Heat Transfer Enhancement in Double Tube Heat Exchangers Using Twisted Tape Turbulators

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Abstract

This dissertation investigates the effect of twisted tape turbulators on the thermal performance of double tube heat exchangers to improve sustainability and energy efficiency. The need to enhance these exchangers' heat transfer mechanisms which are essential for a variety of engineering applications was the driving force behind the study. The objective was to investigate how well twisted tape turbulators with various twist ratios could improve thermal performance. ANSYS Fluent was used to perform a thorough computational fluid dynamics (CFD) analysis that included turbulators with twist ratios of 3.5, 4, and 4.5 to simulate the heat transfer process.

As part of the methodology, the heat exchanger's intricate models were built, and the turbulators were integrated to evaluate the effect they had on pressure drop and heat transfer. The results showed that turbulators greatly increase the rates at which heat is transferred. Most effective turbulator had a twist ratio of 3.5, which increased the Nusselt number and friction factor by about 97.6% and 160.50%, respectively at a Reynolds number of 550 when compared to the configuration without twisted tape turbulator inserted. But this improvement came at the expense of higher pressure drops, so the use of turbulators must be done with balance.

These findings have far-reaching implications, as they indicate that double tube heat exchanger efficiency could be significantly increased by the strategic application of twisted tape turbulators. This improvement not only contributes to the ongoing effort to use energy in a more sustainable manner, but it also offers a feasible way to achieve significant energy and financial savings in industrial applications that depend on effective heat exchange mechanisms.

Keywords: Double tube heat exchangers, Twisted tape turbulators, Twist ratio, Nusselt number, Friction factor, Thermal performance, Heat transfer enhancement, CFD

Acknowledgements

This study, which examines how twisted tape turbulators affect the efficiency of double tube heat exchangers, was made possible by the advice, assistance, and contributions of many people. To everyone who has contributed to this journey, my sincere gratitude is extended.

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I would especially like to thank my peers and colleagues for their helpful criticism at different points in the study. Their viewpoints and criticisms have been extremely helpful in improving the research's quality and refinement. I sincerely thank my family and friends for their unwavering support, tolerance, and encouragement. Their confidence in my skills and their unwavering support have been my pillars of strength during this difficult but worthwhile project. In addition, I would like to thank the earlier researchers in the field whose work has provided the foundation for this project. Their work has served as both an inspiration and a useful resource.

Lastly, I would like to express my gratitude to everyone else who helped make this project a success, whether directly or indirectly. Your help has been tremendous, and this accomplishment is proof of the strength of teamwork and mutual understanding.

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Nomenclature

Roman Symbols

Symbol	Description	Unit
Q	Heat transfer rate	W
U	Overall heat transfer coefficient	$W/m^2.K$
d_i	Inner diameter of the tube	mm
d_o	Outer diameter of the tube	mm
L	Length of the tube	m
m	mass flow rate	kg/s
T	Temperature	K
P	Pressure	Pa
ΔP	Pressure drop	Pa
f	friction factor	-

Greek Symbols

Symbol	Description	Unit
η	Thermal performance factor	-
μ	Dynamic viscosity	$Pa.s$
ν	Kinematic viscosity	m^2/s
λ	Thermal conductivity	$W/m.K$
ρ	Density	kg/m^3

Subscripts

Symbol	Description
TR	Twist Ratio

Dimensionless Numbers

Symbol	Description
Re	Reynolds number
Pr	Prandtl number
Nu	Nusselt number

1 Introduction

1.1 Heat Exchangers

Heat exchangers are used regularly in many different engineering applications and are essential to the effective transfer of thermal energy. Their adaptability extends to a wide range of industries, including power generation, oil and gas processing, chemical processing, HVAC systems, and automotive technology. A heat exchanger's basic function is to enable the transfer of thermal energy between two streams of fluid without requiring direct contact between them. The integrity of each fluid is preserved while thermal energy transfer is ensured by this separation. Thus, heat exchangers are crucial parts that have a big impact on operational performance and energy efficiency in a lot of different industries.

1.2 Double Tube Heat Exchangers

For heat transfer applications, one configuration the double tube heat exchanger stands out for its efficiency, affordability, and simplicity. The two concentric tubes that make up the double tube heat exchanger are the inner and outer tubes, through which the primary and secondary fluids, respectively, pass. Numerous industrial processes find this design appealing because to its numerous benefits, which include low pressure drop, minimum fouling, and ease of production. That being said, there is a continuous effort to improve the heat transfer efficiency of double tube heat exchangers.

Figure 1: An industrial Double tube heat exchanger (www.jcequipments.com, n.d.)

1.3 Different Approaches to Heat Transfer Enhancement

In the field of engineering, efficient heat transfer is essential to the best operation of many kinds of systems and applications. Numerous methods have been created by researchers to improve heat transfer in heat exchangers. These techniques fall into two general categories: passive and active strategies.

1.3.1 Passive Heat Transfer Enhancement

To improve heat transfer, passive methods rely on the built-in properties of heat exchanger components or fluid flow. Using expanded surfaces inside the heat exchanger tubes, like fins, is an example of a passive approach. Fins enable better thermal performance without requiring more energy input by increasing the surface area available for heat transmission. When simplicity, dependability, and low energy usage are crucial, passive approaches are frequently used (Tavousi *et al.*, 2023).

1.3.2 Active Heat Transfer Enhancement

Techniques for actively enhancing heat transfer include purposefully adding energy or other external components to a heat exchanger system to increase heat transfer. Vortex generator addition is one of the promising active technologies under investigation. To create turbulence and alter the flow patterns, vortex generators are objects or structures that are carefully positioned within a heat exchanger's fluid path. These generators can take on several shapes, including delta wings or winglets. Vortex generators enhance the heat exchanger's total heat transfer efficiency by introducing controlled vortices into the flow, which in turn increases the convective heat transfer coefficient (Tavousi *et al.*, 2023).

1.4 Problem Statement and Rationale

The motivation behind this research lies in the pressing need for more energy-efficient and cost-effective heat transfer solutions in an era marked by increasing concerns about sustainability, energy conservation, and environmental impact. Heat exchangers play a pivotal role in various industrial processes, and their energy consumption has a substantial impact on both operational costs and greenhouse gas emissions. Enhancing the performance of heat exchangers is imperative for achieving energy efficiency and reducing environmental footprints.

This project is dedicated to a detailed numerical exploration of the heat transfer performance of double tube heat exchangers when equipped with twisted tape turbulators of different twist ratios, in comparison to heat exchangers without turbulators. Through a combination of numerical simulations, this study aims to shed light on the profound impact of turbulators on heat transfer coefficients, thermal efficiencies, and pressure drops within double tube heat exchangers. The objective is not merely to understand the underlying fluid dynamics but also to provide valuable insights that engineers and researchers can harness to optimize double tube heat exchangers for diverse applications.

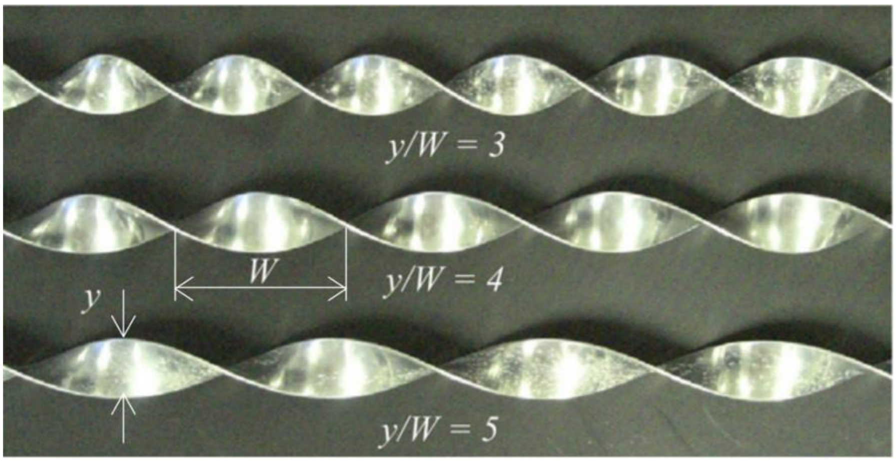


Figure 2: Twisted tape turbulators with different twist ratios (Eiamsa-ard and Seemawute, 2012)

1.4.1 The Significance of Heat Transfer Enhancement

Efficient heat transfer is fundamental across various engineering disciplines and daily activities, particularly in heat exchangers. The ability to transfer heat between two fluids with minimal losses and within a reasonable timeframe is crucial for maintaining optimal temperature conditions, enhancing energy conversion, and preventing overheating. The heat transfer coefficient (U) quantifies the rate at which heat is transferred in each heat exchanger configuration. A higher U-value signifies better heat transfer efficiency, resulting in quicker temperature equalization between fluids an essential goal in heat exchanger design and operation.

The integration of turbulators into heat exchangers provides an intriguing avenue to achieve higher U-values. Turbulators, inducing vortices and turbulence in fluid flow, disrupt laminar boundary layers, promoting enhanced heat transfer. This controlled chaos introduced by turbulators has the potential to substantially increase the convective heat transfer coefficient, leading to a more energy efficient heat exchanger. This efficiency improvement can contribute to reduced energy consumption, decreased operational costs, and a smaller environmental footprint.

In the realm of heat exchangers, the double tube heat exchanger, comprising two concentric tubes, has gained attention for its simplicity, durability, and reliability in various applications. The inner tube handles the primary fluid requiring heating or cooling, while the outer tube facilitates heat exchange with the primary fluid. However, like other heat exchangers, the double tube heat exchanger faces challenges, primarily achieving high heat transfer coefficients without an excessive increase in pressure drop. Striking an optimal balance between enhanced heat transfer and minimal energy consumption is crucial. Turbulators offer an innovative solution, intensifying the heat transfer process within the double tube heat exchanger and addressing this delicate equilibrium.

1.5 Aims and Objectives

The aim of this project is to assess the influence of twisted tape turbulators on the heat transfer efficiency of a double tube heat exchanger. To achieve this aim, this project structured around several key objectives:

1. To evaluate the impact of twisted tape turbulators on heat transfer efficiency quantitatively by comparing thermal performance metrics between various twist ratios (3.5, 4, 4.5), such as the Nusselt number and thermal performance factor.

2. To examine the pressure drop and friction factor, as well as how they relate to twist ratios, in order to assess the hydraulic effects of employing twisted tape turbulators.

3. To determine which twist ratio maximises the enhancement of heat transfer.

4. To model heat transfer processes using sophisticated Computational Fluid Dynamics (CFD) simulations, validate the results against empirical data and existing literature to ensure accuracy and reliability of the findings.

1.6 Scope of the project

This project is dedicated to a numerical assessment of the impact of twisted tape turbulators on the heat transfer performance of a double tube heat exchanger. The scope encompasses the variation of twist ratios to analyse their influence on heat transfer coefficients and pressure drops. The investigation will employ ANSYS Fluent, a Computational Fluid Dynamics (CFD) software, for simulations aimed at comprehensively studying heat transfer coefficients and pressure drop characteristics. The study will draw comparisons between configurations with and without turbulators, with the objective of quantifying the improvement in heat transfer efficiency. Scheduled to run from September 2023 to April 2024, the project holds implications for the optimization of heat exchanger performance in industries where efficient heat transfer is crucial.

2 Literature Review

2.1 Evolution of heat exchangers

The development of heat exchangers dates to the late 1800s, when Albrecht Dracke's patent for a plate heat exchanger in 1878 was granted. In the early 1900s, heat exchangers that were economically feasible began to appear. Considerable progress was made between the 1880s and the 1920s, particularly in plate heat exchangers, which found use in pasteurizing milk, among other applications. The shell and tube heat exchanger was invented in the 1920s and was first applied in the oil industry for things like oil heaters and coolers. Together, Otto Happel and Professor Ludwig Prandtl developed the closed-circuit air conditioning system in 1920, which used the elliptical finned tube as a breakthrough in air-cooling technology (Metz, 2022).

In the 1930s, copper alloys were used in the UK to create brazed plate-fin heat exchangers, and Sweden invented the spiral plate heat exchanger. Numerous industries, including aviation engines, nuclear engineering, cryogenic air separation, ammonia manufacturing, offshore processing, and syngas production, have found use for plate-fin heat exchangers. Work on air-cooled condensers for steam turbines was started in 1935 by Otto Happel and Dr. Kurt Lang, and eventually culminated in the first air-cooled condenser pilot project at Waltrop Colliery in 1939. With a better knowledge of shell side pressure drop, shell and tube heat exchanger technology made enormous improvements in the 1940s. The shell and tube heat exchanger was the result of a patent application filed in 1955 by Babcock & Wilcox Co. and approved in February 1965, which furthered the continuous progress of heat exchanger technology (Metz, 2022).

2.2 Double tube heat exchangers

A heat exchanger that uses two tubes to do its job is known as a double tube heat exchanger. Heat and air are commonly transported using this unit. Enabling two distinct flows to interact at a conductive barrier to help with thermal energy transfer is the aim of a heat exchanger. Double tube heat exchangers are a particular kind of tube with a central conductive barrier that keeps liquids from flowing in one direction and an adjacent pipe from forming an annulus. The working fluid is carried by the inner half of the tube, while the outer half serves as a conductor. Through the inner tube, the resultant heat exchange takes place. While the cold flow passes through the outer shell, the hot flow passes through the inner tube. Double tube heat exchangers are commonly employed in counterflow applications, which use the flow in the opposite direction. Double tube exchangers are widely used in high-temperature and high-pressure applications because of their robust construction and capacity to expand. When the hot flow is greater than the cold flow during counterflow, they might also experience a temperature cross. The design, fluid characteristics, and flow types are the primary determinants of heat exchanger performance (Louis et al., 2022).

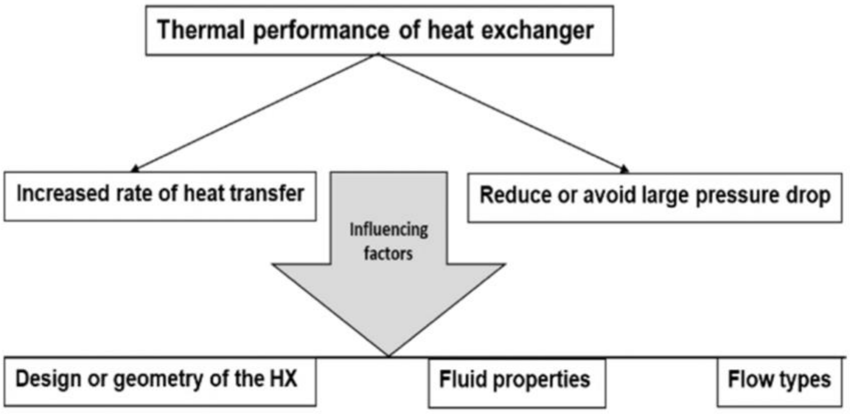


Figure 3: Diagram illustrating the parameters that affect heat transfer performance. (Louis et al., 2022)

2.3 Heat transfer enhancement methods in double tube heat exchangers

Active, passive, and compound techniques are the three general categories into which heat transfer enhancement techniques fall. Purposefully introducing energy or other external components into a heat exchanger system is one way to actively enhance heat transfer. The addition of vortex generators is one of the exciting new technologies being researched. The inherent characteristics of heat exchanger parts or fluid flow are the foundation of passive methods. One example of a passive strategy is the use of fins , turbulators or other expanded surfaces inside the heat exchanger tubes. Conversely, no external power is used with passive techniques. The compound heat transfer method is a hybrid approach that combines passive and active mechanisms. There are very few applications for that very difficult technique (Hasan and Naji, 2023).

