pumping capacity while adhering to the heat exchanger's stated design and lifespan. Helical inserts are the most often used and effective method of improving heat exchangers.

The purpose of this study is to examine the ANSYS CFX tool's performance for twin tube heat exchangers with helical inserts. An investigation of the heat flow and temperature distribution throughout the pipe will be conducted in comparison to the heat exchanger without helical inserts.

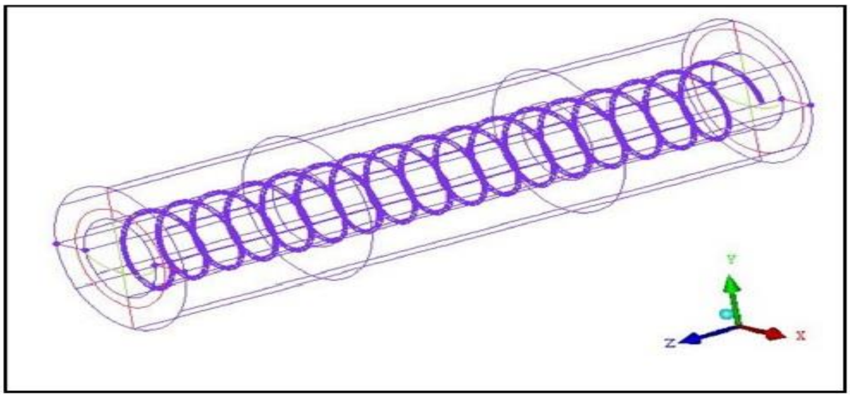

Figure 1.7 Heat Exchanger Model with Helical Insert (Pitch = 5 mm).

Making a solid that defines a field of fluid flow is the primary objective of geometry development. The research process starts with this. The present models were gathered in terms of size and geometric descriptions. Table 3 will simulate helical dimensional inserts in the heat exchanger.

In this phase, the region and geometry growth are decided. The entry and exit are represented by the form of the 2D area. Restrictions must be set aside for outlets, entrances, and other locations that are defined by regional planning. The model for the double heat exchanger in the specified sizes, with 5 mm and 15 mm helical inserts, is seen in Figure 1. The areas will spread out naturally when the mesh is built. The CFD model's process of spatial discretization is called mesh creation.

The Tetrahedron portion makes the decisions for meshing. This method evaluated the form of the Tetrahedron mesh unit and the mesh element size 375458 in order to produce surface and volume meshes.

Table 3 Boundary condition and specification of CFD Analysis

Boundary conditions and specifications of CFD analysis.

Domain Specifications	Data
Flow type	Counterflow
Fluid	Water
Fluid domain	Double tube
Solid domain	Turbulator and tube surface
Turbulator material	Aluminium
Tube material	Copper
Heat transfer Model	Thermal Energy
Inlet Boundary Conditions – Cold fluid	28 °C with 0.2 m/s
Inlet Boundary Conditions- Hot Fluid	90 °C with 0.2 m/s

More rotations on the tape result in increased turbulence and heat transmission. As a result, heat transport is more efficient. At medium turn up to fifty percent, twisted tape with the best output in comparison to a straight casing was produced. The middle turn's twisted tape performs between 21 and 29 percent better than it does in other circumstances. When twisted band inserts were used instead of a single pipe, the heat transmission rate changed by 13 to 16 percent.

Table. 4 Heat transfer characteristics analysis.

Variable		Without Helical Insert	Pitch 5 mm	Pitch 15 mm
Temperature [C]	Inlet	25.81116	25.71435	25.75052
	Outlet	26.21485	26.92986	26.90444
	Difference	0.403692	1.215505	1.153915
Wall heat transfer coefficient [W m^{-2} K^{-1}]		764.4623	1253.036	1004.4551

This is a result of the swirl flow that enters the DPHE internal tube. As can be seen from the data, helical inserts significantly raised the tube's heat transfer coefficient. The coefficient of heat transmission significantly increased for both the 5 mm helical pitch inserts and the 15 mm pitch inserts when compared to the normal model, increasing by 63.91% and 31.39% respectively. The turbulence generated during the transmission is the cause of this.

