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THERMAL PERFORMANCE IMPROVEMENT OF SHELL AND HELICAL COIL HEAT EXCHANGER

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THERMAL PERFORMANCE IMPROVEMENT OF SHELL AND HELICAL COIL HEAT EXCHANGER

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Tareq H. ABED

DEDICATION

I'd want to express the deepest appreciation with my first instructor, my mother, who was also my first supporter and role model along the trip, as well as my brothers. This dream never would come true if it weren't for you.

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I'd want to direct my thankfulness to everybody who has sustained me during this journey, which has lasted for a long time. I'd need to show appreciation for my adviser, Asst. Prof. Dr. Ibrahim KOÇ, for his compass even while I thought I was misplaced and for being an outstanding part of the work's pinnacle. I'd also like to express my gratitude to my boss for his encouraging words, which significantly improved the quality of this project. Finally, I want to express my gratitude to this institution for welcoming me over out the years and firmly establishing itself as my home. I owe a debt of gratitude to my parents, whose beliefs and teaching inspire me to have requesting questions; to my brothers and people for unconditional love; and to my nation, which, though being inanimate, keeps me grounded and serves as an sample of resiliency.

ABSTRACT

THERMAL PERFORMANCE IMPROVEMENT OF SHELL AND HELICAL COIL HEAT EXCHANGER

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Nowadays, energy consumption increases so it is necessary to enhance the efficiency and performance of heat energy transition. The effects of perforated twisted tape on heat transfer factor, effectiveness, Nusselt number, and pressure drop are studied numerically. Modeling of HE with the perforated twisted tape is applied where finite volume manner is utilized to perform the setup and complete the solution. Validation of numerical results and experimental previous results is done and there is an excessive settlement between the numerical and experimental results. The range of Res is from 3800 to 18000. The results indicated that the *U* rises with the rise of Re where the perforated twisted tape achieves the extreme improvement of heat transfer coefficient achieving the numbers from 965 to 1250 W/m^{2}K. The perforated twisted tape has the highest ratio of enhancing Nu following the numbers from 65 to 115 and this can be explained as the velocity rises, the turbulence level increases. HE effectiveness increases with the growth of Re where the perforated twisted tape attained the supreme enhancement of effectiveness reaching the numbers from 0.35 to 0.85. It is indicated that the twisted tape configuration has the maximum ratio of ΔP increase as the complicity of twisted tape rise the ΔP. Contours and streamlines of hot and cold water cross the HE explains the distributions of temperature, velocity, and pressure.

Keywords: HE, Perforated twisted tape, Thermal performance, Helical coil

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LIST OF ABBREVIATIONS

CFD	:	Computational Fluid Dynamics
HE	:	Heat exchanger
HCHE	:	Helical coil heat exchanger
GHE	:	Ground heat exchanger
HCTTT	:	Helically coiled twisted trilobal
MWCNT	:	Multi-wall carbon nanotube
NTU	:	Number of transfer unit
TIT	:	Tube-in-tub

LIST OF SYMBOLS

A_s	:	Surface area, m^2
M	:	Mass flow rate, kg/s
D	:	Hydraulic diameter, m
T	:	Temperature, ◦C
P	:	Spring pitch, m
N	:	Number of revaluations
t	:	Thickness, m
h	:	Tape height, m
w	:	Tape width, m
d	:	Hole diameter, m
C_p	:	Specific heat, J/kgK
Q	:	Heat transfer rate, W
g	:	Gravity acceleration. m/s^2
p	:	Pressure, Pa
U	:	Overall h, J/kgK
u	:	Velocity, m/s
n	:	Number of tubes
L	:	Spring length, m
h	:	H, J/kg
T_o	:	Ambient temperature, ˚C
Nu	:	Nusselt number
ρ	:	Density of water , kg/m^3
F	:	Correlation factor
k	:	Thermal conductivity, W/mK

Re	:	Reynolds number
ΔP	:	Pressure drop, Pa
μ	:	Viscosity , Ns/m^2
T_{lm}	:	Logarithmic mean temperature
f	:	Friction factor

SUBSCRIPTS

cw	:	Cold water
out	:	Out
in	:	In
ave	:	Average
hw	:	Hot water
min	:	Minimum
surr	:	Surrounding
max	:	Maximum
Nu	:	Nusselt number
ε	:	Effectiveness

1. INTRODUCTION

Heat exchanger (HE) is essential components in a diversity of industrial processes, containing heat ventilation and air conditioning, petroleum processing, refrigeration, and food preparation. Shell and helically coiled tube HEs that are typically made up of helical coiled tubes and a cylindrical shell are some of the maximum extensively utilized HEs in the applications stated.

1.1 HEAT EXCHANGER

When two or more fluids, a solid surface and a fluid, or solid particles and a fluid are in thermal contact at dissimilar temperatures, thermal energy is transferred by HE. In most HEs, no external energy or work is utilized.

1.1.1 Heat exchanger classification

HEs can be categorized in a variety of ways. Categorizing can be based on the quantity of fluids, transfer procedures, and heat transfer methods. Usual HEs are divided into types based on their structure and flow configurations. Compact and non-compact HEs are another artificial categorization established by the heat transfer and surface space to volume percentage. As the types of tools, types of application, and design approaches vary, this classification is developed. The process function of HEs may also be categorized, as shown in Figure 1.1. HEs can also be classified over fluid type such as gas and gas, gas and liquid, liquid and liquid, gas and two phase, liquid and two phase, and so on.

1.1.2 Helical coil heat exchanger

Because of their compactness, easiness of production, and heat transfer effectiveness, this is the most popular type of HE. They're widely utilized in the power, food, and nuclear sectors, as well as in refrigeration, heat recovery, air conditioning, and space heating system. Figure

1.1 shows the arrangement rendering to procedure function, condensers arrangement, and arrangement of liquid to vapor phase change exchangers.

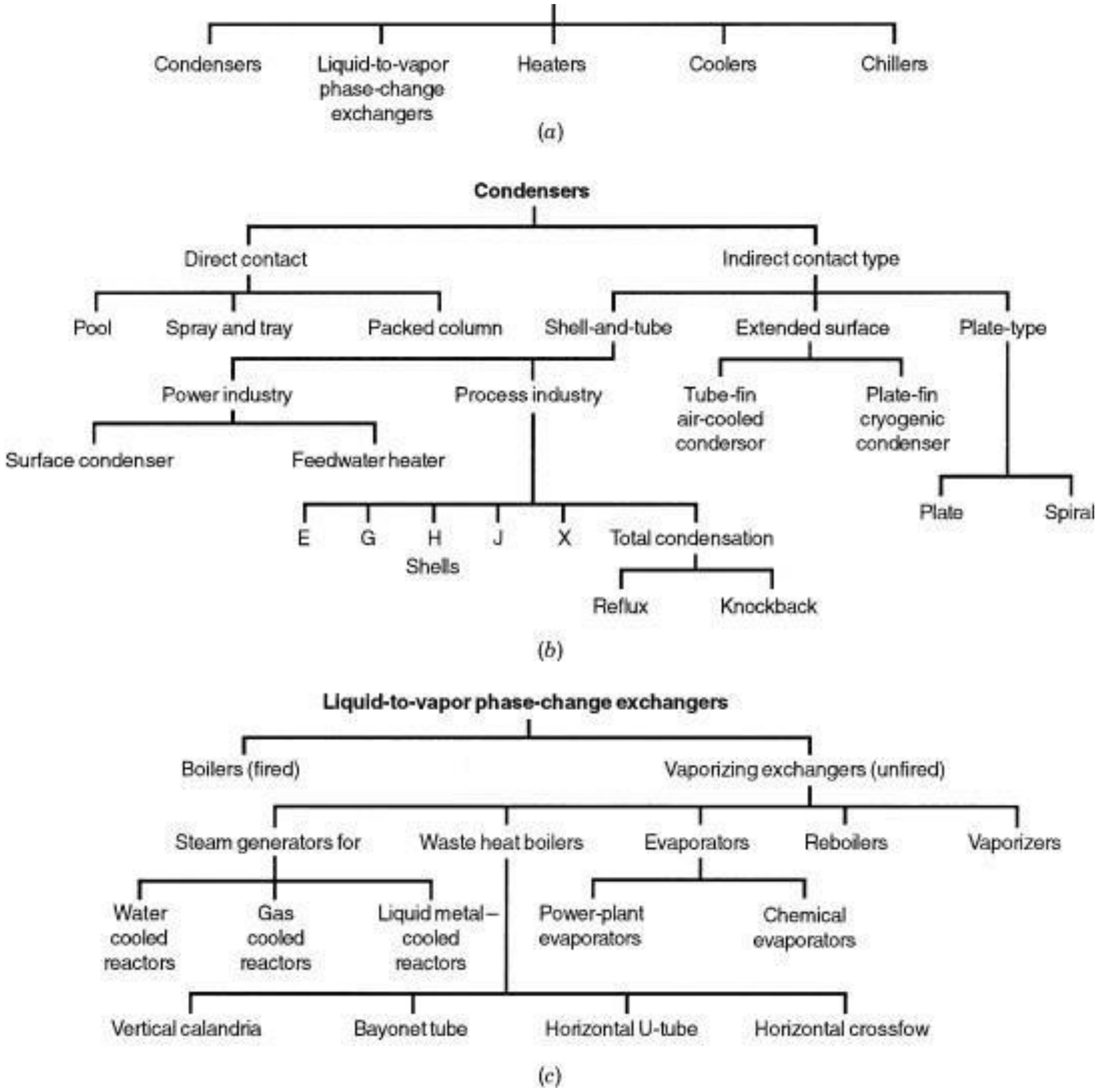

Figure 1.1 (a) Arrangement rendering to procedure function; (b) condensers arrangement; (c) arrangement of liquid to vapor phase-change exchangers [1]

1.1.3 Helical coil heat exchanger advantages

There are several advantages to using a helical coil HE, including its small size, which is a significant profit. Upper film factors, or the percentage at that heat is transmitted from one fluid to another over a wall, and better utilization of obtainable ΔP outcome in more effective and cost-effective designs. True counter current stream performs the most of the available LMTD (logarithmic mean temperature difference). Significant temperatures and severe temperature differentials may be handled using helical shape without causing great prompted stresses or requiring expensive extension joints. The exchanger's benefits are enhanced by its high pressure capabilities and the capability to completely clean the check fluid stream region.