2.4 Turbulators in passive enhancement

Prominent among passive strategies are turbulators, turbulators are components or devices that improve heat transfer that are installed into the flow passages of heat exchangers or pipes. The principal aim of these devices is to cause disturbances to the uniform flow of fluid and generate turbulence in the boundary layer. This helps improve mixing and heat exchange between the fluid and surrounding surfaces. Placed carefully inside the heat exchanger or pipe, turbulators can take many different shapes, including ribs, fins, helical coils, and twisted tapes. Turbulators provide several important benefits for heat exchangers. First off, by generating turbulence in the fluid flow, they can raise the convective heat transfer coefficient and enhance thermal efficiency. Because of the improved heat transfer, the heat exchanger's overall size is needed to match a given heat transfer rate, since the hot and cold fluids can exchange heat more effectively. Turbulators reduce the possibility of stagnant zones where deposits can build up and encourage more even fluid distribution, which can help mitigate problems like fouling. Nevertheless, using turbulators has certain drawbacks as well. The rise in pressure drop across the heat exchanger is one obvious disadvantage. It takes more energy to pump the fluid through the system because of the increased frictional losses brought on by the turbulators' turbulence. When energy efficiency is the main consideration in an application, this increased pressure drop may play a crucial role. Turbulators may also make heat exchanger design and manufacturing more difficult, which could result in higher initial costs and more difficult maintenance.

2.5 Twisted tape turbulators

Twisted tape turbulators stand out among other turbulators as an affordable, easily fabricated, detachable solution with excellent fluid dynamics performance and fouling resistance. These inserts improve thermal performance by reducing fouling and increasing shear stress at the tube wall by creating swirling flows at the pipe inlet. But this also results in an increased pressure drop, so one must carefully weigh the benefits of better heat transfer against the costs of energy use (Palsson, Beaubert, and Lalot, 2013).

2.6 Material and design considerations for twisted tape turbulators and double tube heat exchangers.

It is essential to choose the right materials and take certain design factors into account when creating twisted tape turbulators and double tube heat exchangers to maximise heat transfer while guaranteeing durability and lowering maintenance requirements. To improve heat transfer capabilities, metals with high thermal conductivity are usually the preferred choice for twisted tape turbulators. Due to their excellent thermal properties and relatively low cost, copper and aluminium are common materials. However, because of its superior resistance to corrosion and fouling, stainless steel may be preferred in environments where corrosion resistance is crucial, even though it has a lower thermal conductivity. Important design factors that affect the tube's pressure drop and heat transfer efficiency are the tape's width, thickness, and twist ratio (Dehankar et al., 2022).

Depending on the application, different materials may be chosen for these heat exchangers. Because of their superior heat transfer rates, copper and its alloys are preferred for general heating and cooling applications, while titanium may be used in circumstances involving highly corrosive fluids. These exchangers' smooth interior surfaces prevent fouling and corrosion, and their design frequently takes ease of cleaning and maintenance into account. Furthermore, by generating turbulent flows that interfere with the formation of boundary layers on the tube surface, improving methods like the insertion of twisted tapes can greatly increase the efficiency of heat transfer (Khaled and Mushatet, 2023).

2.7 Previous studies on twisted tape turbulators in double tube heat exchangers

In the realm of heat transfer enhancement using twisted tape turbulators, several studies have provided valuable insights into the impact of twist ratios on heat transfer performance of a double tube heat exchanger. Lim, Hung, and Tan (2017) experimentally investigated the impact of twisted-tape inserts in a laminar flow regime in a concentric tube heat exchanger in counter flow configuration, with a particular focus on Reynolds numbers between 450 and 1350. They investigated twist ratios of y=2.5, 4, and 6 by using hot and cold water as working fluids. They discovered that these turbulators greatly improve heat transfer, increasing the Nusselt number by up to three times, but at the expense of a tenfold increase in friction factor, which suggests a higher pressure drop.

Jassim, Hussin, and Abbass (2017) conducted an experimental study to assess the impact of twisted tape inserts on heat transfer enhancement in a circular tube within a double pipe heat exchanger. The impact of twisted tapes with varying twist ratios (5, 4.5, 4, and 3.5) on heat transfer rates and friction factors were investigated by using hot and cold water as working fluids and in counter flow configuration. In comparison to a plain tube without inserts, the study showed that twisted tape inserts greatly improve heat transfer, with enhancements ranging from 50.54% to 56.98% across the different twist ratios. These results demonstrate how well twisted tape inserts work to increase heat transfer efficiency in heat exchanger systems, especially when there is laminar flow and Reynolds numbers between 300 and 1100. The enhanced fluid mixing and decreased thermal boundary layer thickness resulting from the induced secondary flow and turbulence were identified as the causes of the observed increase in heat transfer.

Gouda and Das (2008) performed an experimental study where twisted tape inserts were used to improve heat transfer in a double-pipe heat exchanger within the Reynolds number range of 3400 to 100000. The working fluid were hot and cold water in counter flow configuration. In comparison to a baseline smooth tube setup, they used twist ratios of y=2.149, 3.127, and 4.705 to examine their effects on the system's thermal performance and pressure drop. The performance improvements were carefully measured in the study, and the results showed notable gains in heat transfer efficiency up to 2.87 times that of the smooth tube for specific twist ratios. Simultaneously, there was a significant increase in the friction factor, which is a measure of pressure drop, reaching up to 9.1 times that of the smooth tube. This clear increase in friction factor and heat transfer efficiency with decreasing twist ratios highlights the benefits and drawbacks of utilising twisted tape inserts in heat exchanger applications. The study emphasises the delicate balance that must be struck between controlling the corresponding rises in pressure drop and attaining notable gains in thermal performance.

The existing literature, including studies by Lim, Hung, and Tan, Jassim, Hussin, and Abbass, Gouda and Das collectively establish a comprehensive understanding of the relationship between twist ratios and heat transfer enhancement. Generally, lower twist ratios are associated with improved heat transfer, yet the optimal twist ratio may vary based on specific conditions and configurations.

3 Methodology

This project's methodology uses a methodical, numerical approach to evaluate how twisted tape turbulators affect the thermal efficiency of double tube heat exchangers. This investigation hinges on the comprehensive utilization of Computational Fluid Dynamics (CFD) software, specifically ANSYS Fluent, to simulate and investigate the fluid flow and heat transfer properties inside the heat exchanger. The main goal of this methodology is to capture the intricate relationships between fluid dynamics and heat that twisted tape inserts impose on the effectiveness of heat transfer across the heat exchanger.

First, a detailed 3D model of the double tube heat exchanger is created using the top CAD programme, CATIA. This model has an inner tube and an outer tube with exact diameters and lengths, meticulously designed to mimic a real-world heat exchanger setup. To investigate their impact on the heat exchanger's performance, twisted tape turbulators with different twist ratios are introduced into the inner tube. This twist ratio variation is a key variable in our analysis, providing information about the best configurations to maximise thermal efficiency.

After developing the model, the next crucial stage is to create a structured mesh inside the fluid domains and around the twisted tapes using ANSYS Fluent's mesh generation tool. To make sure the simulation results are accurate and unaffected unduly by the mesh size or density, this mesh is refined through a series of mesh independence tests. Within this mesh domain, the governing equations for fluid flow and heat transfer which include the continuity, momentum, and energy equations are solved. Understanding the dynamics at work, including the system's energy, momentum, and mass conservation, depends heavily on these equations.

The boundary conditions are carefully set to represent the heat exchanger's actual operating conditions. These requirements include defining the material properties of the tubes and the twisted tapes, setting the outer tube wall as adiabatic to minimise heat losses, and defining the inlet temperatures and mass flow rates for both the hot and cold fluids. Furthermore, the operational Reynolds numbers imply that the flow regime inside the tubes is laminar, which is consistent with the normal operating conditions of these heat exchangers.

A comparison with experimental data from the available literature is done to validate the simulation results. Ensuring the validity of the numerical simulations and the conclusions derived from them is contingent upon the completion of this validation step. Moreover, a thorough analysis is conducted on the effects of the twisted tape turbulators on the improvement of heat transfer inside the heat exchanger. By evaluating various twist ratios and their impact on thermal performance, a thorough understanding of how to maximise the efficiency of these passive devices is provided.

The flowchart presented below provides a visual representation of the Computational Fluid Dynamics (CFD) simulation process adopted in this study.

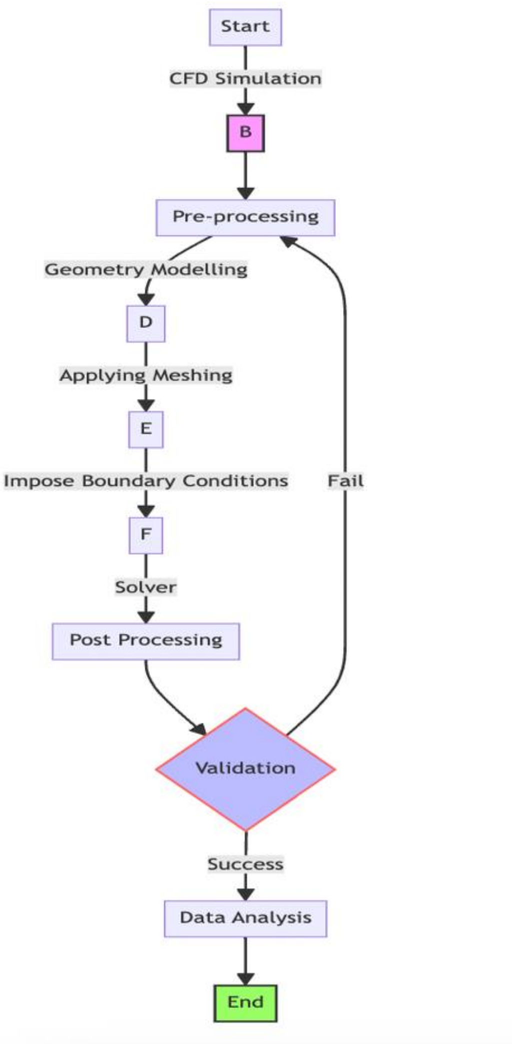


Figure 4: Flow chart for this study

3.1 CAD Modelling

The model of the double tube heat exchanger and twisted tape turbulators were designed using CATIA software and it begins with the design of the inner and outer tubes. With an outer diameter (d_0) of 22.2 mm and an inner diameter (d_i) of 19.9 mm, the inner tube is modelled. This is accomplished by first drawing a circle that is 19.9 mm in diameter, then extruding it to the desired length of 1250 mm to create the inner tube. To get the required outer diameter of 22.2 mm, a second extrusion is then carried out on the outer periphery of the inner tube with a thickness of 2.3 mm. In a similar manner, but with the appropriate dimensions, the outer tube is modelled with an outer diameter of 100 mm and an inner diameter of 95 mm. The heat exchanger's basic structure is completed by aligning the two tubes coaxially.

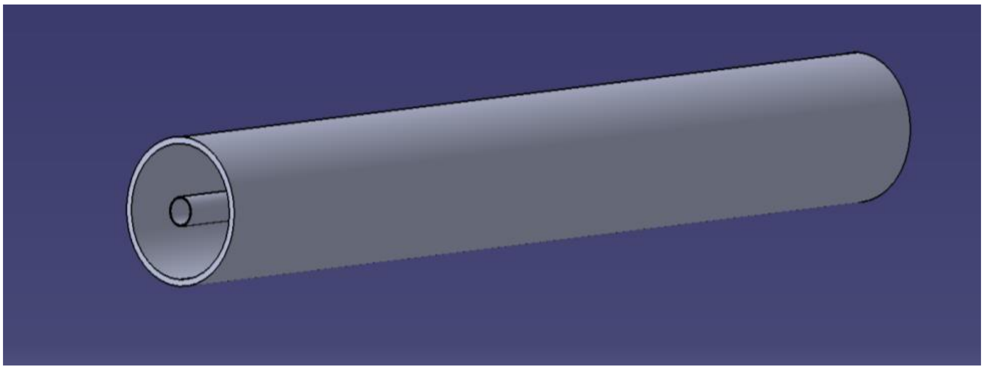


Figure 5: Isometric view of the modelled heat exchanger

The twisted tape turbulators were designed to enhance interaction with the fluid within the heat exchanger's hot water tube. The twist ratio (TR), a key parameter dictating the effectiveness of the tapes, was calculated as the product of the TR value and the tape width (W) to determine the axial pitch (AP). For instance, a tape with a TR of 3.5 and a width of 19.9 mm has an AP determined as 3.5 x 0.0199 meters = 0.06965 meters. This calculation reflects the approach for defining the tapes' twist based on the work of Jassim, N.A., Hussin, K.A. and Abbass in 2017. Selected twist ratios of 3.5, 4 and 4.5 were implemented to investigate their effect on heat transfer performance.

Each tape had a constant width of 19.9 mm and thickness of 0.8 mm since it was modelled after a base strip that measured 1000 mm in length. Because of the width's consistency throughout all variations, it was possible to compare and examine various TRs and how they affected heat exchange efficiency. A helical sweep with axial pitches calibrated to exact measurements 0.06965 metres for a TR of 3.5, 0.0796 metres for a TR of 4, and 0.08955 metres for a TR of 4.5 was used to create the twists.

The twisted tapes were centred and put into the heat exchanger's inner tube after modelling. To precisely create the geometry and helical structures, CATIA V5 was the only software used throughout the entire design and development process. The models were made to have consistent lengths and precise dimensions by rigorous multidimensional control measures, which improved the accuracy and reliability of the numerical work. The goal was to closely match the experimental results carried out by Najim and his associates with the numerical simulations to provide important new information about the effectiveness of twisted tape turbulators in heat exchangers. The twisted tapes of all three twist ratio values are given in the Figure below for the length of 1 m of each tape.