Prasad Gilbile, Rushikesh Pisal et al. (2022) [3] Because of its small design and excellent heat exchange capacity, tube type heat exchangers are often used in a wide range of industrial settings. A curved pipe's turbulence causes dean vortices to develop, which raises the heat transmission coefficient. ANSYS Fluent is used to analyse heat transfer properties for spiral, helical, and conical tubes, including heat transfer coefficient and heat rate. Furthermore, three distinct tubes' temperature distribution, velocity distribution, and pressure drop are shown. Using a Fluent solver and a steady-state numerical simulation, the exit temperature of fluid passing through tubes is estimated. Every CFD experiment takes into account tubes with comparable lengths and diameters. For all tube forms, the mass flow rate influences the heat transfer fluid's output temperature. At a mass flow rate of 0.04 kg/s, the spiral tube reaches a maximum exit temperature of 338.39 K. The heat transfer coefficient of a spiral tube is 2.57% greater than that of a conical tube and 0.44 percent higher than that of a helical tube at a mass flow rate of 0.04 kg/s. Furthermore, compared to helical and conical tubes, the spiral tube has a 2% higher pressure drop.

Since tubes are crucial, several tube types—such as helical, spiral, and conical—are taken into consideration. Their internal comparisons are then carried out to identify the most efficient tube; in this case, computational fluid dynamics (CFD) methods utilising ANSYS is used. Using fluid, analytical simulations are run to determine parameter variations. These variations were then considered as mass flow rate changes (i.e., 0.4–1.2 kg/sec). All simulations were examined to determine the heat transfer behaviour of each tube, and the results were plotted on graphs.

In the solver, the Energy equation is used. The convergence conditions for all equations involving mass, momentum, and energy are $10^{-3.}$ The boundary conditions of the Fluent are as follows:

- Boundary conditions for the inlet: The inlet is a mass flow inlet with a constant inlet temperature of 300 K and a mass flow rate that varies from 0.04 kg/sec to 0.12 kg/sec.
- Boundary condition for the outlet: The vent has a pressure equivalent to that of the atmosphere.
- The boundary condition for the wall is the stationary wall at 353 K.

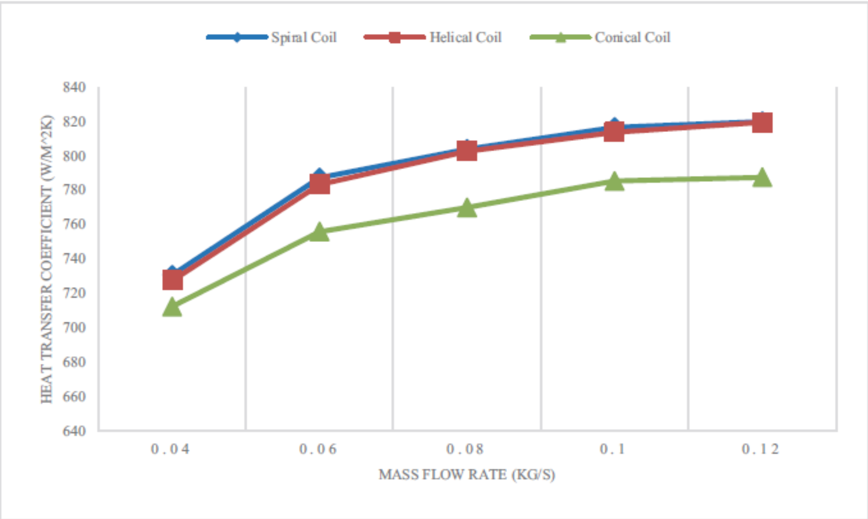

Figure1.8. Mass flow rate vs Heat transfer coefficient.

This paper offers a numerical research utilising ANSYS Fluent to determine the thermal and flow properties of spiral, helical, and conical tubes.
More than 0.032 percent for helical tubes and 0.18 percent for conical tubes is the average spiral tube outlet temperature. Less than 0.15 percent of the diameter of the helical tube is made up of the conical tube's diameter. The findings indicate that the spiral tube's pressure drop is more than 2% of the helical and conical tubes' respective pressure drop. It is expected that the spiral tube would have a greater heat transfer coefficient than the helical and conical ones. Compared to the helical tube and the conical tube, the spiral tube has a heat transfer coefficient that is 0.44 percent and 2.57%, respectively, greater.