1.1.4 Helical coil heat exchanger disadvantages

Coiled tube HEs have the following disadvantages: they are much more costly to construct than straight tube HEs, they are harder to keep clean, but they're not suitable for concentrating or crystallization purposes.

1.1.5 Applications

Helically coiled exchangers are becoming more popular. Liquid heat and cooling, steam boilers, vaporizers, cryogenic cooling, and exhaust condensing are some of the applications[2].

1.1.5.1 Sample Cooling

To guarantee product quality within acceptable tolerances, continuous monitoring of process output is required. Grab-sample cooling is required before to delivery to lab staff for analysis, therefore a small, low-cost device is required to efficiently chill sample streams to desired temperatures.

1.1.5.2 Pre-cooling of the analyzer

At or around their boiling temperatures, many components are treated as liquids. A decrease of pressure occurs as the liquid goes past a measurement equipment, causing the liquid to flash or boil. When dealing with two-phase flow, measurement instruments lose precision. When measuring a two-phase fluid, traditional volumetric or velocity measurement devices incur accuracy errors. This is a big issue from the standpoint of the procedure. Ammonia, carbon dioxide, sulfur dioxide, Freon, and ethylene are examples of common liquids that are treated at their boiling point. It may be essential to chill the liquid before passing it over an analyser to avoid flashing and compromising measurement accuracy. Numerous plants include a small helically HEs in their quantity packages to cool the saturated fluid earlier taking measurements. Because the ΔP over the measuring instrument is pre-cooled before to measurement, there is no flashing or two-phase flow.

1.1.5.3 Seal Coolers

Centrifugal pumps need refrigeration of their mechanical parts to ensure an adequate mechanical seal serviceability. The pumping seal fluid absorbs the heat generated at the gasket to shaft contact surface, which must be drained. Small helical HEs were employed in this purpose for a long time when they can efficiently refuse heat captured by the seal liquid even while tolerating high system pressures. Helical coil units act as seal coolers for liquid vacuum pumps, collecting heat generated by the pump as well as heat produced by condensation vapors in compressing.

1.1.5.4 Condensers

Condensers in a procedure round, for example reflux condensers or ejection exhaust condensers at the conclusion of a method, are frequently employed with helical coil HEs. The tube bundle may be inserted into a distilling tower, storage tank, or container due to the coil design. This permits vapors flowing up a vessel to touch and condense on the cooled tube bundle. The condensate that recirculates back into the tower can be redirected to another location. Not only is there an advantage from direct reflux with the bundle put directly into the vessel, but it also eliminates overhead pipes and support structures.

1.1.5.5 Compressor Inter- and After-Coolers

For every HE, these are demanding responsibilities. A helical coil unit's compactness reduces package size and layout. Perhaps the finest feature of a helical coil is its capacity to bear numerous thousand psi functioning pressure at last compression at a reasonable cost.

1.1.5.6 General Applications

Although the uses for helical coil HEs described above are the most frequent, their usage in industry is considerably broader and more diversified. Interchangers, preheaters, vapor condensers, boilers, batch coolers, and vessel and casing coolers are all typical uses for helical oil units. Helical coil HEs have a number of benefits, including increased thermal efficiency, compactness, ease of maintenance, and cheaper installation costs. A helical coil unit should be considered when an application demands equipment that can withstand high working pressures and/or extreme temperature gradients.

1.2 HEAT TRANSFER ENHANCEMENT IN HELICAL COIL HEAT EXCHANGER

Due to its compact shape, simplicity of production, and heat transfer performance, helical coiled tube HEs seem to be the most popular form of curved tube HE. They've also utilized in a number of industry sectors for a long time, including food processing, nuclear power, and electricity generating, and also thermal management, refrigeration, and air conditioning. Helical coiled HEs are recognized to be have better heat transfer properties in comparison to plain tube HEs attributable to the fluid velocity, which is vertical to the axisymmetric fluid direction, resulting in enhanced fluid mixture and a reduced in the width of the thermal boundary layer. The auxiliary flow is thought to account for 16–20% of the fluid flow speed.

This effect is explained by the centrifugal force induced either by coil's curves, which will be more visible in laminar regime due to limitation fluid combining in straight tube laminar flow. Brownian motion has been shown to enhance heat transfer characteristics in fluids with nanoparticles, such as nanofluids. Helical coiled tube HEs were subjected to a variety of passive and active techniques in terms of organizational performance. Fluid additions, coil and tube changes made, over the use of blades, fins, and inner springs are examples of passive methods. Two active techniques that can be utilized are generated pulsating and pipe rotating. The geometry and design characteristics of helical coils, including tube diameter and pitch, have an impact on their performance. The bulk of these methods were developed to enhance fluid mixture and, as either a function, the heat transfer rate at the wall. [3].

2. LITERATURE REVIEW

2.1 INTRODUCTION

Many investigations are shown the heat transfer process in various sorts of HEs. In comparison to conventional tubes HEs, shell and HCHEs were beneficial by way of heat transfer tools because of their compact and higher heat transfer factors.

Castelain et al. [4] improved the performance of a shell and HCHE by incorporating a ho.llow tube into the side of the shell, which allows cold fluid to enter the HE. Numerical simulation was utilized to estimate the performance of a modified shell and HCHE to that of a typical vertical shell and HCHE. The outcomes of the study demonstrated that the redesigned HE was successfully designed. In general, incorporating a hollow pipe into the HE's shell side resulted in increased heat transfer by regulating fluid flow in the shell side. In the run, the U was determined. The U was found to be between 1600 and 3150 W/m^{2}K. In addition, the *h* of the coil side was found to be in the range of 5700–13400 W/m^{2}K in this investigation. Furthermore, there was an average variation of 8% between simulation and experimental data.

In a constant, laminar stream over a tube, Sen et al. [5] investigated the phenomena of stable heat transfer increase owing to chaotic particle trajectories. The performance of two distinct coils is numerically examined and compared, one with normal mixture and anther one with chaotic mixing. The processes of increased heat and momentum transmission over change of the barrier and interior boundary layers are investigated using flow fields and isotherms.

Raghavan et al. [6] calculated the comparative advantages of employing a HCHE for heating liquids over a conventional tube HE. The design of the HE and the water bath temperature around the HE both influenced the h, according to the findings. The transitional and turbulent regimes were utilized in all of the tests. Manglik and Bergles [7] finished an analysis of the use of twisted tape supplemented in tubular HEs and their thermos hydraulic performance. Twisted tapes improve heat transmission by creating minor flows, growing stream speed owing to tube separating and obstruction, and essentially extending the helical flow length. Fin effects may be present depending on the tape-edge to tube-wall contact. The use of these materials in single and two phases (boiling and condensation) flows is discussed, and heat transfer and ΔP findings from several studies were shown. The nature of swirl flows and their scaling, as well as the establishment of predicted correlations for U and friction factors, were all examined. Also briefly described were certain features of the usage of geometrically modified twisted-tape inserts, as well as compound application with other enhancing techniques.

Rennie et al. [8] experimented and calculated convection heat transfer for helically coiled tubes. Using varied properties dimensions, the outer Nu was linked to the Rayleigh number. Offered the feed and bath temperature, coil parameters, and stream velocity, the finest relationship was attained by using the coil a whole length as the parameter. The creation simulations were utilized to establish an estimation model for predicting the output liquid temperature flowing over an HCHE. The expected output temperature was calculated and the results measured in the lab. The expected temperatures are near to the theoretical values, suggesting that the technique was obtainable here may be used to predict outlet temperatures from HEs of comparable size.

Raghavan et al. [9] looked at two extents and parallel and counter stream designs for helical coil HEs. Temperature data was collected as inner tube and annulus flow rates were changed. The numerical data was compared to the Nu in annulus side. For the bigger HE, the experimental data matched the computational results well. However, there were some discrepancies among the experimental and numerical results for the smaller coil; these discrepancies might were owing to the Wilson plots' nature. Overall, the results supported the validity of earlier numerical work for the most part. The relation between the U and the inner Dean number aimed at the minor coil for shell mass stream rates is illustrated in Figure 2.1.