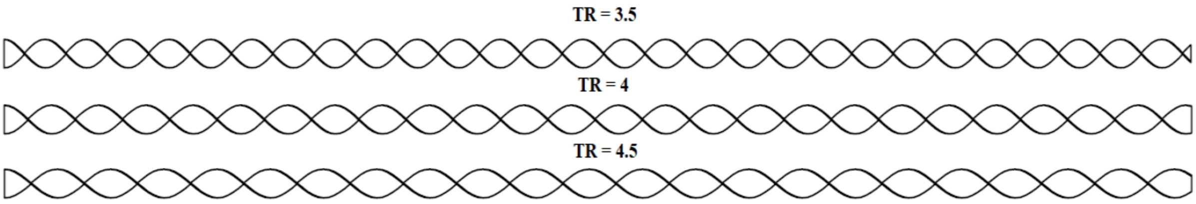


Figure 6: Twisted Tape Turbulators

The assembly procedure for each of the models was the same as to put the tape in the center of the double tube which gives the resemblance of design for each case as given in Figure below for TR 4 assembly. The Appendix includes the engineering drawings for both the twisted tape turbulators and the double tube heat exchanger.

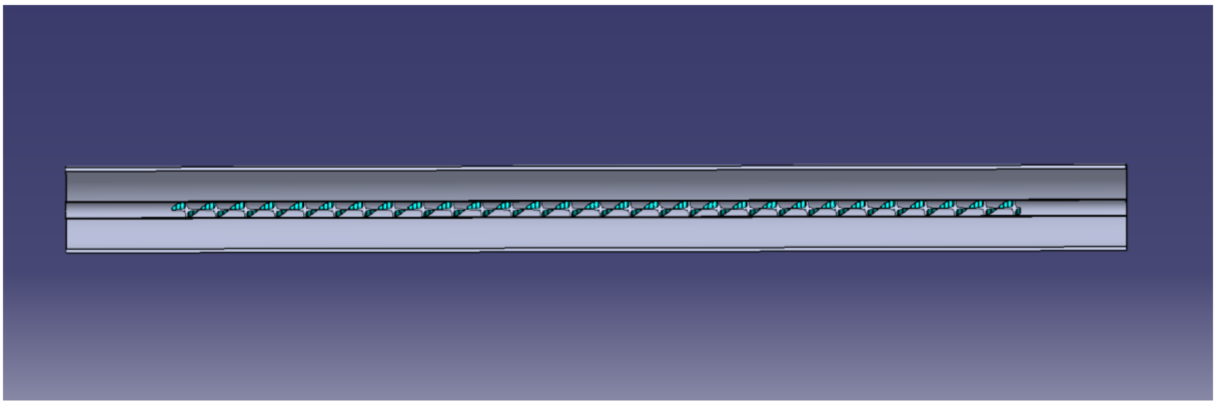


Figure 7: Section view of the assembled model of the double tube with twisted tape for TR 4

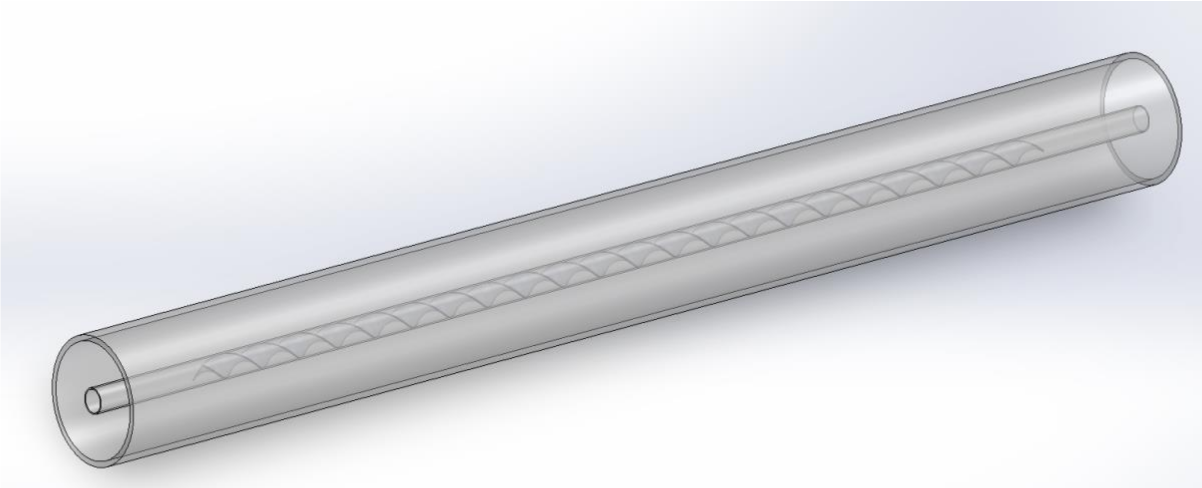


Figure 8: Assembled model of the double tube with twisted tape for TR 4

3.2 CFD Domain Configuration

As part of the simulation setup, boundary conditions that are necessary to define the heat exchanger's operating environment must be defined. Temperatures at the inlet, flow rates, and other relevant factors are specified precisely. Four double tube heat exchangers were modelled; three of them were assembled with twisted tape turbulators of varying twist ratios (3.5, 4 and 4.5), and one was assembled without one. For the simulation, each of the four assembly models were imported as a STP file into the Ansys workbench.

After importing the CAD model, the Volume Extract tool in ANSYS Space claim is used to separate and identify the fluid domains that the simulation will be run within. The tool was used to identify the areas that the hot and cold water, respectively, occupied for the double tube heat exchanger. These areas are essential for establishing boundary conditions and comprehending the exchanger's heat transfer properties.

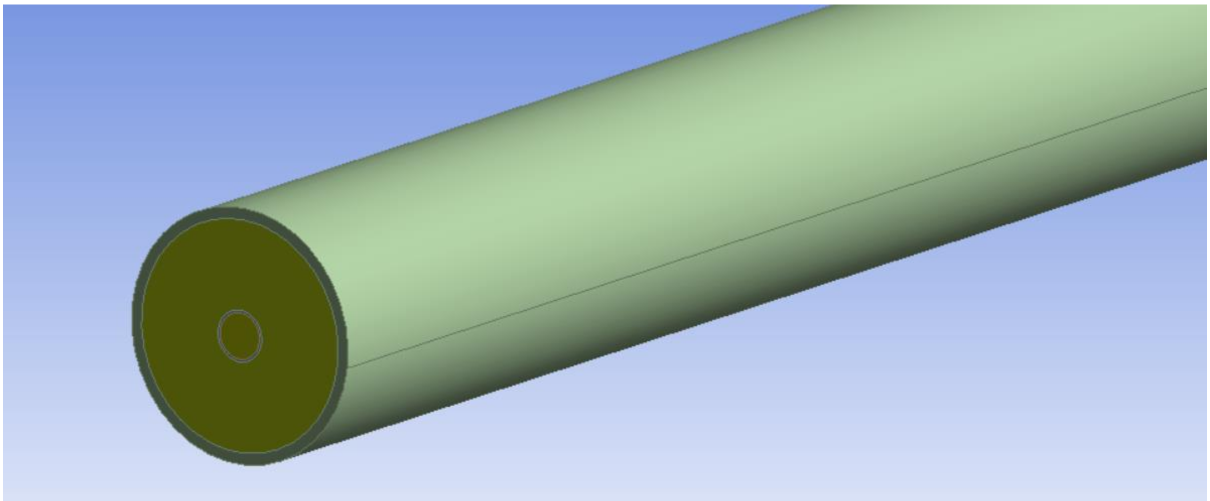


Figure 9: Volume generated for how water and cold water in inner and outer tubes respectively.

The Boolean command in ANSYS Design Modeler was used in the models with twisted tape inserts to define the interface between the twisted tapes and the hot water channel precisely. The geometry of the twisted tape had to be subtracted from the volume designated for the hot water to complete this process. A clear boundary between the hot water flow and the tape's surface was made possible by this subtraction, which eliminated the area that the twisted tape had previously occupied. This technique ensured a uniform approach for illustrating the heat exchanger configurations across all models with tape inserts. To compare their heat transfer performance, this consistency was essential. This technique offered a solid basis for carrying out exact numerical simulations intended to evaluate improvements in heat transfer efficiency by precisely defining the interface zone between the fluid and the surfaces of the inserted tapes.

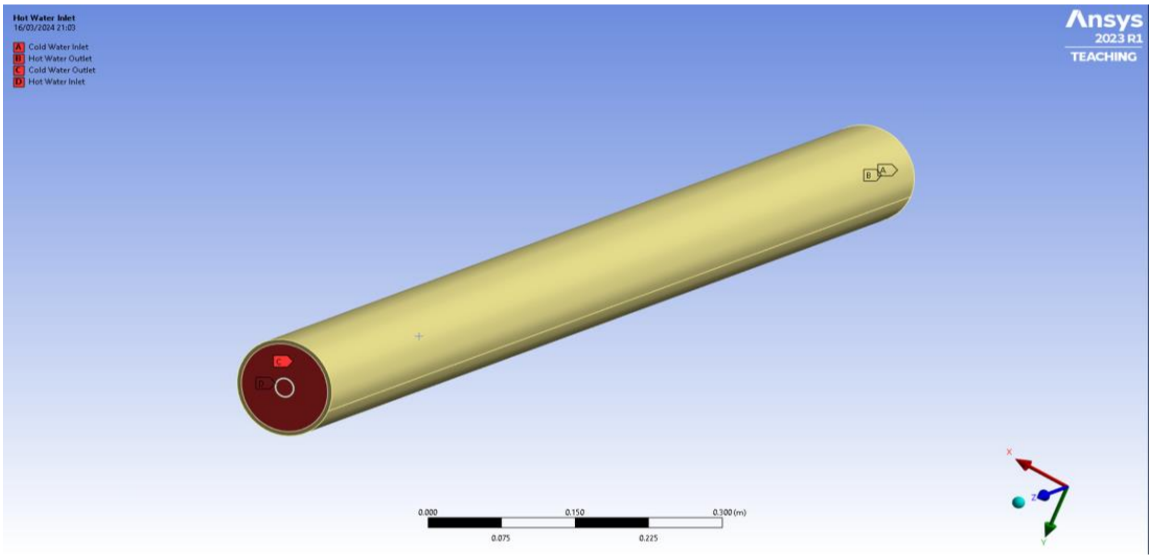


Figure 10: Isometric view of the double tube heat exchanger in ANSYS highlighting the inlets and outlets

An isometric view of the double tube heat exchanger is shown in Figure 1, with key areas such as the cold water inlet (A), hot water outlet (B), cold water outlet (C), and hot water inlet (D) highlighted. These elements are essential to the heat exchanger's operation because they allow the passage of fluids at various temperatures, which aids in the transfer of heat. In addition, the schematic offers dimensional references along the pipe's length, which are crucial for figuring out the efficiency of heat transfer and flow characteristics.

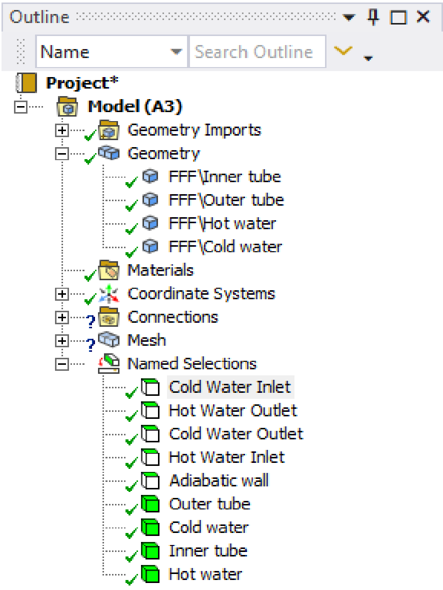


Figure 11: ANSYS project tree

The ANSYS project tree is shown in Figure 2, which explains the geometric arrangement of the model's components, including the named selections and inner and outer tubes. Because the named selections are carefully arranged to match various physical domains and boundary conditions in the model, like the inlets, outlets, and adiabatic walls, they are especially important. The accuracy and effectiveness of the heat exchanger design process are improved by these choices because they facilitate the targeted analysis of simulation results, allow for the precise application of boundary conditions, and speed up the meshing process.

3.3 Meshing process

Computational fluid dynamics (CFD) simulations depend heavily on the meshing process, which has a direct impact on the analysis's accuracy, convergence, and computational efficiency. A uniform and methodical meshing technique was used for all models of the double tube heat exchangers with twisted tape turbulators of different twist ratios (TR 3.5, 4, 4.5) to guarantee the reliability and comparability of the simulation results.

3.3.1 Meshing and mesh independence

To maintain consistency and accuracy in the numerical simulations, the geometries were meshed using ANSYS Fluent meshing, with the same methodology applied to all models. The creation of structured meshes along the borders of the water and tube domains was a crucial step in the meshing process because it ensured uniformity and controlled mesh density. To create a structured mesh that incorporates the heat exchange between hot and cold water within the geometry of the heat exchanger and is more likely to yield dependable results, an equal number of elements were used to divide the edges of the tubes and water domains. The mesh that was created for the models is shown in figure 9.

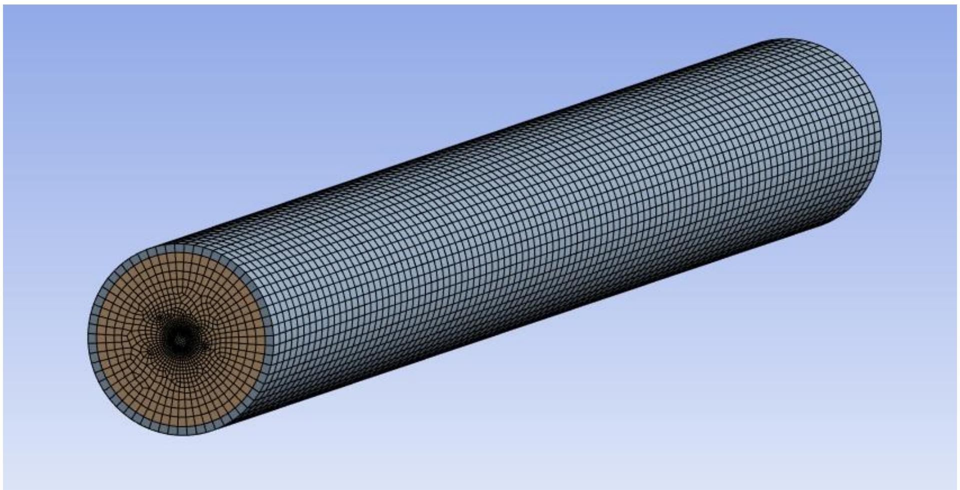


Figure 12: Structural mesh representation on the heat exchanger body

A similar method was then used for the geometries of all the cases including the double tube heat exchanger without twisted tape inserted which serve as the base case. To obtain a structural mesh on the volume domains of inner and outer tubes, hot and cold water, and inserted tapes, the heat exchanger models with the twisted tape inserts of TR 3.5, 4, 4.5, and 5 were also meshed using the same technique, splitting the edges with a similar number of elements. Hexagonal mesh elements were produced by effectively dividing the domain into a structured mesh using the volumes' split edges. When it comes to numerical analysis, a structured mesh made of hexagons is more likely to yield accurate results than an unstructured mesh made of irregularly shaped elements.