N. Sreenivasalu Reddy, S. Gowreesh Subramanya et al. (2021) [4] The purpose of this paper is to examine the effects of various tube-in-tube helically coiled heat exchanger topologies. The fluid flow and heat transfer in a tube-in-tube helical heat exchanger were predicted using commercial CFD models. By changing the dean number, several inner tube configurations have been simulated. After verification, it is discovered that the numerical findings closely match the data that has been published in the literature. Friction factor and Nusselt Number are calculated for various angular locations. When using geometry E instead of a circular tube, the Nusselt Number and friction factor rise by 17.05% and 15%, respectively, at a Dean number of 400.

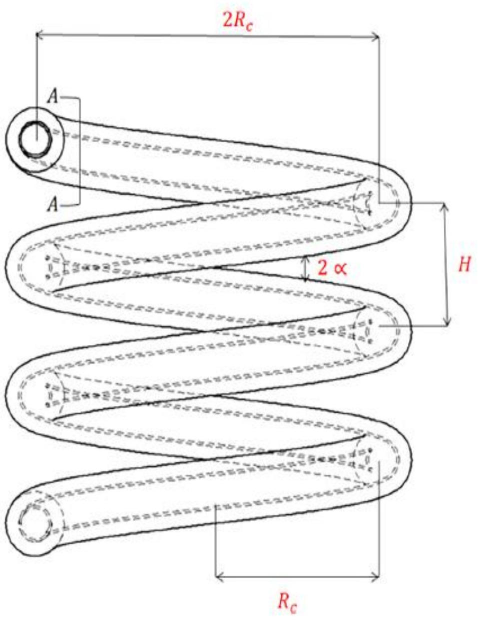

Figure1.9. Geometry of a helical pipe.

The helically formed coil tube heat exchanger with its specifications is shown vertically in the illustration. The definition of curvature $\delta = d/Rc$ is the ratio of the tube diameter to the coil diameter, whereas $\lambda = H/\pi RC$ is the ratio of the pitch to the developed length of a single turn. The expression $De = Re\ \delta^{0.5}$ refers to the Dean Number, where Re is the Reynolds Number.

Table 5 Geometry details and Geometry with different shaped tubes

Parameters	Inner Tube	Outer Tube
External diameter (m)	0.026	0.0508
Helical diameter (m)	0.77	0.77
Pitch (m)	0.1	0.1
Velocity (m/s)	0.01	0.038–0.068
Dean number (dimensionless)	200	200–400
Prandtl number (dimensionless)	7	7

Geometry	Design Modification
A	Circular Tube
B	Square Tube
C	Ellipse Tube
D	Pentagon Tube
E	Hexagon Tube

Comparing the Nusselt number to the plain tube at a dean number of 200, Figure 1.10 demonstrates that it is elevated 1.125, 1.145, 1.175, and 1.2 times.

The fluctuation of the total heat transfer coefficient with the Dean Number is seen in Figure 1.12. The total heat transfer coefficient rises with the Dean Number as predicted. The total heat transfer coefficient is higher for the geometries from B to E than it is for the round tube.

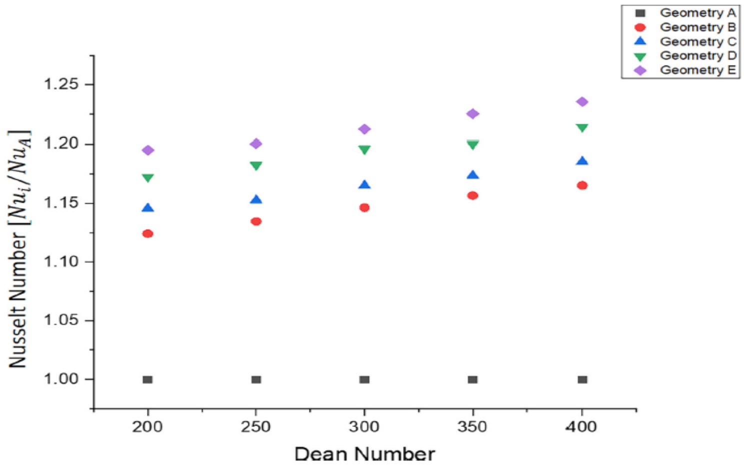

Figure 1.10 Comparison of Nusselt number for individual geometries.