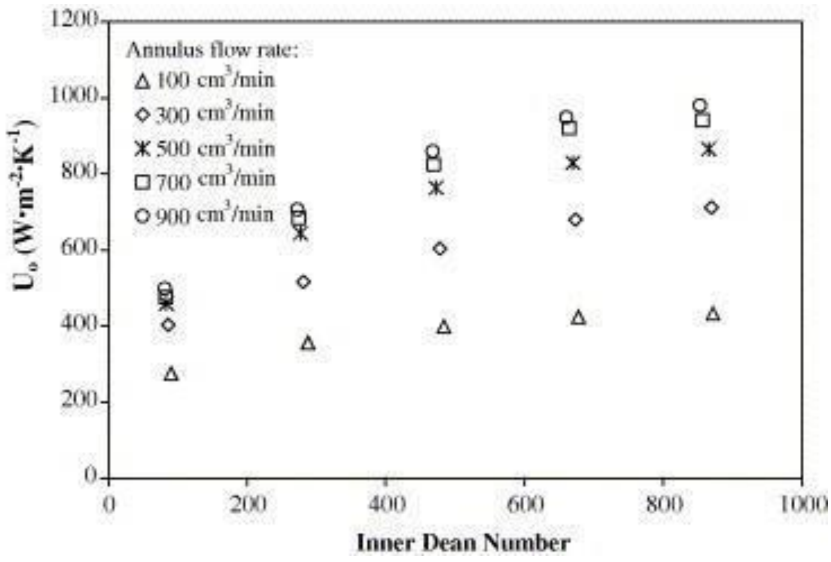

Figure 2.1 U against the inner Dean number aimed at the minor coil for shell mass stream rates [9]

Using computational fluid dynamics, Miura et al. [10] investigated a essential model of a four channel plate HE with plane plates. Experimental findings were associated to numerical estimates for heat load produced from a 3D Computational Fluid Dynamics (CFD) model as well as a 1D plug-flow model using parallel and series flow configurations. The CFD model represents the exchanger's channels, plates, and conduits, as well as the uneven flow distribution between channels and flow maldistribution inside the channel. The CFD results, particularly for the series arrangement, were in good accord with experimental data.

In a concentric double tube HE, Eiamsa-ard and Promvonge [11] looked at how heat transfer and flow friction were affected by installing a helical screw tape with and without a core rod. Helical tape of loose fit with or without core rod was placed in the HE's inner tube, and hot water was forced into the tube dependent on its Re, which ranges from 2000 to 12,000. According to the testing results, the loose fit, helical tape with and without core rod boosts the average Nu by 230 percent and 340 percent, respectively, over the similar plain tube. The f for the loose fit, helical tape without core-rod was approximately half that of the one with core-rod, and the Nu was only around half those of the one with core-rod. Moreover, the improvement of helical screw-tapes effectiveness ranges between 1.00 and 1.17, 1.98 and 2.14 for cassettes with and without core rod, correspondingly.

Mahajani et al. [12] conducted a fluid-to-fluid heat transfer experimental or theoretical investigation of a HCHE. For a real HE, it is discovered that specifying a constant temperature or constant heat flux boundary condition does not result in appropriate modeling. The HE is examined in terms of conjugate heat transfer and temperature dependent heat transport medium characteristics. For the estimate of heat transfer properties, an experimental setup is built. The experimental findings are contrasted to the results of the CFD simulation. The interior *h* of the *h* is calculated using a correlation built based on the experimental data. A correlation is built based on the experimental data to compute the interior *h* of the helical coil. The results are shown in Figure 2.2.

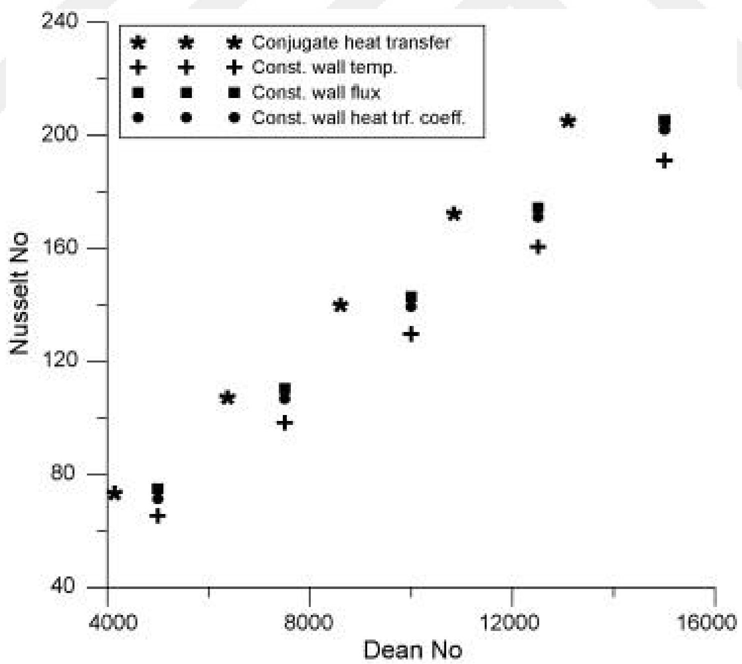

Figure 2.2 The relation between the Nu and the dean number [12]

Salimpour [13] investigated the *U* in the shell and helically coiled tube HEs in an experimental setting. Three HEs with dissimilar coil pitches were designated as check pieces for the both parallel and counter flow. Where completely necessary parameters, as input and outflow tube and shell side’s temperatures, fluids flow rate, and so on, were monitored by means of suitable equipment. The projected tube side heat transfer factor was compared to current hs for various boundary conditions and kept in good alignment.

For numerous Res, tube and coil diameter fractions, and dimensionless coil pitch, Taherian et al. [14] looked at mixed convection heat transmission in a coil and shell HE. Both laminar and turbulent flow were studied inside the coil. On the HE shell side h, the effects of coil pitch and tube diameters were studied. To define that length matches the data, many formulas were suggested based on the use of different characteristic lengths in various Nu computations. In comparison to earlier comparable research, the boundary conditions for the helical coils were a unique aspect of this work.

Moawed [15] studied experimentally the forced convection in the external faces of helically coiled tubes with a continuous barrage heat flow. The studies were carried out in a suction-mode open-circuit airflow wind tunnel device. The results of the experiments revealed that these variables have a significant impact on the average h. At constant Re and pitch ratio, the average Nu (Nu_m) grows as grows. At constant Re and diameter ratio, Nu_m also grows when pitch ratio grows. There was a lot of consistency between the current experimental results and earlier studies. Re, diameter ratio, and pitch ratio were all connected to the average Nusselt values.

Mohammed and Narrein [16] quantitatively examined the impact of various geometrical factors combined with nanofluid on heat transfer and fluid flow properties in a helically coiled tube HE. This study looked at the impact of flow configuration (parallel and counter). The helically coiled tube HE's Nu, heat transfer rate, ΔP, efficacy, and performance index were all evaluated. The findings demonstrate that different geometrical variables, for example the helix diameter and inner tube radius, have an influence on the HCTHE's laminar flow performance. In comparison to previous comparable studies, it was discovered that the counter flow arrangement surpassed the parallel flow configuration, which is a unique characteristic of this research as seen in Figure 2.3.

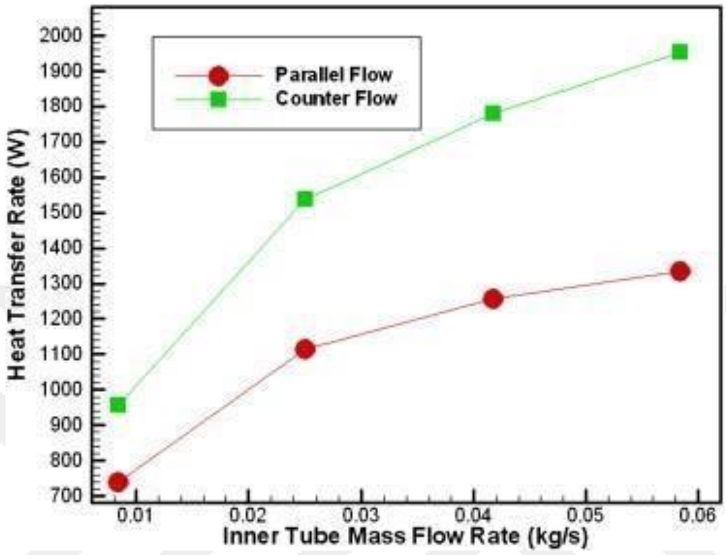

Figure 2.3 For various flow configurations, heat transfer rates vs inner tube mass flow rates are shown [16]

Dange et al. [17] investigated heat transmission in a cone formed helical coil HE at several Res in an experimental setting. This article compares heat transmission in a cone shaped helically coil versus a basic helical coil. It was discovered that the HE for the helical coil of cone shaped is extra effective than the HE for the basic helical coil. The heat transfer rates for the cone helical coil are greater than for the basic helical coil, according to the outcomes. The heat transfer rates for the cone shaped helical coil were found to be 1.18 to 1.38 times higher than for the basic helical coil.

Pawar and Sunnapwar [18] compared experimental data to CFD calculations for Newtonian fluids with temperature independent and continuous fluid characteristics, as well as the flow patterns in helical coils for various M numbers. For non-Newtonian fluids, testing of Nu correlation, Prandtl number, and coil curves fraction as an useful measure of Nu for a variety of outcomes under isothermal and – anti situations was investigated, as was trying to test of Nu similarity, Prandtl number, and coil curvature fraction as a through measure of Nu for – anti fluids for a wide range of frequencies below isothermal.