In addition to building a structured mesh, a mesh independence study was conducted to determine the sensitivity of the computations to variations in mesh resolution. The study included a planned procedure for increasing the number of elements and assessing how it affected the outcomes. The average temperature at the hot water's outlet was selected as the independence study's output parameter. The study's goal was to monitor the temperature change as the mesh density increased to calculate the appropriate amount of mesh refinement to achieve convergence of the results. The continuous method used in this work allowed for the selection of an appropriate mesh size that maximised both computational efficiency and accuracy, as well as important results regarding the sensitivity of the computations to mesh. The mesh independence study utilised the meshing details listed in table 1.

Table 1: Details of the mesh independence study

Output variable		**Average temperature of hot water outlet**		
Input variable		Mesh density (Number of elements)		
Number of elements employed				
75389	165784	293524	420598	678941

The mesh independence study that was conducted using the information in the above Table served as the exclusive basis for choosing a mesh that can yield accurate findings. Mesh independence was tested on a single type of heat exchanger featuring the TR 3.5 twisted tape turbulator. The mesh independence study's findings are included in the following section along with other findings, and all heat exchanger models were subjected to additional in-depth analysis using the chosen mesh density.

3.4 Solution method

An entire structure of equations for simulating laminar flow and heat exchange actions in the double tube heat exchanger was used in the numerical simulations performed in ANSYS Fluent. The governing equations for the analysis were the energy equation, momentum equations (also known as the Navier-Stokes equations), and continuity equation. These are the equations that are provided:

Continuity equation:

$$\nabla(\rho u) = 0$$

Momentum equation:

$$\nabla(\rho u.u) = -\nabla P + \Delta(\mu.\nabla u) + F$$

Energy Equation:

$$\nabla(\rho uE) = \Delta(k\nabla T) + Q$$

Ensuring the continuity of mass throughout the entire flow field, the continuity equation demonstrates the concept of mass conservation throughout the fluid domains. Maintaining the state of balance of fluid flow rates within the heat exchanger was made possible in large part by the equation previously mentioned. Derived from the Naiver-Stokes equations, the momentum equations explain the conservation of momentum in fluid flow. These equations made it possible to predict pressures, shear stresses, and flow velocities within the fluid domains, which in turn allowed for the useful investigation of flow dynamics and displacement trends in fluid velocities. In addition, the heat exchanger's internal heat transfer processes were simulated using the energy equation. Conduction and convection are the two heat transport modes considered in this equation, which addresses the fundamentals of energy conservation. ANSYS Fluent facilitated the evaluation of heat transfer performance by estimating temperature distributions across solid boundaries and within fluid domains by solving the energy equation.

3.5 CFD Setup

The simulations are run in steady-state with a laminar flow model. The SIMPLE algorithm is used for pressure-velocity coupling, with second-order upwind schemes for momentum and energy equations. This setup guaranteed the accuracy of the flow and thermal fields, which allowed for a trustworthy analysis of the performance effects caused by the twisted tape turbulators. It also offered stability and efficiency in the simulations.

3.6 Boundary conditions

In ANSYS Fluent, boundary conditions are crucial because they allow the properties of heat transfer and fluid flow to be defined inside the computational domain. In the double-tube heat exchanger model, boundary conditions were used to simulate the flow of heated water through the inner tube and cold water through the outer tube. The table below provides the boundary conditions that were used.

Table 2: Details of boundary conditions applied on the models.

Condition	Value
Hot water mass flowrate (kg/s)	0.0055
Cold water mass flowrate (kg/s)	0.022
Hot water inlet temperature (K)	333.15
Cold water inlet temperature (K)	298.15
Twisted Tape material	Aluminum
Inner tube material	Copper
Outer tube material	PVC
Flow regime (Cold and hot water)	Laminar

To accurately reflect the heat exchanger's operating environment, boundary conditions are carefully defined. At 333.15 K and a mass flow rate of 0.0055 kg/s, hot water is introduced into the inner tube, while cold water enters the annular space between the tubes at 298.15 K and a mass flow rate of 0.022 kg/s. Both fluids have pressure outlet condition at their outlets, which allows them to exit without creating backflow or unwarranted pressure changes. The inner tube walls and the surfaces of the twisted tapes are tested under no-slip condition to precisely capture the fluid-solid interactions. The condition of the outer tube wall was set to adiabatic to mimic insulation and reduce heat loss.

After putting all the above setups in place, simulations were run for all cases, and the findings are covered in the report's next section.

Table 3: Summary of the numerical set up and test conditions.

(A) Numerical set up	
(a) Inner tube dimensions	$d_i = 19.9\ mm$ $d_o = 22.2\ mm$
(b) Outer tube dimensions	$d_i = 95\ mm$ $d_o = 100\ mm$
(c) Tube lengths	$1250\ mm$
(d) Inner tube material	Copper (Cu)
(e) Outer tube material	PVC (Polyvinyl Chloride)
(B) Twisted tapes	
(a) Material	Aluminium
(b) Length	$1000\ mm$
(c) Tape width	$19.9\ mm$
(d) Thickness	$0.8\ mm$
(e) Axial pitches	$69.65, 79.60, 89.55$
(f) Twist ratios	$3.5, 4, 4.5$
(C) Test conditions	
(a) Flow regime in inner and outer tube	Laminar
(b) Working fluid	Water
(c) Flow arrangement	Counter flow
(d) Hot water inlet temperature	333.15 K
(e) Cold water inlet temperature	298.15 K
(f) Hot water mass flow rate	$0.0055\ kg/s$
(g) Cold water mass flow rates	$0.022\ kg/s$

4 Results and analysis

This section of the dissertation delves into the computational analysis carried out to investigate the impact of twisted tape turbulators on the thermal efficiency of a double tube heat exchanger. The primary objective of the simulations was to discern the heat transfer enhancements and fluid friction characteristics introduced by turbulators with varying twist ratios of 3.5, 4, and 4.5 in a laminar flow regime. ANSYS Fluent, a sophisticated Computational Fluid Dynamics (CFD) tool, was employed to simulate the heat exchange process and fluid dynamics within the system. Essential simulation parameters, including inlet temperatures, flow rates, and the material properties of water, copper, and PVC, were meticulously selected to replicate the experimental investigation carried out by Jassim, N.A., Hussin, K.A. and Abbass (2017). Furthermore, a study of mesh independence was conducted to determine the accuracy and reliability of the simulations. This study involved adjusting the mesh resolution and assessing how it affected the independence of the findings. This study aims to give a thorough understanding of temperature distributions, heat transfer coefficients, and pressure drops to investigate the impact of twisted tape inserts on the thermal effectiveness of the double tube heat exchanger. Through the presentation and analysis of this data, the study seeks to put light on the possible advantages of using twisted tape inserts to increase heat transfer efficiency in industrial heat exchanger applications. The validation of simulation results against established empirical correlations and experimental results ensured the reliability of the computational models and facilitated a comprehensive understanding of the turbulators' efficacy in double tube heat exchanger performance enhancement. Also cost benefit analysis of twisted tape turbulators are presented.

4.1 Validation

The current study underwent its first validation using the Seider and Tate correlation, an empirical correlation. The simulation results were compared to the average Nusselt number in a counter flow configuration that was derived from the equation.

Table 4: Results of the numerical and empirical correlation for the Nusselt number in counterflow and various Reynolds numbers

Re	Nu (Seider and Tate)	Nu (CFD)	Error (%)
350	5.99	5.54	8.12
550	6.95	6.73	3.17
750	7.70	7.56	1.81
950	8.33	8.20	1.56
1100	8.74	8.82	0.91

For the second validation, the results of the average friction factor in a counter flow configuration obtained from the simulations of the double tube heat exchanger without a twisted tape turbulator inserted were compared to the experimental results Jassim, N.A., Hussin, K.A. and Abbass published work.

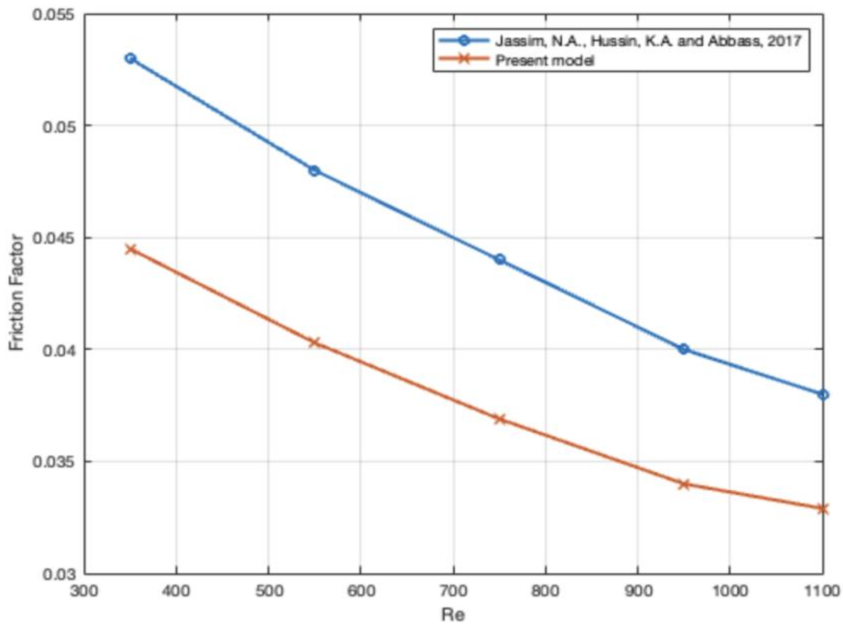


Figure 13: Results of the numerical and Jassim, N.A., Hussin, K.A. and Abbass published work

The outcomes of the second validation using the published work of Jassim, N.A., Hussin, K.A., and Abbass are displayed in Figure 10. Less than 20% separated the current study's findings from those of Jassim, N.A., Hussin, K.A., and Abbass's published work. The accuracy and dependability of the simulations are ensured by the effective validation of the simulation results using both experimental and numerical methods.

4.2 Mesh independence study

It was essential to conduct a mesh independence study to guarantee the validity and efficacy of the current study's analysis. There are four distinct geometric models, and each one needs to be meshed independently, as was made evident in the previous explanation about the modelling in the pre-processing of the current study given in section 4. The five models include the base model of the double tube heat exchanger without the tape inserts and the other four models are of the same double tube heat exchanger with the twisted tape inserts of TR 3.5, 4 and 4.5. These geometric models were designed in CATIA and were imported into the Design Modeller of ANSYS Workbench where volume generation for the hot and cold fluids was carried out. The meshing of these models was also carried out in ANSY'S Fluent where the edge sizing technique was applied, and a hexagonal structured mesh was created.

There is always a possibility that the results might vary by adjusting the size of the element on the mesh. Consequently, it was crucial to make sure that the current study's findings were unaffected by changes made to the mesh density. Since it would have taken a lot of work to complete this convergence study for all four models, only one model was chosen, and the mesh density was increased by reducing the element size. The average temperature at the hot water outlet was set as the output parameter with the mesh density as the input parameter for each mesh density, and a numerical simulation was run. The mesh sensitivity analysis was conducted using the heat exchanger model with TR. 3.5 for this purpose. The mesh independence study results are displayed in the figure below.

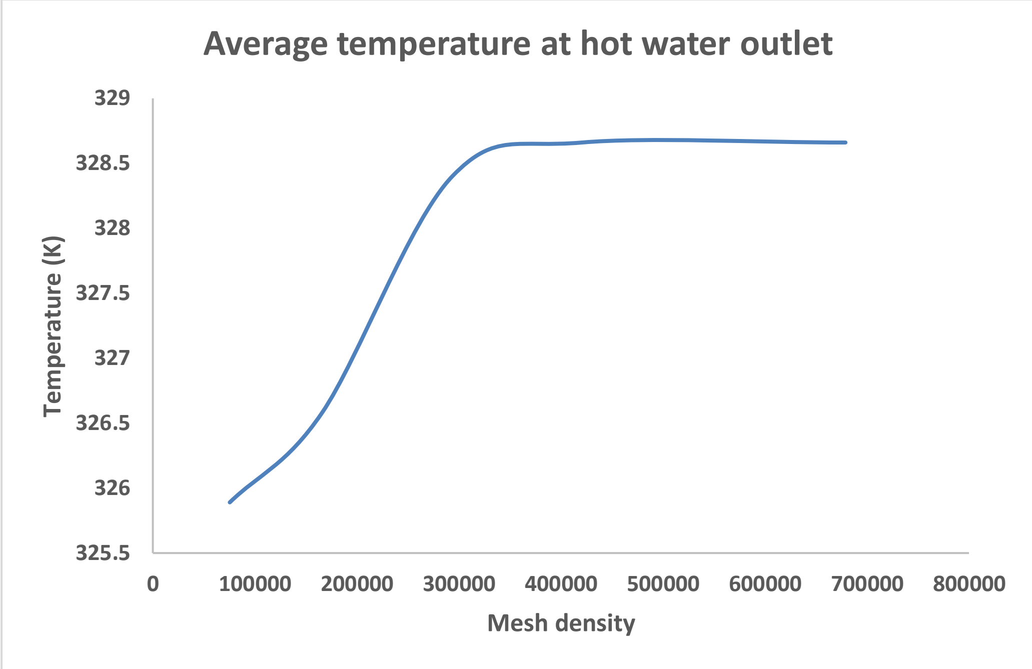


Figure 14: Mesh sensitivity analysis for appropriate mesh selection

As seen in the above Figure, there was variation in the behaviour of the temperature change at the hot water outlet with respect to the mesh density for the initial values. After the mesh density of 293k elements, the values became constant and independent of mesh changes, although the behaviour for the initial mesh densities changed slightly. The converged mesh for the study was produced by a further increase in mesh density that rested on similar values. As a result, a mesh density of 293k or greater could be applied to get trustworthy outcomes. As a result, the converged mesh with a lower cutting range of 293k was chosen and generated on each of the other models used in the analysis of the current investigation. It was possible to choose a mesh with a higher element density, but that would have required more processing power. As a result, choosing the mesh with 293k elements was advantageous for the investigation's time management and processing capacity.

Four important non-dimensional parameters are used to analyse the performance of the double tube heat exchanger with twisted tape turbulators: the friction factor (f), Reynolds number (Re), Nusselt number (Nu), and thermal performance factor (η). These parameters are essential to determining the characteristics of fluid friction and heat transfer enhancement.