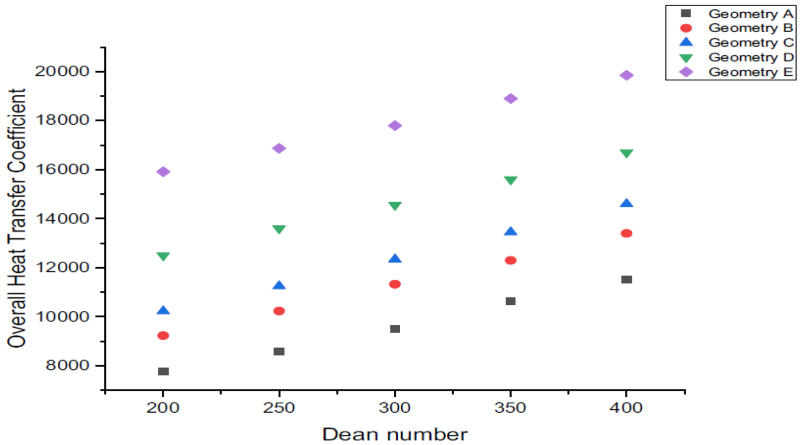

Figure 1.12 Overall heat transfer coefficient versus Dean number.

In order to examine heat transfer and the friction factor of fluid flow in the annulus area of a tube in tube helical heat exchanger for the laminar regime at various Dean Numbers, a numerical analysis has been conducted. The behaviour of the overall heat transfer coefficient under the influence of various heat exchanger inner pipe cross-sections showed that the Dean Number had a significant impact on both effectiveness and overall heat transfer coefficient. Higher friction is produced with low Dean Numbers in tube helical heat exchangers due to the usage of an inner pipe with a variable geometry. For Geometry B through E, the Nusselt Number is higher than that of a circular tube and was seen to rise with Dean Number. When comparing the Nusselt number and friction factor with a circular tube, the adoption of geometry E results in increases of 17.05% and 15%, respectively, at a Dean number of 400. In comparison to Geometry A, the Nusselt number in Geometry B rises by 13.73%. Nusselt numbers are found to grow by 1.45% in geometry B to C and by 3.24% in geometry C to E.

CONCLUSIONS :

Based on the current research, it can be inferred that variations in the heat exchanger's geometrical parameter, heightened turbulence intensity, and increased tangential flow caused by different kinds of inserts are the primary causes of the heat transfer augmentation in all situations. The improvement of heat transport is significantly impacted by modified geometrical characteristics, such as dimpled tubes, helical impressions and inserts, among others. The heat transfer coefficient vs design number plot in the numerical analysis is reviewed here. After a dimpled pipe heat exchanger was analysed, design 5 was determined to have the maximum heat transfer coefficient, around 9000 W/m^2K [1]. Based on the data, it can be concluded that the helical inserts have significantly raised the tube's heat transfer coefficient. The helical (1004.4551 W/m^2K) insertion pitch of 15 mm has a high value. When 5 mm pitch inserts are used, the heat transfer coefficient significantly improves and approaches an exit. [2]. Additionally, it can be observed that the rate of heat transfer has a maximum at the beginning (i.e., from 0.04 kg/sec to 0.06 kg/sec) and then gradually changes. The conical tube's coefficient of heat transfer is also lower than the other two, while the spiral and helical tubes exhibit relatively similar rates of heat transfer [3].
Many researchers have conducted extensive research on the use of various modified parameters in the heat exchanger to improve the heat transfer characteristics covered in this review; however, there is still unexplored territory when it comes to other tube geometries, such as conical, parabolic, frustum, etc., which could be the subject of future studies.

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