Lele et al. [19] investigated the conical coil HE's thermal analysis. Nu and f are paramters of flow rates, cylinder diameter, and cone angle, according to the study. Nu rose as the tube flow rate increased, while it decreased as the shell flow rate of, cone angle, and tube radius increased. Heat transfer and *f* features were considered in detail as a meaning of the flow rate of shell side, cone angle, and tube radius. The experimental correlations were provided to bring forth the physics of the conical coil HEs' thermal features.

Panahi and Zamzamian [20] investigated the effect of a helical cable put within a helical coiled tube experimentally. Experiments were conducted in two different ways. The coiled tube fluid was water inside the first manner and air in the second mode. Each scenario was investigated for a hollow coiled tube and a coiled tube with tabulator at various fluid flow rate. For all cases, the fluid on the shell side was hot water. The results revealed that this form of turbulator may be utilized in coiled tubes, resulting in a considerable increase in the total *h* and, therefore, pressure decrease. The *h*, ΔP, efficacy, and the number of transfer units (NTU) were all analyzed and addressed.

Alimoradi and Veysi [21] premeditated heat transmission and entropy formation in steady state forced convection heat transfer in SHCHEs. The influence of geometrical HE factors including radius, coil radius, inlet radius of shell, shell diameter, coil heights, shell stature, pitch, and distance from inlet and exit of shell on heat transfer rate and entropy production has been examined concurrently. The crucial and optimum values for these parameters were established to minimalize and increase the heat transfer rate per entropy production, respectively.

Souyri et al. [22] focutilized on the true shape of the HE and the energy retrieved from the ground in a 3D finite element model of helical coil Ground HEs. The created model was applied to a single GHE as well as numerous GHEs. The results suggest that operating the GHE in an irregular small time mode increases its performance. In the case of several GHEs, the best spacing between them (of 1 m diameter) was at least four times the GHEs radius for line or four-sided arrangements and six times the GHEs radius for hexagonal arrangements, according to the research. Exterior of the simple conventions of the standard 2D axisymmetric models, the created 3D finite element model might be useful in exploring helical coil GHE difficulties.

Hashemi et al. [23] utilized numerical simulations to examine heat transmission, ΔP, and entropy creation in casing and helically coiled tube HEs. The heat transmission rate was increased by placing shell fins on the coiled tube's external surface. The depth and figure of fins, in addition to the velocity of the fluid on the shell side, fluctuate. The study's primary findings include some recommended correlations for estimating the shell side Nu and friction factor. The link between the NTU, the rate of entropy formation, and the thermal efficacy were also determined. The model was confirmed by comparing the numerical values of both sides' Nus, as well as the f on the coil side, to the expected standards founded on past empirical correlations. A sample issue was established and answered in the concluding portion of this research as a guide for the designer of these sorts of HEs.

Sabeti et al. [24] examined the influences of wire coil supplements inside HEs at various Res. A significant struggle was undertaken to construct operational hexahedral meshes across all of the heat exchanger geometries to get trustworthy and confirmed findings. The verified models then clarified the object and circumstances that would optimally enhance heat transmission in twin pipe HEs. The results of this study show that using suitable wire coils to enhance Nusselt values by 1.77 times was possible. Proper friction coefficient and Nu correlations for various coiled wire inserts with varying geometric configurations under laminar flow were proposed as a result of the numerical simulation. The correlations, unlike the previous ones, were based on the occupied spaces that helical wires occupy within tubes; hence, the two updated correlations may both be employed for nonuniform helical wire insert designs.

Kshirsagar et al. [25] improved the *h* in a SCHE by means of various size concentrations of SiO_2 and water nanofluid, researchers. Hot nanofluid flows over the helical tube, while cold water flows over the HE shell side. The hot nanofluid's fluid flow rate was changeable. At 50 liters per hour (LPH), the cold water flow rate remains constant. The results reveal that raising the mass flow rate and volume concentrations of SiO_2 and water nanofluid boosted the hs of nanofluids. In the case of comparing to water fluid, the *h* of SiO_2 and water nanofluids was 28.71 % greater. The *h* of SiO_2 and water nanofluid for a fluid flow rate of 50 LPH was 65.81 % and 82.46 % greater than for fluid flow rates of 30 and 40 LPH, respectively. Comparing with water, the *f* for SiO_2 and water nanofluids were 52.61 % and 62.60 % greater, respectively.

Palanisamy and Mukesh Kumar [26] evaluated the ΔP and heat transfer of the cone helically coiled tube HE using multi wall carbon nanotube (MWCNT)/water nanofluids. For the nanofluids volume concentrations of 0.1 %, 0.3 %, and 0.5 %, respectively, the experimental Nu was 28 %, 52 %, and 68 % greater than water. The pressure decrease of 0.1 %, 0.3 %, and 0.5 % nanofluids was established to be 16 %, 30 %, and 42 % greater than that of water, respectively. It was discovered that handling MWCNT poses no immediate danger and that even after multiple test runs, there was no appreciable degradation of the coiled tube inner wall surface. As a result, MWCNT/water nanofluids were being utilized as a replacement for standard heat transfer fluids in cone helically coiled tube HEs to enhance heat transmission while reducing pressure loss.

Bantan et al. [27] examined the thermos-hydraulic properties of HEs, a novel form of the helically coiled tube HE. The flow regime under investigation was turbulent. The effects of the

Nu and *f* on the Re, orientation and sector angle, and coil radius were investigated. Equations for estimating the Nu and *f* as functions of the specified parameters were proposed for each kind of HE. It was discovered that part by part HEs with a semi-circular cross section were further effective comparing to tube in tube and quadrant circular cross section HEs.

Dbouk et al. [28] employed helically coiled twisted trilobal tube (HCTTT) in the HE. To comprehensively estimate comprehensive performance, two estimation standards, performance estimation measures and filed synergy number (Fc), were introduced. The results showed that the HCTTT achieves great in the hydraulic and thermos performance than the helically coiled oblique tube, and helically coiled plain tube (HCPT). According to the HCPT, the augmentation fraction of flow resistance was up to 24 % –38 %, while the Nu of HCTTT was increased by more than 19 % –31 %.

Almitani et al. [29] looked into the exergy of fluid flow and thermal energy transfer in the sector by sector and tube in tube (TIT) kinds of HCHEs. New formulae for estimating efficiency and coefficient exergy as functions of the two flows were proposed. Non-dimension coil radius and pitch, Res. These equations were utilized to compere the performance of these HEs. Exergy effectiveness drops by 21.8 %, 25.7 %, and 21.1 %, and the factor of exergy performance drops by 8%, 9.3%, and 14.8 % for HEs with half circle cross section, quadrant circle cross section, and TIT HEs, correspondingly, when the dimensionless coil diameter was doubled.

Khoshvaght-Aliabadi et al. [30] improved the thermal efficiency of a coil HE using a helical tube by twisting the construction. The perverted wall avoids the formation of thermal boundary layers in the flow path and modify the position and strength of created minor flows and velocity contours constantly, resulting in a more uniform temperature. For a model with median levels of design characteristics, a 14.2% increase in Nu and a 7.7% increase in *f* were measured. The helical-diameter has the greatest influence on the thermal hydraulic parameters of the helical-twisted tube, whereas the twist-pitch and helical pitch were second and third, respectively. As the helical diameter and twist pitch were reduced, the overall hydrothermal performance increases. At a Re of 900, the model with a helical diameter of 50 mm achieves the highest performance index of 1.98.

Alias et al. [31] experimented and calculated three sorts of helical microtubes coils: circular, oval, and elliptical. Working fluids and base fluids were Al_2O_3-water and ZnO-water at three volume fractions of 1.0 %, 1.5 %, and 2 %. For all geometries, several values of pitch were evaluated with a constant pitch/diameter ratio of 1. The results suggest that helical microtube curvature swirls were a key factor in increasing heat transmission. It also indicates that when the volume fractions of nanofluids and the Re grow, heat transmission and friction loss rise. The research also revealed that using helical microtubes significantly improves the heat transfer ratio, with the maximum improvement ratio achieved when using circular shape with 2% alumina nanofluid. Alumina nanofluid outperformed ZnO-water nanofluid overout a wide range of flow conditions, with the greatest thermal performance of 3.1 achieved at a Re of 1800 and alumina nanofluid at 2%. In addition, based on experimental data, additional empirical correlations were hypothesized and published.

2.2 THE NOVELTY OF THE STUDY

From the earlier literature review, it is observed that various researchers calculated the effects of different baffles configurations and nanofluids materials on helically tubed HEs but fewer studies investigated inserts inside coils. Spring wire insert inside the tube was utilized but the perforated twisted tape of the helical tube's HE was not utilized. Many experimental studies were completed to investigate the performance of shell and helically tube HEs but fewer numerical studies were indicated. In this study, the finite element method is utilized to study the effects of twisted tape on HE performance such as effectiveness, h, and ΔP were studied numerically. Contours and streamlines of temperature, velocity, and pressure were extracted to have a deep understanding of the fluid motion and heat transfer distribution.

3. NUMERICAL STUDY

In this section, the three-dimensional model that is accomplished by computer aided design (CAD) software and perforated twisted tape of the helical tubes HE dimensions were introduced.

3.1 HELICAL COIL HE MODELING

The physical model that is utilized to simulate the motion of water inside the helical coil HE with a perforated twisted tape inserted inside the coil is illustrated in Figure 3.1.