The Nusselt number is given by:

$$Nu = \frac{hD}{k}$$

Where, h and k represent the convention heat transfer coefficient and thermal conductivity of the fluid.

Based on laminar flow, the following is the definition of the empirical correlation of the Nusselt number for the inner and outer tube (Sieder and Tate, 1936):

$$Nu = 1.86(Re\,\mathrm{Pr}\frac{D}{L})^{\frac{1}{3}}$$

Where Reynolds number, Prandtl number, tube diameter, and length of a double tube heat exchanger are represented by the letters Re, Pr, d, and L.

The velocity of fluid flow is computed with the help of the Reynolds number and is given by:

$$Re = \frac{\rho VD}{\mu}$$

To evaluate the pressure losses brought on by the insertion of twisted tapes, which may affect the pumping power needed for the fluid to pass through the heat exchanger, the friction factor in the tube is computed by (Zhang et al. 2012):

$$f = \frac{\Delta P \times 2d}{L \times \rho \times V^2}$$

Where ΔP, V and D are pressure drop across the tube, average velocity of fluid and tube diameter.

Thermal performance factor yields the effect of heat transfer intensification, which is expressed by the following formula (Guo et al. 2011):

$$\eta = \frac{Nu/Nu_p}{\left(\frac{f}{f_p}\right)^{1/3}}$$

where Nu, f, Nu_p, and f_p are the Nusselt number and friction factor values for a tube with and without twisted tape insert configuration, respectively, from the same Re.

This thorough analysis must be included to verify the simulation results and provide an in-depth understanding of the fluid flow and heat transfer inside the double tube heat exchanger with twisted tape turbulators.

4.3 The impact of inserting a twisted tape turbulator

The results of this investigation have been meticulously presented in the form of temperature contours at the hot and cold water stream outlets as well as longitudinal cross-sectional temperature representations of the heat exchanger. Additionally, the performance dynamics of the heat exchanger under study have been effectively illustrated by graphical representations that relate Nusselt numbers and friction factors at different Reynolds numbers.

4.3.1 Analysis of Temperature Contours

The temperature distribution inside the double tube heat exchanger under various configurations is comprehensively shown visually by the contour plots produced from the Computational Fluid Dynamics (CFD) simulations.

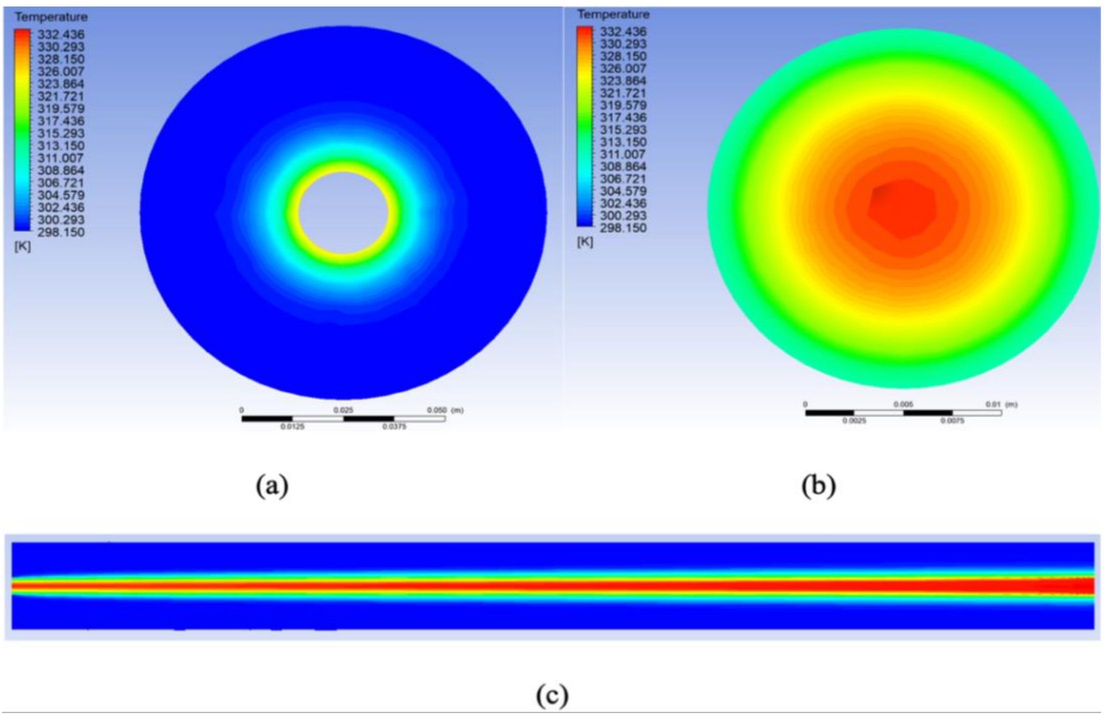


Figure 15: Temperature contour of the double tube heat exchanger without twisted tape turbulator inserted (a) Cold water (b) Hot water (c) Longitudinal cross-section

The double tube heat exchanger without a turbulator is shown in Figure 15, where a constant temperature profile along the tube's length indicates a laminar, undisturbed flow. This homogeneity suggests that, in the absence of turbulence, the thermal energy is mostly transferred along the tube's length, with minimal convective mixing to improve heat transfer.

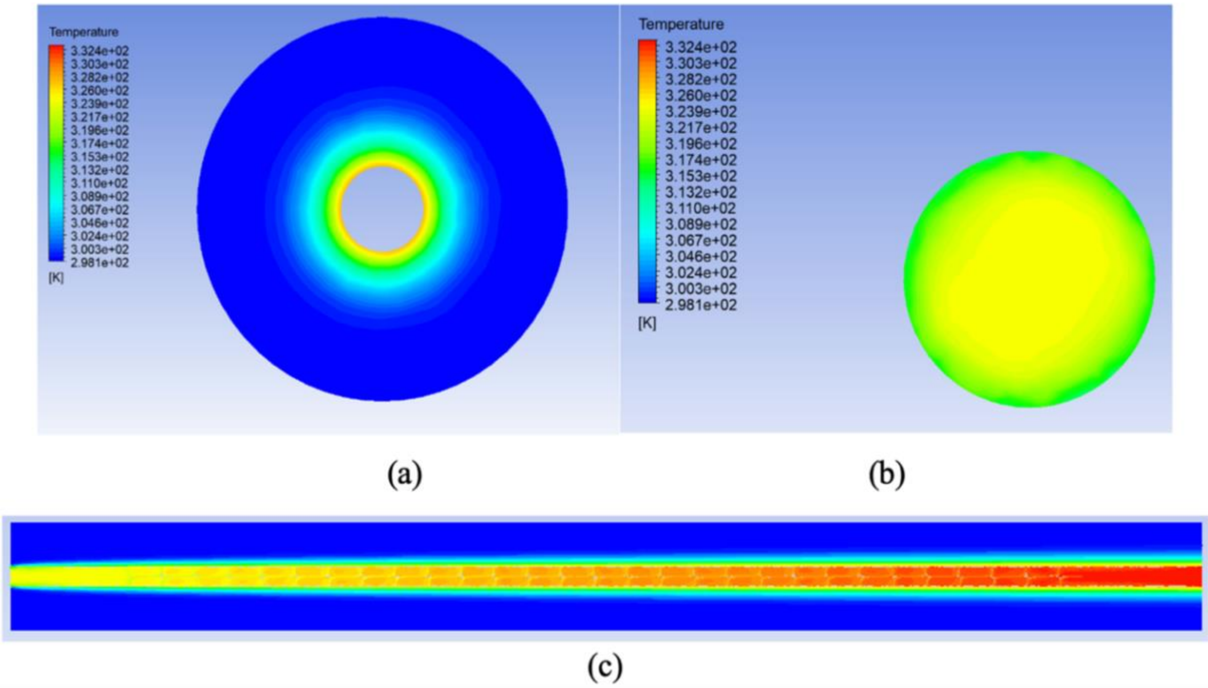


Figure 16: Temperature contour of the double tube heat exchanger with twisted tape turbulator of TR 3.5 (a) Cold water (b) Hot water (c) Longitudinal cross-section

On the other hand, Figure 16 displays a temperature pattern that is more dynamic, with a twist ratio (TR) of 3.5. The turbulator's presence produces detectable temperature changes, indicating that it creates secondary flow patterns that improve fluid particle mixing and, in turn, the thermal exchange between the hot and cold water regions. The double tube heat exchanger's ability to transfer thermal energy depends on this improved mixing.

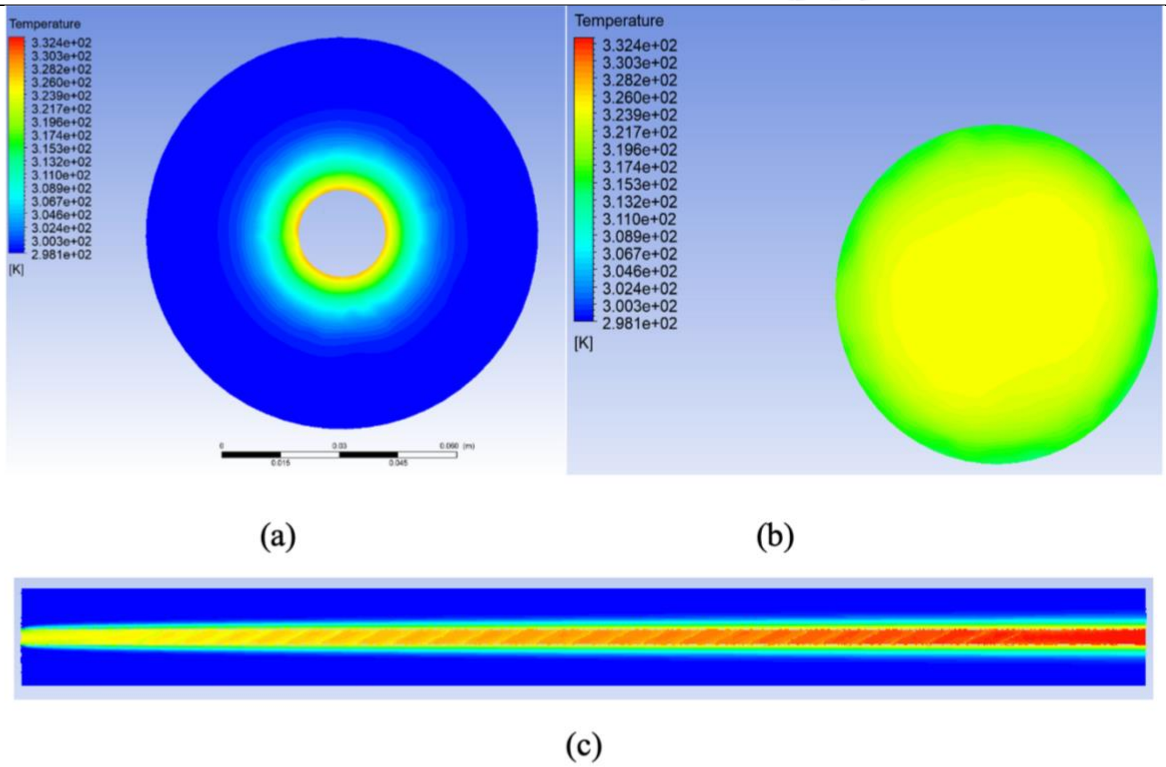
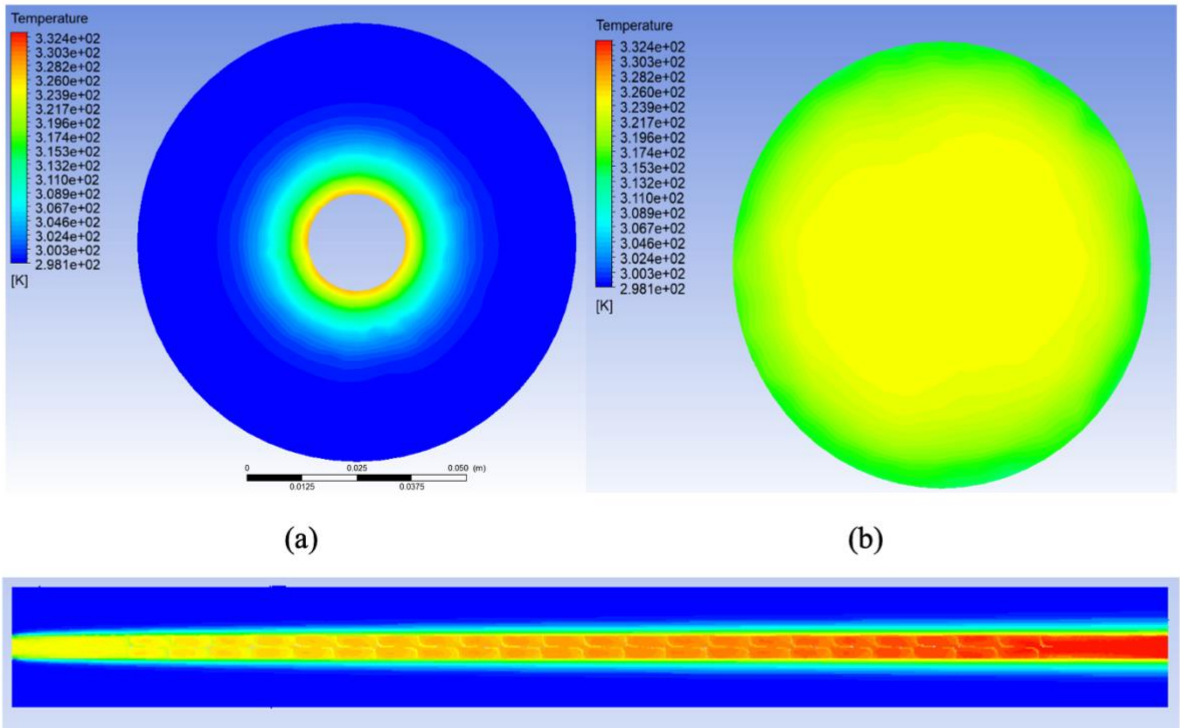


Figure 17: Temperature contour of the double tube heat exchanger with twisted tape turbulator of TR 4 (a) Cold water (b) Hot water (c) Longitudinal cross-section

Moving on to Figure 17, we can see that the turbulator with a TR of 4 adds a less severe but still noticeable temperature variation along the tube's length. The lower level of thermal variance in comparison to the TR 3.5 suggests a drop in the induced turbulence intensity and, as a result, a minor reduction in the heat transfer efficiency.



(a) (b)

(c)

Figure 18: Temperature contour of the double tube heat exchanger with twisted tape turbulator of TR 4.5 (a) Cold water (b) Hot water (c) Longitudinal cross-section

Lastly, the heat exchanger with a turbulator having a TR of 4.5 is shown in Figure 18. Among the turbulated cases, this one has the most consistent temperature profile along the length of the tube, indicating that the higher twist ratio reduces flow disturbance and hence has a smaller impact on thermal mixing. Even though there is still some evidence of turbulator impact, it is not as strong as it was in the cases with lower twist ratios, suggesting that the benefit of enhanced heat transfer decreases as twist ratio increases.

The diverse impacts of twisted tape turbulators on heat exchanger performance are depicted in these plots collectively. The best thermal mixing and heat transfer enhancement are made possible by a lower twist ratio of 3.5. Heat exchanger optimisation for operating demands necessitates careful consideration of the progressively declining thermal mixing and heat transfer efficiency with increasing twist ratio.

4.3.2 Impact of Twisted Tape Turbulators on Heat Transfer and Friction Factor

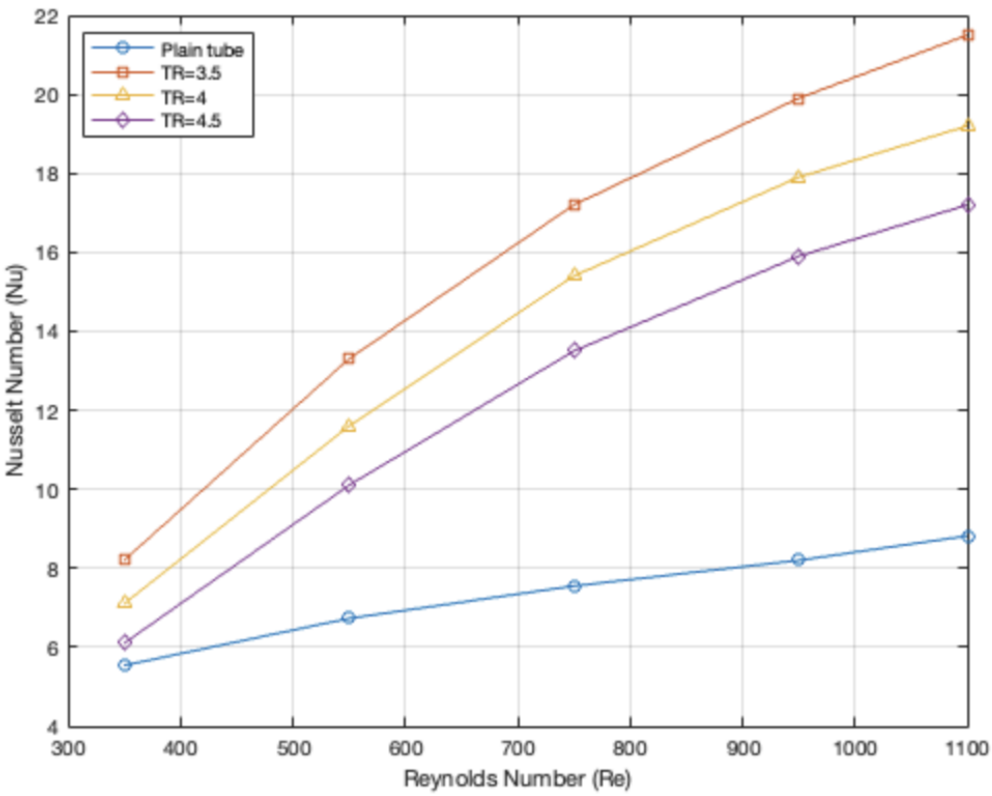


Figure 19: Influence of twisted tape ratios on the Nusselt number

The Nusselt number and the Reynolds number have a positive correlation, as seen in the graph above, for all configurations. This suggests that an increase in the Reynolds number within the tube improves convective heat transfer, which is reflected in a higher Nusselt number. This effect is enhanced even more by the presence of twisted tape turbulators. Of the turbulators that were tested, the tube that has the TR 3.5 turbulator has the highest Nusselt number across all Reynolds numbers, which indicates the greatest enhancement of heat transfer. Higher twist ratios cause the effectiveness to gradually decline; the plain tube exhibits the lowest Nusselt numbers, indicating that it has the least effective heat transfer in the laminar flow regime under investigation.

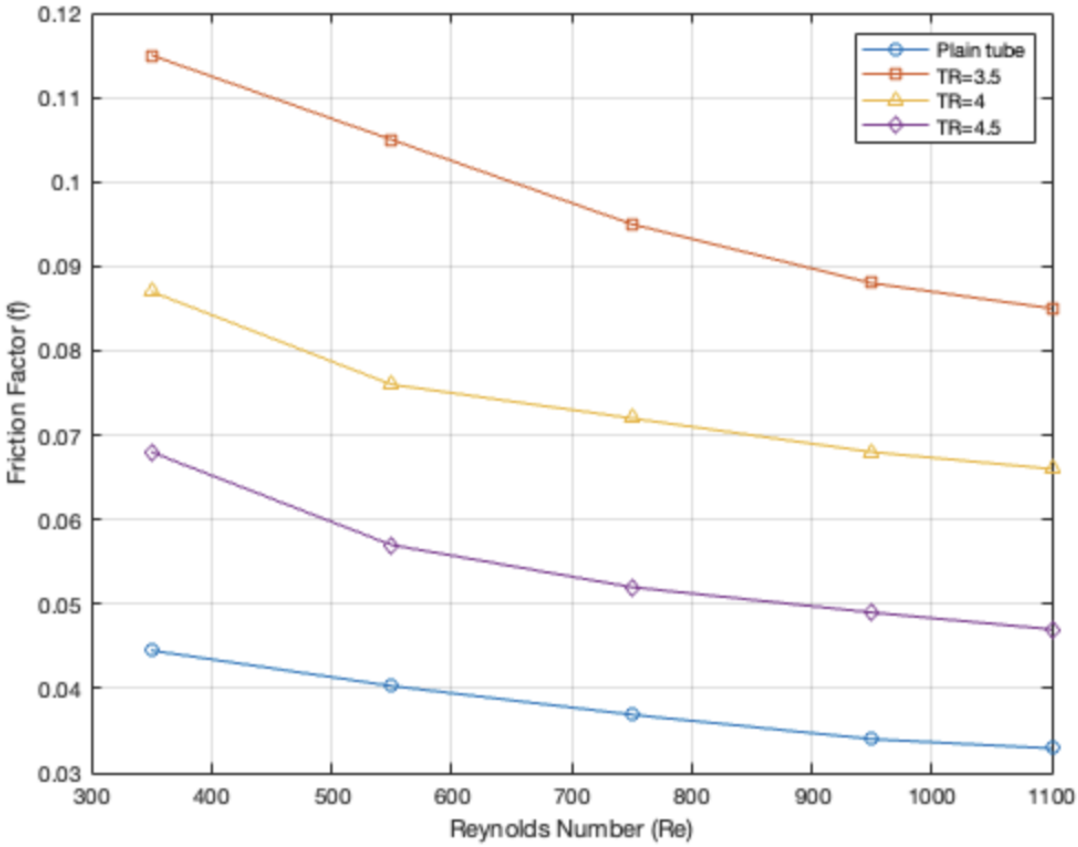


Figure 20: Influence of twisted tape ratios on the friction factor

The relationship between the Reynolds number and the friction factor (f) is shown in the graph above. In this case, a higher friction factor denotes a greater flow resistance. The least amount of flow resistance is indicated by the plain tube, which has the lowest friction factors. Twisted tape turbulators cause induced turbulence, which disturbs laminar flow and raises the energy needed to maintain flow rate, increasing the friction factor. The TR 3.5 configuration exhibits the highest friction factor among the turbulators, which is consistent with the most noticeable improvement in heat transfer that has been noted.

4.3.3 Percentage enhancement

The percentage increase in the average Nusselt number and friction factor compared to the plain tube at a Reynolds number of 550 and with varying twist ratios of twisted tape turbulators is calculated using the following formulas:

For the Nusselt number:

$$Enhancement_{Nu}(\%) = \left(\frac{Nu_{turbulated} - Nu_{plain}}{Nu_{plain}}\right) \times 100$$

For the friction factor:

$$Enhancement_{f}(\%) = \left(\frac{f_{turbulated} - f_{plain}}{f_{plain}}\right) \times 100$$

(a) (b)

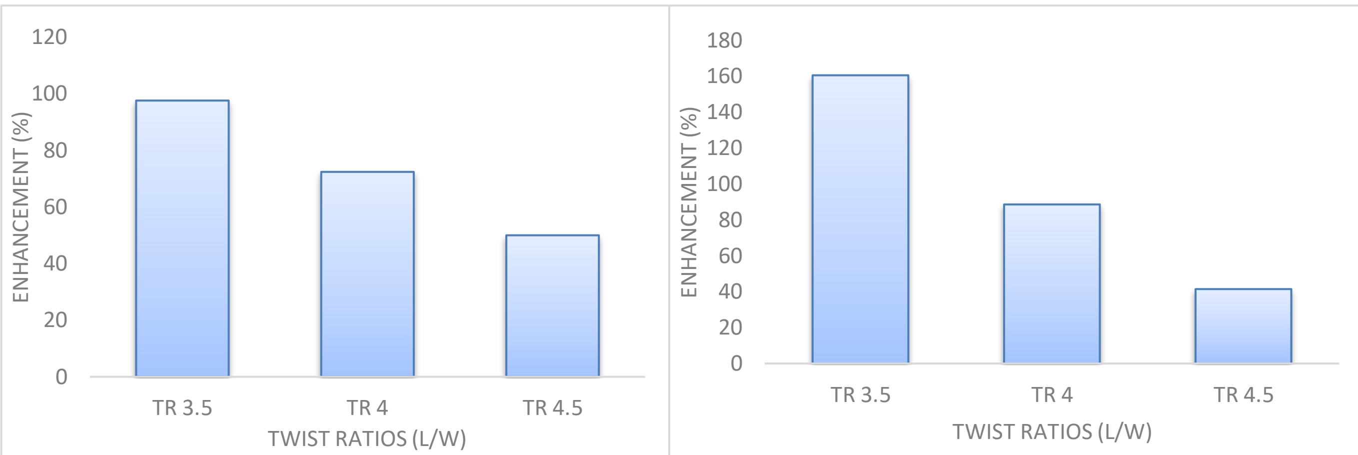


Figure 21: Performance enhancements with twisted tape turbulators; (a) average Nusselt number increase and (b) average friction factor increase, compared to a plain tube.

It is evident that the double tube heat exchanger's flow resistance and heat transfer properties have changed since twisted tape turbulators were added. In terms of the heat transfer rate, as measured by the Nusselt number, the turbulators with a twist ratio of 3.5 exhibit an 97.6% improvement over the plain tube at a Reynolds number of 550. This improvement is further diminished to 72.4% for a twist ratio of 4, and only slightly reduced to 50% for a twist ratio of 4.5. This pattern indicates that although turbulators significantly increase heat transfer, the degree of this improvement depends on the turbulator's geometry, specifically the twist ratio.

Turbulators provide a greater flow resistance in terms of fluid friction, as indicated by the friction factor. At a Reynolds number of 550, the TR 3.5 configuration shows the maximum increase in the friction factor, with an enhancement of 160.50% over the plain tube. The additional energy needed to pump fluids through the heat exchanger is indicated by this. The friction factor enhancements at twist ratios of 4 and 4.5 are marginally smaller, at 88.59% and 41.44%, respectively, and are consistent with the previously mentioned reduced heat transfer enhancements.

4.3.4 Thermal performance factor

One of the factors that is crucial for figuring out a double tube heat exchanger's thermal-hydraulic performance is the thermal performance factor. Figure 22 shows the variation in the twist ratio of twisted tape turbulators on thermal performance vs Reynolds number.

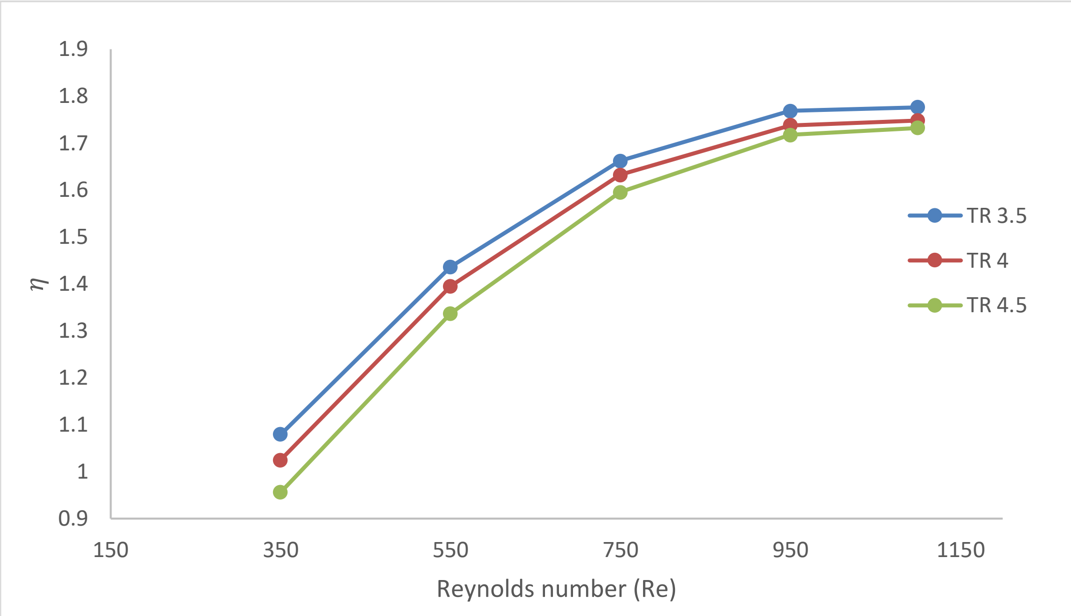


Figure 22: Variation in twist ratio of twisted tape turbulators on thermal performance factor

The graph above illustrates how different twist ratios (TR) of twisted tape turbulators affect the thermal performance factor (represented by η) of double tube heat exchangers. The Reynolds number (Re), a measure of the flow regime inside the heat exchanger tubes, is used to evaluate the thermal performance. The thermal performance of the three twist ratios 3.5, 4, and 4.5 is compared for a range of Reynolds numbers, from 350 to 1100.

Several important conclusions can be drawn from the graph:

1. Thermal performance factor improvement with increasing Reynolds number: For all twist ratios, there is a noticeable improvement in thermal performance factor as the Reynolds number increases. This implies that as the Reynolds number increases, the twisted tape turbulators become more effective at enhancing heat transfer.

2. Effectiveness of various twist ratios: Among all the Reynolds numbers examined, the heat exchanger with a TR of 3.5 has the best thermal performance. This suggests that, within the range under study, this specific twist ratio is the most effective at enhancing heat transfer. In comparison to other configurations, the TR of 4.5 shows the lowest thermal performance, suggesting it is less effective.