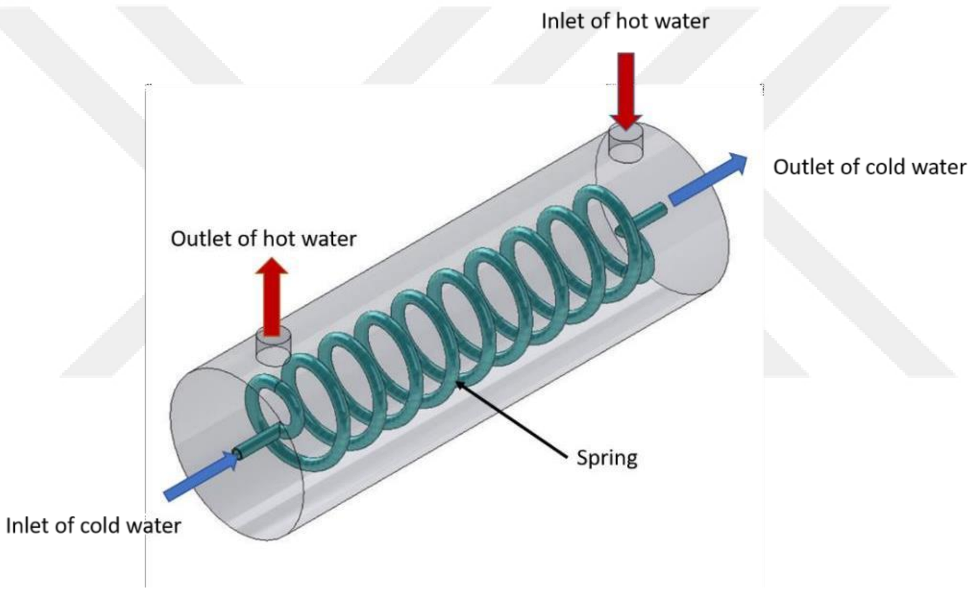

Figure 3.1: Three dimensions model of cold and hot sides

The inlets and outlets of cold and hot water were illustrated in the figure where the cold water flows inside the helical coil and the hot water moves inside the shell side. The specifications of the helical coil that is fabricated from the copper material because of high thermal conductivity were investigated in Figure 3.2.

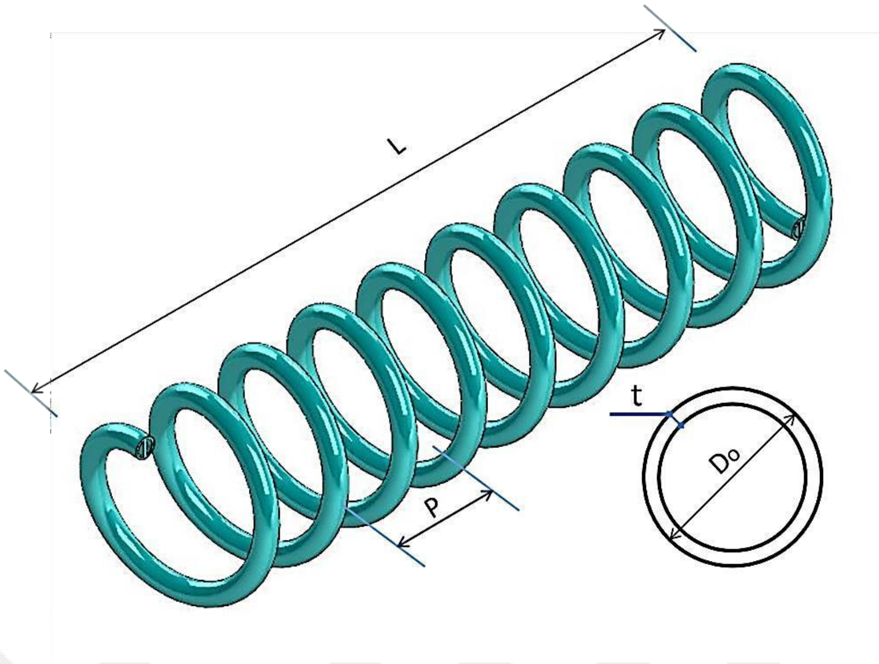

Figure 3.2: Three model of helical coil

The dimensions of the helical coil with 30 mm pitch is shown in Table 1.

Table 1: Specifications and dimensions of helical coil

Parameters of helical coil	**Dimensions**
Spring length, **L**	285 mm
Spring pitch, **P**	30 mm
Number of revolutions, **N**	9.5
Outer tube diameter, $\mathbf{D_o}$	8 mm
Tube thickness, **t**	1 mm

For heat transfer enhancement, perforated twisted tape has a rectangular cross-section inserted inside the helical coil as seen in Figure 3.3. More illustration for the tape and hole inside the tube is investigated in Figure 3.4 to show the contacts between them where the distance between the holes centers equals 30 mm.

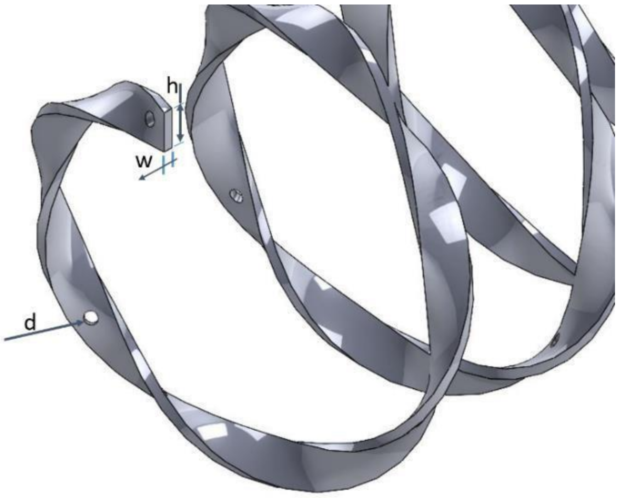

Figure 3.3: The specifications of perforated twisted tape

Figure 3.4: Shape of tape inside the coil

Small holes with 2 mm diameter were distributed on the surface of the twisted tape. where the distance between the holes centers equals 30 mm. More specifications of perforated twisted tape were illustrated in Table 2.

Table 2: Specifications and dimensions of perforated twisted tape

Parameters of perforated twisted tape	**values**
Tape height, **h**	6 mm
Tape width, **w**	1.2 mm
Hole diameter, **d**	2 mm
Number of holes	30
Twisting angle	25^{o}
Twisted tape pitch	30 mm

To study the effects of utilizing perforated tapes, three cases (only helical coil, twisted tape, perforated twisted tape) were performed as seen in Figure 3.5.

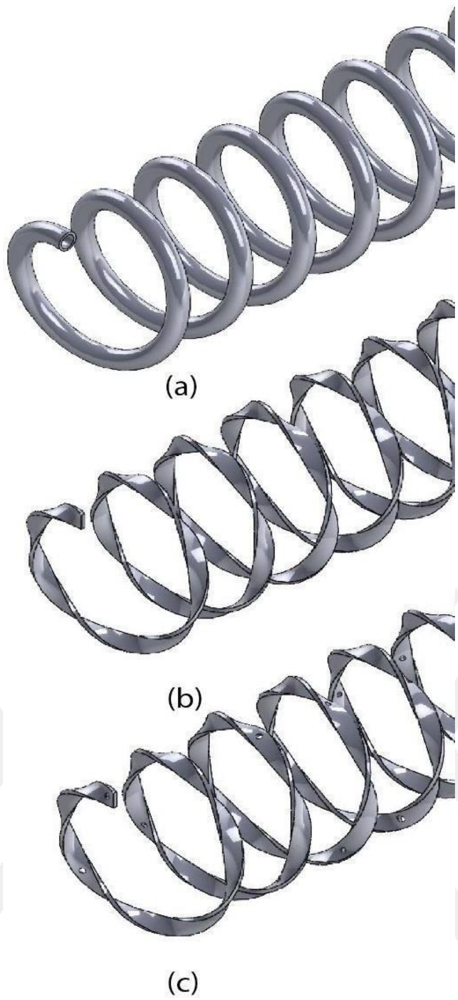

Figure 3.5: Test runs cases (a) only helical coil, (b) twisted tape, (c) perforated twisted tape

3.2 MESH GENERATION

A complicated system containing physical domains of a helical coil, perforated twisted tape, hot oil, and cold water has been meshed with an unstructured tetrahedron mesh in this work. Aside from the helical coil and perforated twisted tape, mesh enhancements were utilized. The mesh generation for the HE and the helical coil is shown in Figure 3.6. To fulfill the mesh dependency check, four grid systems with 1.324, 1.854, 2.561, and 2.823 million elements were created. Between the finest grid and the median number of grids, the inaccuracy in results values is less than 1.51 % and 2.26 %, respectively. As a result, the 2.823 million cell model was employed for these experiments.