3. Absolute thermal performance factor values: The degree to which heat transfer has been enhanced in relation to the friction factor penalty is indicated by the actual thermal performance values (n). The observed thermal performance values for Reynolds numbers 350, 550, 750, 950, and 1100 for the TR=3.5 configuration are 1.079, 1.436, 1.662, 1.768, and 1.776, respectively. These values indicate a good trade-off between increased heat transfer and the resulting pressure drop, with a significant improvement in performance, especially at higher Reynolds numbers.

4. Assessment of thermal performance factor: When compared to a plain tube under the same operating conditions, the twisted tape inserts' increased heat transfer surpasses the frictional losses thanks to η values larger than 1. This study's twist ratios all show η values above unity, indicating a net improvement in thermal performance.

4.3.5 Cost benefit analysis of twisted tape turbulators

Because of the increased thermal efficiency and possible energy savings, using twisted tape turbulators in double tube heat exchangers has significant financial implications. Manufacturing and installation are initial costs; however, these are more than offset by significant long-term energy savings. Twisted tape turbulators, for example, have been demonstrated to raise the Nusselt number a measure of improved heat transfer performance by about 97.6%, a figure that is directly related to energy efficiency. Furthermore, more efficient heat exchange processes can result in a 30% reduction in overall energy consumption costs, even with the corresponding increase in pressure drop of roughly 160.50% at a Reynolds number of 550. According to these figures, assuming consistent operation, the payback period based solely on energy savings could be as short as two years, even though the upfront investment may be higher. Therefore, their adoption in industries that prioritise cost-effectiveness and energy efficiency is strongly supported by the long-term benefits in the form of lower energy consumption and operational costs.

5 Conclusions

This study used in-depth computational fluid dynamics (CFD) simulations to explain the improvements in heat transfer efficiency and pressure drops that result from the use of twisted tape turbulators on the heat transfer performance and friction factor of double tube heat exchangers. The considerable potential of turbulators to optimise heat exchanger design for increased energy efficiency and sustainability has been made clear by this study's thorough analysis. The findings of this investigation are stated in the following points:

- The double tube heat exchangers' twisted tape turbulators were implemented, which resulted in a significant gain in thermal efficiency. The most efficient turbulator was one with a twist ratio of 3.5, which increased the Nusselt number by about 97.6% at a Reynolds number of 550 when compared to the configuration without twisted tape turbulator inserted.

- The implementation of twisted tape turbulators led to an increase in the friction factor, which indicates higher pressure drops across the heat exchanger in addition to improved heat transfer. The most notable increase in friction factor was observed in the turbulator with a twist ratio of 3.5, which increased the friction factor by about 160% at a Reynolds number of 550 when compared to the configuration without twisted tape turbulator inserted, highlighting the need for a balanced design strategy to maximise thermal performance and energy efficiency.

- The study found that a twist ratio of 3.5 was the best, providing the greatest improvement in both thermal performance and friction factor, out of the three twist ratios examined (3.5, 4, and 4.5). This shows that to maximise heat transfer efficiency while controlling the resulting pressure drop, lower twist ratios which create more turbulence and fluid mixing are preferable.

- Efficiency of thermal performance factor: The graph confirms that turbulators improve heat exchanger efficiency by showing that, for all twist ratios, the thermal performance factor (η) rises with the Reynolds number. Notably, the

TR 3.5 variant achieves the highest, suggesting the ideal balance between increasing friction factor and enhancing heat transfer.

- According to the findings, twisted tape turbulators can greatly improve heat exchangers operational efficiency across a range of industrial applications. These turbulators help achieve significant energy savings and lower operating costs by enhancing heat transfer mechanisms and carefully controlling pressure drop, which supports the shift to more environmentally friendly industrial processes.

6 Recommendations

After a thorough examination of the twisted tape turbulators found in double tube heat exchangers, a number of important suggestions for future research, enhanced design, and useful applications in the field of thermal engineering can be made. The following suggestions aim to improve heat transfer efficiency and optimise design parameters:

- Twist ratio optimisation: Future twisted tape turbulator designs should place a high priority on optimisation around a twist ratio of 3.5. This ratio was found to be the most efficient in improving thermal performance while allowing for a reasonable increase in friction factor. To fine tune the balance between pressure drop and heat transfer enhancement, more research could look into slightly altering the twist ratio around this optimum.

- Material selection and design considerations: The materials chosen for the tubes and turbulators should be carefully considered. More heat transfer rates could be achieved by choosing materials with higher thermal conductivities. To guarantee long-term operational stability, twisted tapes' physical resilience at high flow rates and temperatures should also be a major design factor.

- Turbulent flow simulations: Expand the research to incorporate simulations within the turbulent flow regime, offering valuable understanding of the performance in varying operational conditions.

- Examine mass flow rates: To maximise heat exchanger performance, examine how different mass flow rates affect thermal efficiency.

7 References

1. Anon, (n.d.). What is Double Pipe Heat Exchanger: Types. Working Principles | Linquip. [online] Available at: https://www.linquip.com/blog/double-pipe-heat-exchangers/.

2. Dehankar, P.B., Joshi, K., Bhosale, V.A. and Mulik, R.N. (2022). Assessment of twist tape thermal performance in heat transfer passive augmentation technique. *Beni-Seuf University Journal of Basic and Applied Sciences /Beni-Suef University Journal of Basic and Applied Sciences*, 11(1). doi:https://doi.org/10.1186/s43088-022-00208-0.

3. Eiamsa-Ard, S. and Seemawute, P., 2012. Decaying swirl flow in round tubes with short-length twisted tapes. *International Communications in Heat and Mass Transfer*, *39*(5), pp.649-656.

4. Gouda, R. and Das, A.B. (2008). *Some experimental studies on heat transfer augmentation for flow of liquid through circular tubes using twisted angles and tapes*. [online] ethesis.nitrkl.ac.in. Available at: http://ethesis.nitrkl.ac.in/4177/ [Accessed 19 Apr. 2024].

5. Guo, J., Fan, A., Zhang, X. and Liu, W., 2011. A numerical study on heat transfer and friction factor characteristics of laminar flow in a circular tube fitted with center-cleared twisted tape. *International Journal of Thermal Sciences*, *50*(7), pp.1263-1270.

6. Hasan, S. and Naji, Z.H. (2023). AUGMENTATION HEAT TRANSFER IN A CIRCULAR TUBE USING TWISTED - TAPE INSERTS: A REVIEW. *Journal of Engineering and Sustainable Development*, [online] 27(4), pp.511–526. doi:https://doi.org/10.31272/jeasd.27.4.8.

7. Jassim, N.A., Hussin, K.A. and Abbass, N.Y.A. (2017) 'Experimental investigation of heat transfer enhancement in circular tube using twisted tape inserts,' *Industrial and Systems Engineering*, 2(2), p. 7. https://doi.org/10.11648/j.ise.20170202.11.

8. Khaled, R.A. and Mushatet, K.S., 2023. CFD Analysis for a Twisted Elliptical Double Tube Heat Exchangers Integrated with a Twisted Tape. *International Journal of Heat & Technology*, *41*(5).

9. Lim, K.Y., Hung, Y.M. and Tan, B.T., 2017. Performance evaluation of twisted-tape insert induced swirl flow in a laminar thermally developing heat exchanger. *Applied Thermal Engineering*, *121*, pp.652-661.

10. Louis, S. P., Ushak, S., Milian, Y., Nemś, M., & Nemś, A. (2022). Double-Pipe Heat Exchangers Using [specific topic]. Encyclopedia. Retrieved 26 Nov 2023, from https://encyclopedia.pub/entry/31261#:~:text=Double%2Dpipe%20heat%20exchangers%20using,without%20affecting%20the%20initial%20cost.

11. Metz, C. (2022). *Who invented the heat exchanger? | Sterling TT*. [online] Sterling Thermal Technology. Available at: https://www.sterlingtt.com/2022/11/08/invention-of-heat-exchanger/#:~:text=History%20of%20heat%20exchangers [Accessed 27 Nov. 2023].

12. Palsson, H., Beaubert, F. and Lalot, S., 2013. Inducing swirling flow in heat exchanger pipes for reduced fouling rate. *Heat transfer engineering*, *34*(8-9), pp.761-768.

13. Sieder, E.N. and Tate, G.E. (1936). Heat Transfer and Pressure Drop of Liquids in Tubes. *Industrial & Engineering Chemistry*, 28(12), pp.1429–1435. doi:https://doi.org/10.1021/ie50324a027.

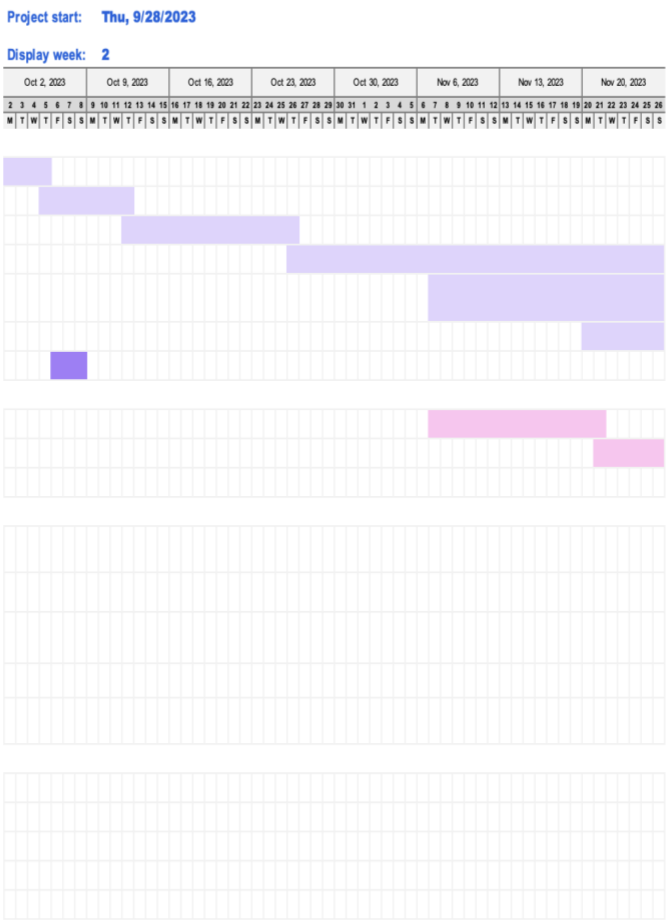
14. Tavousi, E., Perera, N., Flynn, D. and Hasan, R., 2023. Heat transfer and fluid flow characteristics of the passive method in double tube heat exchangers: a critical review. *International Journal of Thermofluids*, *17*, p.100282.

15. Zhang, X., Liu, Z. and Liu, W., 2012. Numerical studies on heat transfer and flow characteristics for laminar flow in a tube with multiple regularly spaced twisted tapes. *International Journal of Thermal Sciences*, *58*, pp.157-167.

8 Appendix

Final year project

TASK	ASSIGNED TO	PROGRESS	START	END
Literature review and research planning				
Review existing literature on double tube heat exchangers, heat transfer enhancement techniques, and the use of turbulators.		100%	9/28/23	10/5/23
Identify the importance of heat exchangers in various industries and the significance of improving their performance.		100%	10/5/23	10/12/23
Examine previous studies on the application of twisted tape turbulators in heat exchangers and the variables that influence their performa		100%	10/12/23	10/26/23
Draft literature review and finalise literature review		100%	10/26/23	11/30/23
Create interim progress report and presentation, using all knowledge gathered.		100%	11/7/23	11/30/23
Outline the methadology used throughout the course of the project		100%	11/20/23	11/30/23
			10/6/23	10/8/23
Geometric modelling and Boundary conditions				
Design twisted tape turbulators with various twist ratios, ensuring the designs adhere to the heat exchanger's geometry		100%	11/7/23	11/21/23
Develop a computational model of the double tube heat exchanger and simulate the insertion of these turbulators within the double tube h		100%	11/21/23	11/28/23
Numerical Simulations and Data Collection				
Conduct simulations to assess heat exchanger performance by comparing heat transfer coefficients, pressure drops, and overall efficiency with and without twisted tape turbulators. Explore the impact of varying twist ratios and flow rates on these parameters to analyze their influence on heat exchanger performance.		100%	1/22/24	2/5/24
Generate pressure drop and heat transfer maps to visualize the impact of turbulator insertion.		100%	2/6/24	2/13/24
Evaluate the results obtained from numerical simulations to determine the effects of turbulators on heat transfer performance and Identify the optimal twist ratio for maximum heat transfer enhancement while considering pressure drop limitations.		100%	2/14/24	2/21/24
Document and report on the findings related to the performance of double tube heat exchanger with and without twisted tape turbulator inserted		100%	2/22/24	3/7/24
Based on the findings provide recommendations for the design and optimisation of double tube heat exchanger when employing twisted tape turbulators.		100%	3/8/24	3/15/24
Report Writing and Poster Preparation				
Begin drafting the comprehensive research report, including the introduction, methodology, and initial results for twisted tape turbulators with different twist ratios		100%	3/16/24	3/23/24
Continue report writing with a focus on the discussion and conclusions		100%	3/24/24	3/31/24
Finalize the report, add references, and create figures and tables for all data collected		100%	4/3/24	4/6/24
Prepare a poster presentation summarizing the project for your final presentation, covering the results for twisted tape turbulator		100%	4/7/24	4/14/24
Submission		100%	4/19/24	



Appendix(i): Project's Gantt chart is displayed.

Logbook

Semester 1

Week	Start Date	Activity	Outcome
1	25/09/2023	• First meeting to go over project scope and methodology with Dr. Noel Perera, project supervisor. • Discussed software tools for the project. • Received guidance on the proposal document detailing Aim, Objectives, and project execution plan.	• Established the foundation for the project's aim and objectives. • Got preliminary advice on methods and tools for project management.
2	02/10/2023	• Carried out extensive research of the literature on heat transfer enhancement techniques and double tube heat exchangers.	• Determined possible directions for further study and advancement. • Clearly stated that passive heat transfer enhancement techniques are the project's main focus.
3	09/10/2023	• Second meeting with Dr. Noel Perera to refine project aims and methodology. • Discussion on the feedback from the proposal document.	• Finalised the methodology and research questions. • Based on comments received from Dr. Noel Perera, the project proposal was improved.
4	16/10/2023	• Thorough investigation into the use of twisted tape turbulators in heat exchangers. • Examined how material characteristics and twist ratio affected turbulator performance.	• Selected twist ratios for the CFD model. • A deeper comprehension of the variables influencing turbulator effectiveness.
5	23/10/2023	• Third project meeting with Dr. Noel Perera to review feedback on the project proposal document.	• Incorporated feedback to improve the proposal report. • Prepared to start writing the interim report.