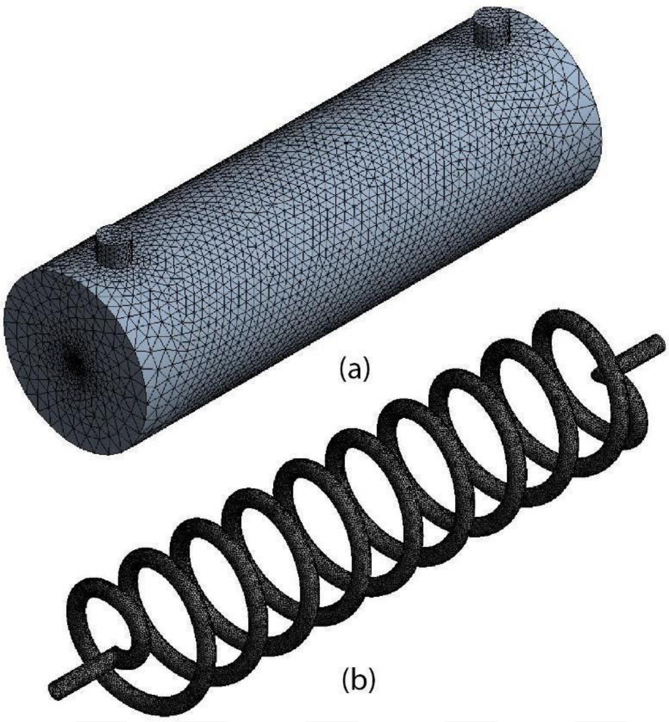

Figure 3.6: Mesh generation for (a) helical coil HE (b) helical coil

Table 3 shows the error percentage of *U* and effectiveness for the four cases of grid generations.

Table 3: Error percentage of *U* and effectiveness

Meshing elements number	U	Effectiveness	U Error %	Effectiveness Error %
1.324 million	95	0.472	2.023%	1.964%
1.854 million	97	0.479	1.351%	1.032%
2.561 million	98	0.481	0.098 %	0.087 %
2.823 million	98.1	0.482	0.002 %	0.003 %

3.3 BOUNDARY AND INITIAL CONDITION

For steady-state analysis, a commercial software tool [32] is utilized to build up and solve the mass and energy equations. For the viscous enhanced wall function model, a pressure-based solver was adopted with the gravity effect and a realizable k-ε The number of simulation iterations required to produce a converged solution is determined by the mass continuity, velocity flow, energy, and turbulent viscosity solution. For pressure-velocity coupling, a simple approach is selected. The convective terms such as momentum, energy, and turbulent kinetic energy equations were discretized using the second-order unwinding methodology. For boundary conditions, a cold water velocity input is assumed at the receiver's intake with the needed values, with the temperature set at 27 ^oC as seen in Table 4: Numerical boundary conditions. The hot water inlet is considered to be at 50 ^oC. The outer surface of the HE is performed at zero heat flux to reach full insulation.

Table 4: Numerical boundary conditions

Boundary conditions	
Re range	3800 to 18000
Pressure outlet of hot water	Atmospheric pressure (101325 Pa)
Pressure outlet of cold water	Atmospheric pressure (101325 Pa)
Heat flux of outer surfaces	0.0
Inlet cold water temperature	27 ^oC
Inlet hot water temperature	50 ^oC

3.4 UTILIZED EQUATIONS FOR RESULTS EXTRACTION

To indicate the *U*, the heat transfer of the cold water in shell side and hot water in tubes were considered from [33]:

$$Q_{cw} = M_{cw} c_{p,cw} (T_{cw,out} - T_{cw,in}) \quad (1)$$

$$Q_{ho} = M_{ho} c_{p,ho} (T_{ho,in} - T_{ho,out}) \quad (2)$$

Where M_{cw} is the cold water mass flow rates, M_{ho} is the hot water mass flow rates, T is the temperature and c_p is the specific heat so the average heat is

$$Q_{ave} = \frac{Q_{wc} + Q_{ho}}{2} \quad (3)$$

The heat balance deviation $\frac{Qwc+Qho}{\dot{Q}_{ave}}$ necessity be below than 5% and that realized in totally investigational tests. The *U* can be performed from [23]:

$$U = \frac{Q_{Ave}}{A_s\,F\Delta T_{Lm}} \tag{4}$$

$$A_s = n\pi DL \tag{5}$$

Where is the outer surface where and *F* is the correlation factor where logarithmic mean temperature difference is

$$\Delta T_{Lm} = \frac{(T_{ho,out}-T_{Cw,out})\ -(T_{ho,in}-T_{Cw,in})}{\ln\frac{(T_{ho,out}-T_{Cw,out})}{(T_{ho,in}-T_{Cw,in})}} \tag{6}$$

The effectiveness (Ɛ) reflects the amount of heat that was actually transmitted as a percentage of the maximum amount of heat that might be transported $\varepsilon = \frac{\text{actual heat transfer } (\dot{Q})}{\text{maximum haet transfer} (\dot{Q}_{MAX})}$ and the effectiveness [34]:

$$\varepsilon = \frac{M_{cw}c_{p,cw}(T_{cw,out}-T_{cw,in})}{(Mc_p)_{min}(T_{ho,in}-T_{cw,in})} = \frac{M_{ho}c_{p,ho}(T_{ho,in}-T_{ho,out})}{(Mc_p)_{min}(T_{ho,in}-T_{cw,in})} \tag{7}$$

Reynolds number can be calculated by:

$$Re = \frac{\rho VD}{\mu} \tag{8}$$

Where ρ is the density, v is the velocity, D is the hydraulic diameter and μ is the viscosity

4. RESULTS AND DISCUSSIONS

4.1 VALIDATION OF NUMERICAL RESULTS

For confirmation of the arithmetical model, previous investigational study outcomes [34] have associated with the result of this study. A comparison between the U versus the volume flow rate for experimental and numerical results is introduced in Figure 4.1. Where a comparison between effectiveness versus the volume flow rate for experimental and numerical results is introduced in Figure 4.2. The average difference between numerical and experiment results for U and effectiveness around 1.92% and 1.12%, respectively. It is indicated that the differences between the experimental and numerical results were acceptable so that the helical coil HE model of CFD modeling being considered is efficient and precise.

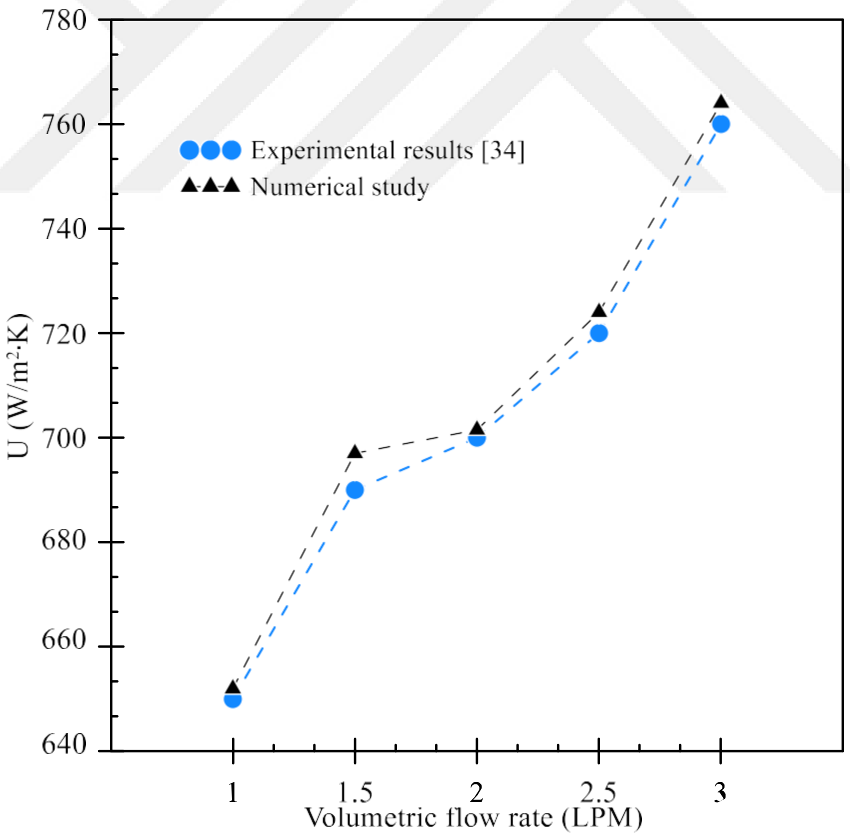

Figure 4.1: The comparison between the experimental and numerical results for the *U*