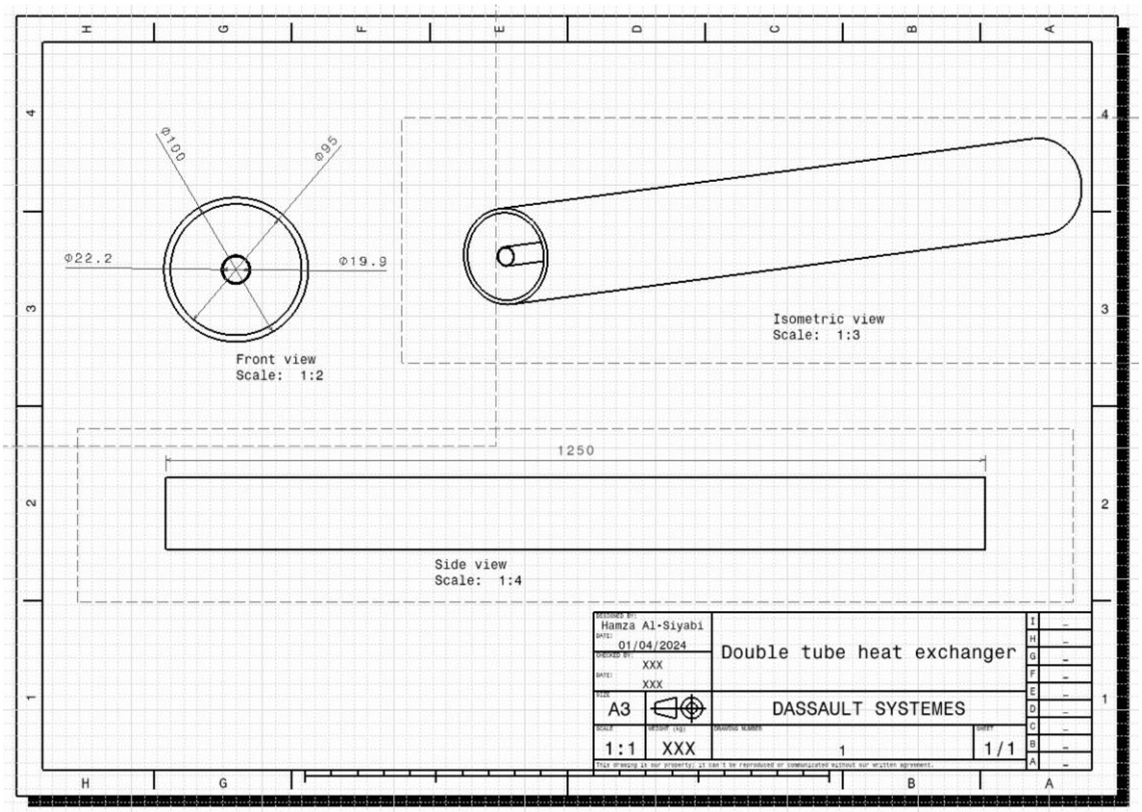
6	30/10/2023	• Fourth meeting with Dr. Noel Perera. • Started working on the interim report, concentrating on the methodology and preliminary results. • Developed a Gantt chart for project tracking.	• Directed to start working on the interim report and presentation. • Structured the report to clearly present methodology and preliminary results. • Advised to create a Gantt chart for project tracking. • Developed a Gantt chart for project tracking.
7	06/11/2023	• Started writing the report's literature review section, emphasising important conclusions from earlier studies, and pointing out any gaps.	• Developed a strong basis for the rationale and argument in the report. • Guaranteed consistency with the aims and objectives of the project.
8	13/11/2023	• Fifth meeting to refine the objectives and aim of the project with Dr. Noel Perera. • Discussed the timeline and feasibility for project completion.	• The project's focus was sharpened, realistic planning was ensured. • Insightful guidance on project scope management was obtained.
9	20/11/2023	• Sixth meeting with Dr. Noel Perera to evaluate progress on the interim report. • Discussed the Gantt chart and received guidance on effective interim report writing.	• Gained insights into improving the quality of the interim report. • Updated the Gantt chart to reflect the project's current status and future steps.
10	27/11/2023	• Final edits and revisions to the interim report and corresponding presentation. • Preparation for submission and presentation of the interim report.	• The interim report was expertly polished.

Semester 2

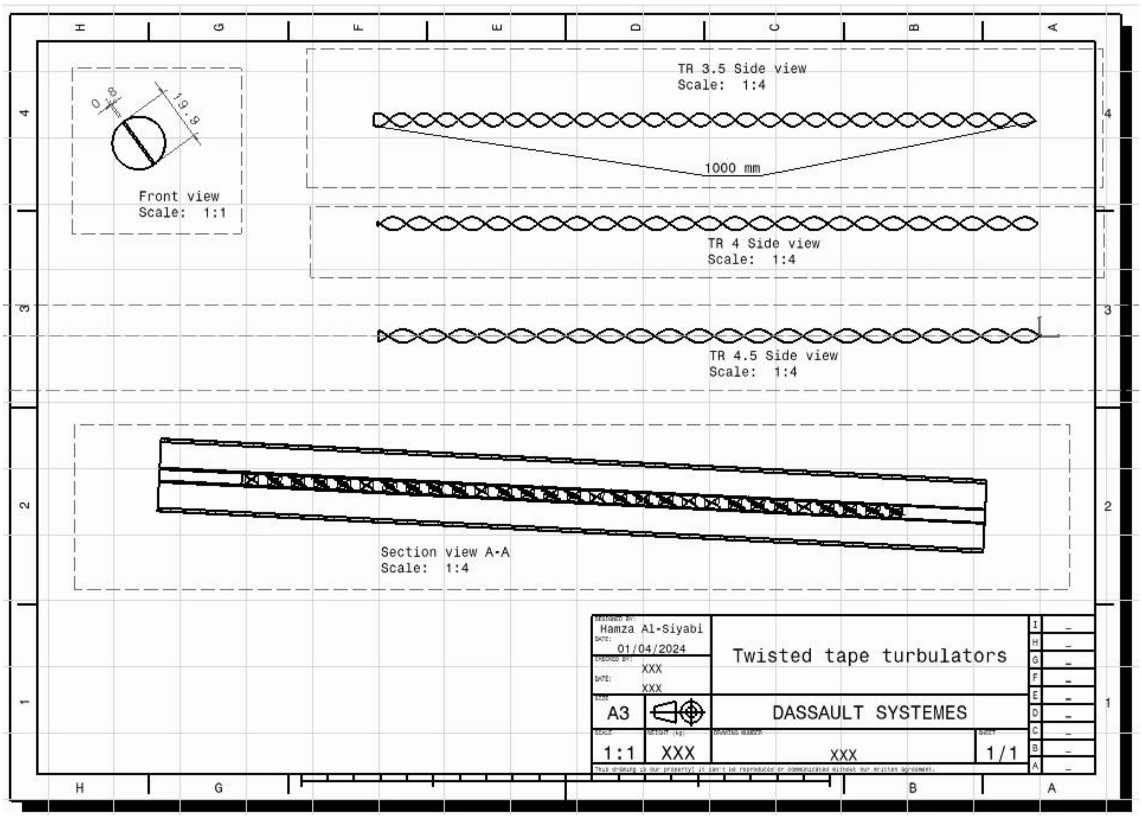
Week	Start Date	Activity	Outcome
1	22/01/2024	• Meeting with Dr. Noel Perera to discuss the interim report and receive feedback.	• Received valuable insights to improve the quality of the report. • Made necessary adjustments to the report structure.
2	29/01/2024	• Initial setup of CAD models and preparation of the CFD domain configuration.	• Established the computational framework for the simulation phase of the project.
3	05/02/2024	• Completed the meshing process and commenced initial CFD simulations. • Held a second meeting with Dr. Noel Perera to discuss the simulation setup and mesh quality.	• Validated mesh independence and ensured accurate setup for simulation work.
4	12/02/2024	• Conducted initial validation studies by comparing simulation results with empirical correlations and experimental data.	• Achieved preliminary validation of the CFD model against experimental and empirical benchmarks.
5	19/02/2024	• Analysed the impact of twisted tape turbulators on heat transfer. • Held a third meeting with Dr. Noel Perera to present preliminary analysis results.	• Identified baseline performance improvements.
6	26/02/2024	• Reviewed validation results and refined simulation setup based on initial findings.	• Enhanced simulation accuracy and prepared for detailed analysis.
7	04/03/2024	• Conducted an in-depth analysis of the temperature contours and flow dynamics within the heat exchanger. • Held a fourth meeting with Dr. Noel Perera to discuss the findings.	• Gained a comprehensive understanding of the thermal effects induced by the turbulators.
8	11/03/2024	• Analysed the impact of twisted tape turbulators on heat transfer and friction factor.	• Developed insights for optimizing turbulator design to balance heat transfer enhancement with pressure drop.

9	18/03/2024	• Finalized the CFD analysis and initiated the drafting of the final report incorporating major findings. • Held a fourth meeting with Dr. Noel Perera to confirm findings.	• Prepared the foundational elements of the final report ensuring that all significant results were included.
Easter Break	25/03/2024 to 07/04/2024	• Utilized the break to begin gathering simulation results from ansys fluent. • Started the documentation of results analyses and findings in the final report.	• Compiled all relevant data and prepared comprehensive sections of the final report detailing the project's findings. • Structured the report to present the impact of twisted tape turbulators on heat exchanger efficiency clearly and concisely.
10	08/04/2024	• Conducted a comprehensive review of CFD results. • Finalized the draft of the final report and sent it to Dr. Noel Perera for feedback on the report structure and content.	• Ensured that the simulation results and analyses were accurately documented in the final report. • Received feedback on the report structure to make necessary adjustments before submission.
11	15/04/2024	• Held the last meeting with Dr. Noel Perera to confirm report structure and findings. • Finalized and submitted the comprehensive final report on 19/04/2024 following a complete review and documentation of all project activities results and recommendations.	• Concluded the project with a well-documented final report highlighting the contribution to the field of heat transfer in double tube heat exchangers.

Appendix(ii): Showing the logbook for this project.

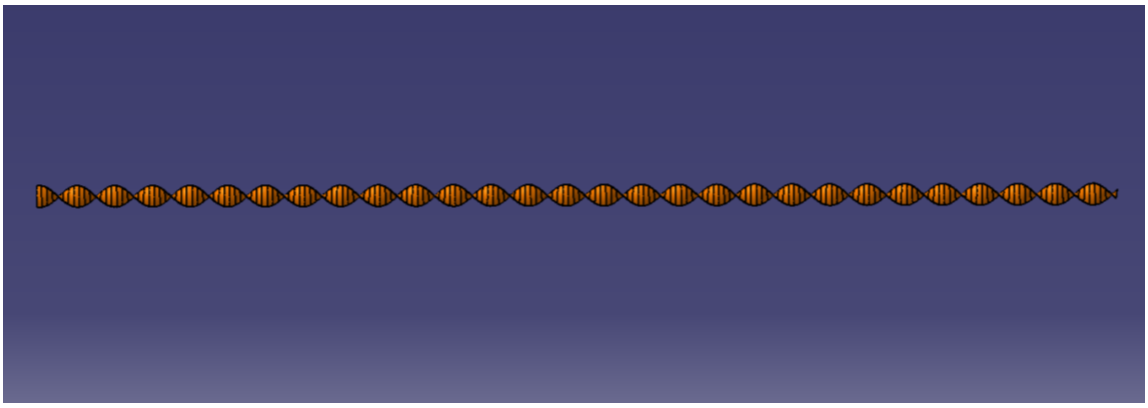


Appendix(iii): Showing Engineering drawing for the Double tube heat exchanger.

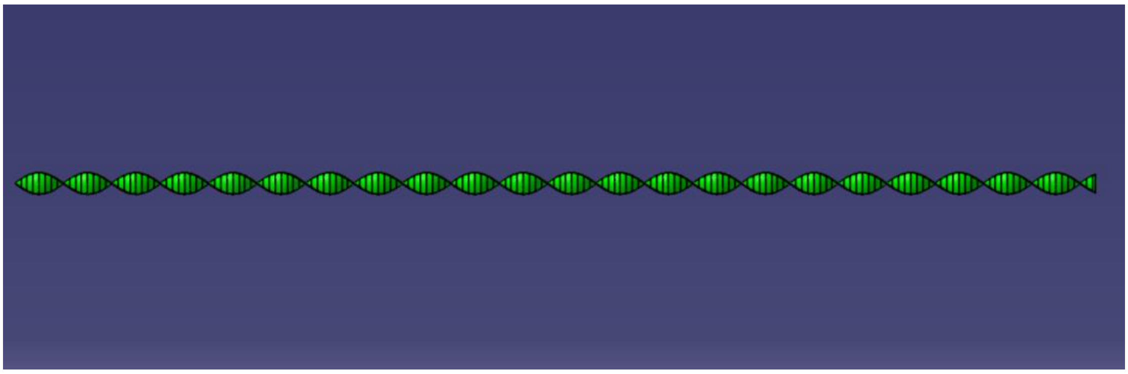


Appendix(iv): Showing Engineering drawing for twisted tape turbulators.

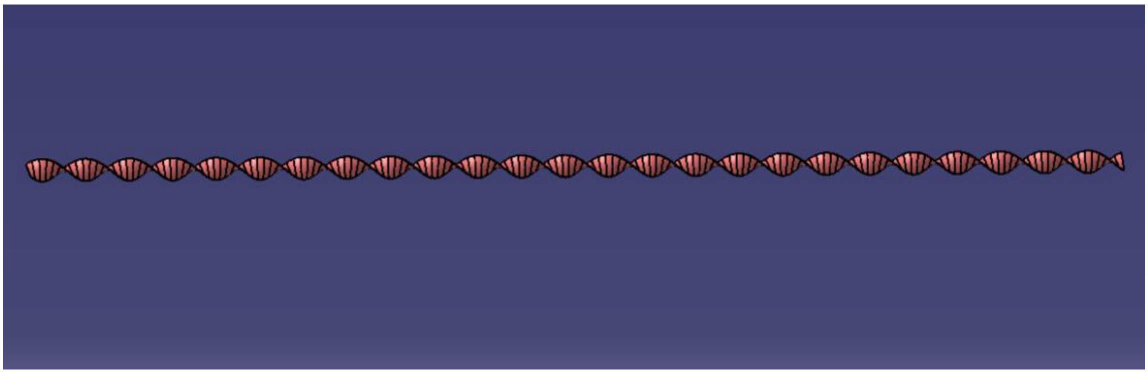
A)



B)



C)



Appendix(v): Showing the cad models for the twisted tape turbulators, A) TR3.5, B) TR 4, C) TR4.5