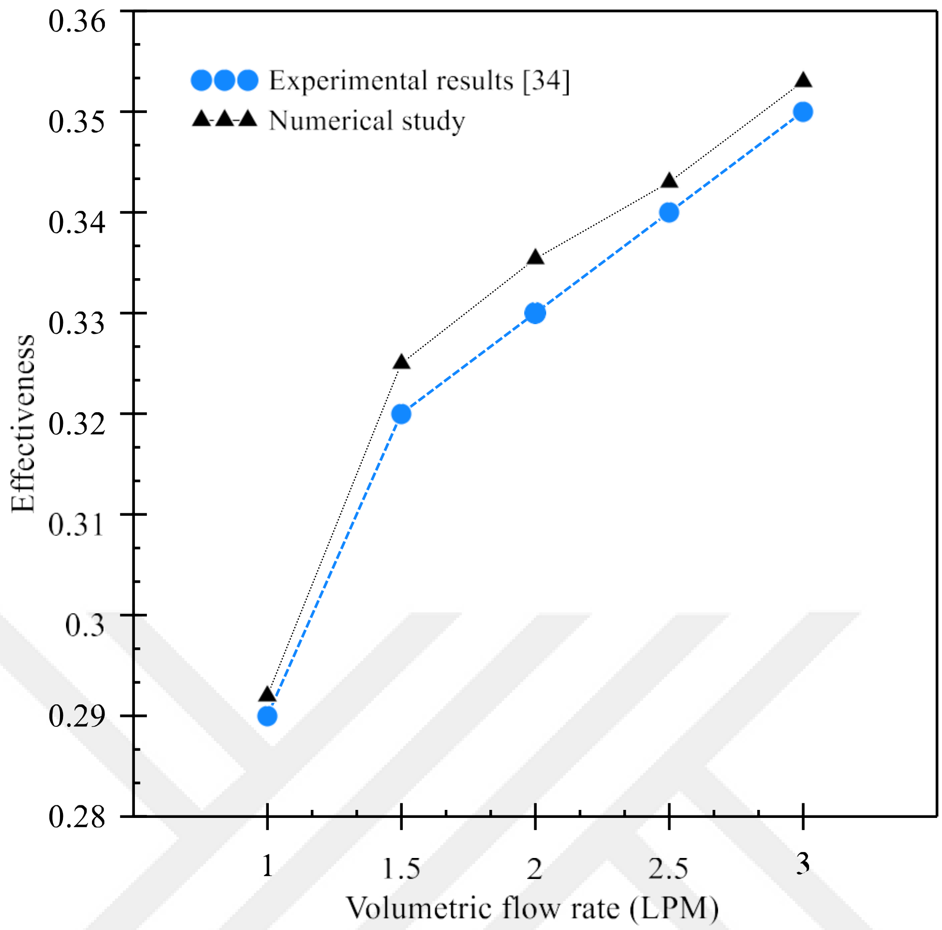

Figure 4.2: The comparison between the experimental and numerical results for effectiveness

4.2 PERFORMANCE ANALYSIS

In this section, the performance parameters for example *U*, Nu, effectiveness, and ΔP of helical coil HE versus the Re with a range from 3800 to 18000 were investigated. The relation between the U and the Res for only helical coil, with twisted tape, and with perforated twisted tape is illustrated in Figure 4.3. The *U* increases with the rise of Re where the perforated twisted tape achieved the maximum enhancement of *U* achieving the numbers from 966 to 1252 $W/m^2.K$. The effects of adding twisted tape to the HE were appeared in the figure where the *U* with twisted tape is higher than the pain helical coil. There are three reasons for enhancement of overall *U* such as helical coil, twisted tape, and perforated twisted tape. This enhancement is resulted because of increase of velocity that leads to rise the turbulence inside the helical coil.

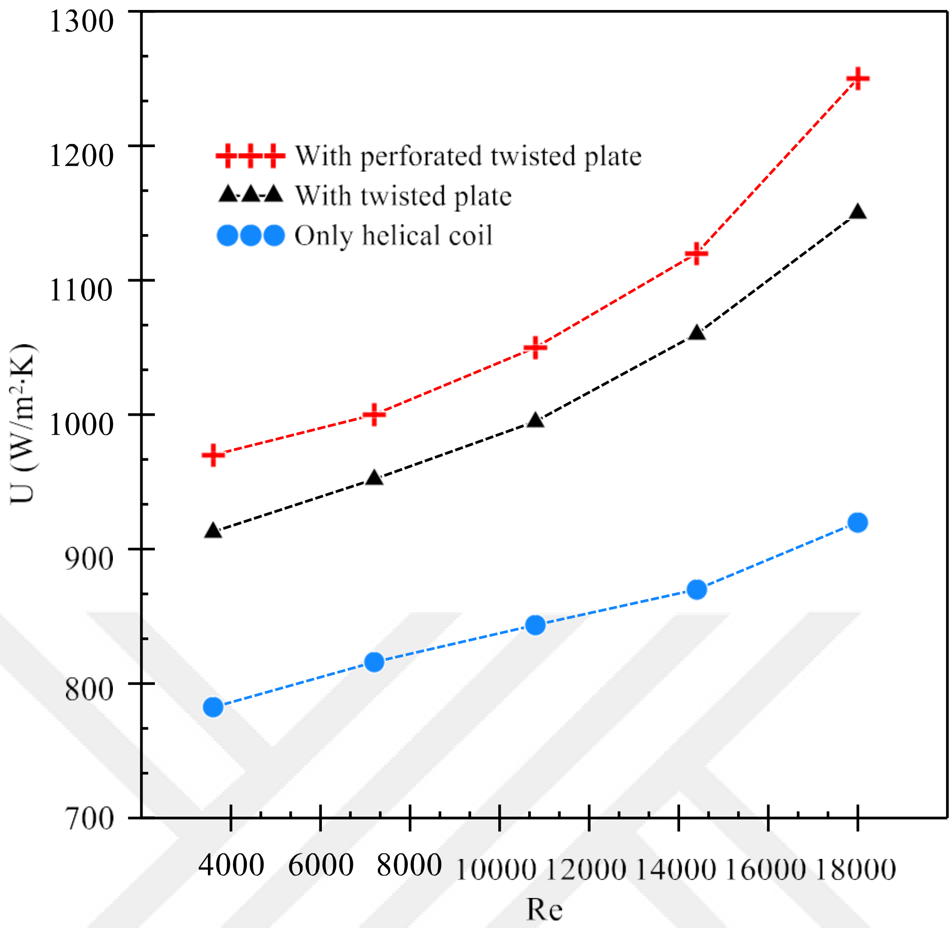

Figure 4.3: The relation between the U and the Res for only helical coil, with twisted tape, and with perforated twisted tape

The deviation of the Nu versus the Re is presented in Figure 4.4 where Nu enhanced with the rise of Re. It is indicated that the perforated twisted tape has the highest ratio of enhancing Nu following the figures from 68 to 115.5. This can be explained as the Re increase the velocity rises so that the turbulence enhanced inside the helical coil so the Nu increases. The holes distributed over the surface of twisted tape increase the velocity and enhance the heat transfer so that the Nu grows.

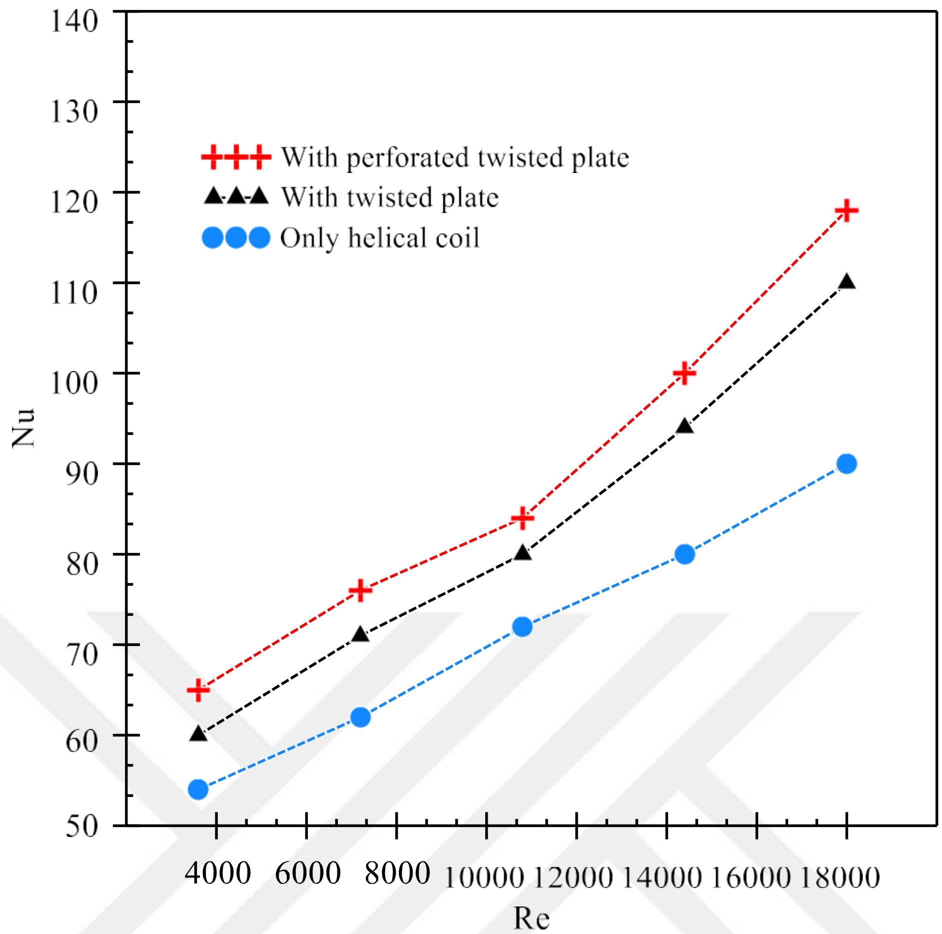

Figure 4.4: The relation between Nu and the Res for only helical coil, with twisted tape, and with perforated twisted tape

Figure 4.5 shows the effectiveness variation versus the Res for only helical coil, with twisted tape, and with perforated twisted tape. HE effectiveness increases with the growth of Re where the perforated twisted tape attained the supreme enhancement of effectiveness reaching the numbers from 0.360 to 0.855. This improvement in effectiveness could be qualified to a reduction in the boundary layer thickness inside the coil due to the presence of twisted tape that performances as turbulators in the coil flow and therefore the heat exchanger effectiveness are enhanced.

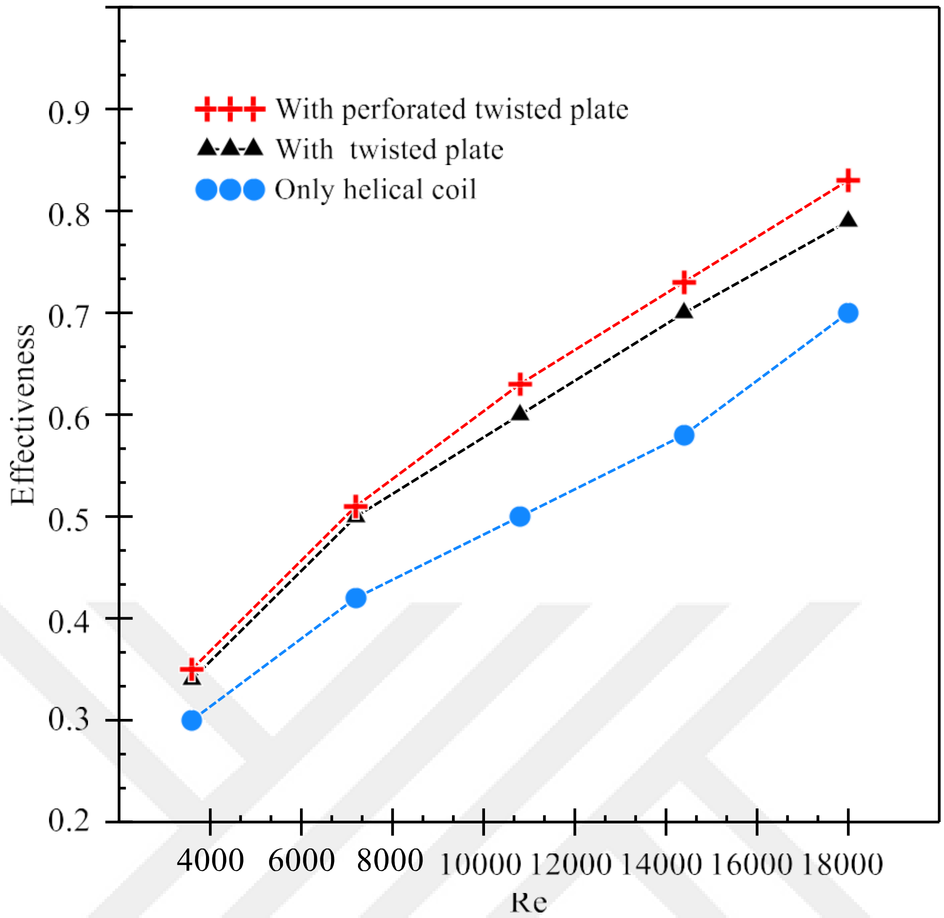

Figure 4.5: The relation between the effectiveness and the Res for only helical coil, with twisted tape, and with perforated twisted tape

Figure 4.5 shows the relation between the ΔP and the Res for three configurations (eg. only helical coil, with twisted tape, and with perforated twisted tape). It can be indicated that the ΔP increase with the rise of Re. The twisted tape configuration has the maximum ratio of ΔP increase as the complicity of twisted tape rises the ΔP. It can be observed that the ΔP in the case of perforated tape is lower than the ΔP in the case of twisted tape as the holes make the flow inside the helical coil more smoothly. It may be stated that flow resistant in helical coil heat exchangers is affected by separation, depth of flowing fluid, and reattachment with twisted tapes inside of the helical coil as compared to simple tubes. These influence are mostly due to dynamic pressure dissipation and extraordinarily high viscosity losses around the twisted tapes and helical coils. Furthermore, auxiliary flows at holes may be caused by the interaction of pressure and inertial forces in the boundary layer, resulting in an rise in pressure drop.

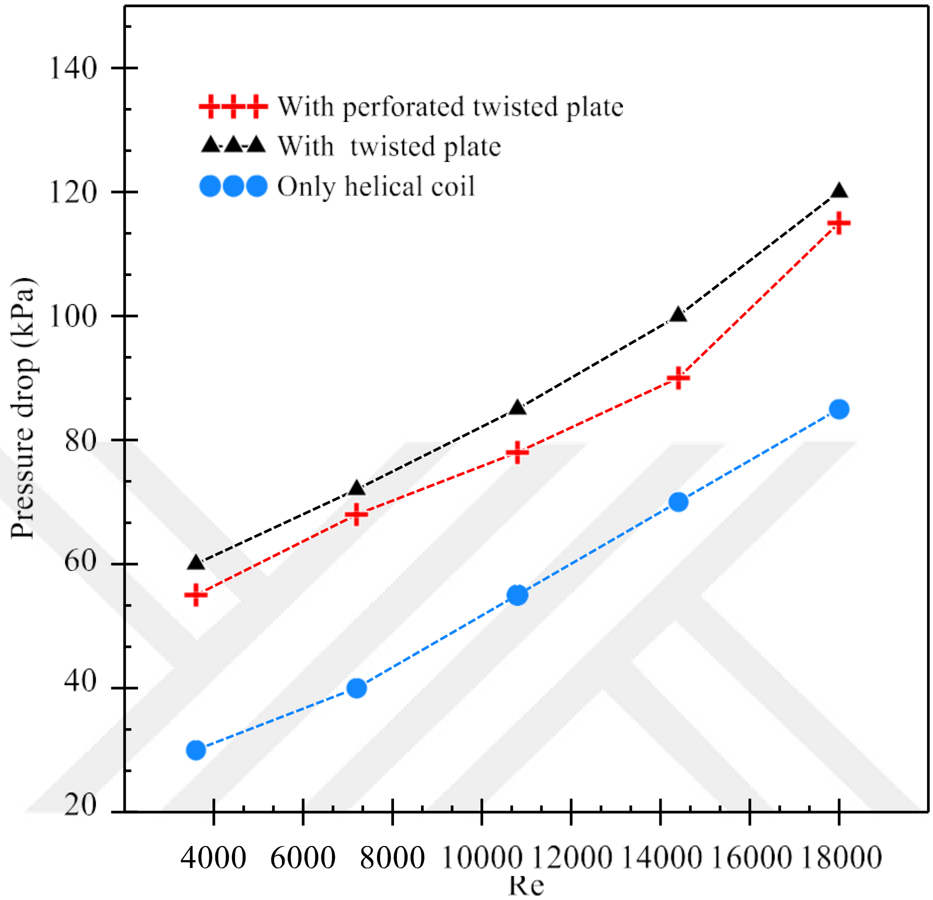

Figure 4.5: The relation between the ΔP and the Res for only helical coil, with twisted tape, and with perforated twisted tape

The temperature distribution of hot water inside the shell side for the three configurations is illustrated in Figure 4.6 where the effects of inserting perforated twisted tape appear. It is indicated that the temperature distribution in the case of twisted tape is better than the temperature distribution in the case of the only helical coil. The temperature distribution of perforated twisted tape shows more turbulence that leads to more heat transfer enhancement.

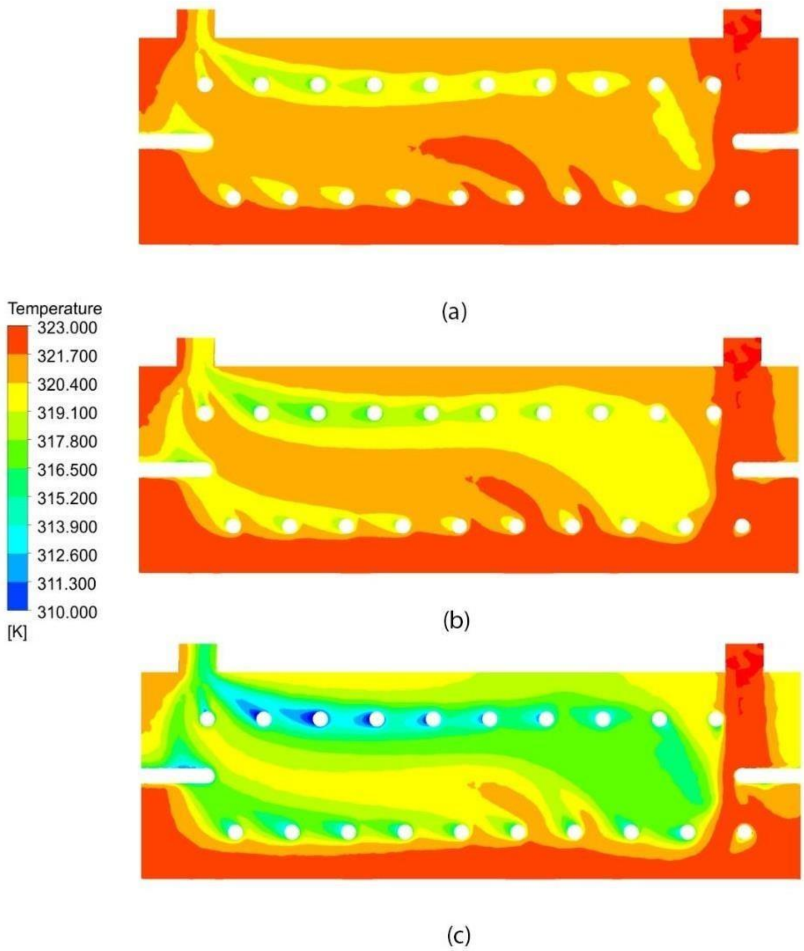

Figure 4.6: Contours of temperature distribution of hot water for (a) only helical coil, (b) with twisted tape, and (c) with perforated twisted tape

The temperature distribution of cold water inside the helical coil for the three shapes is demonstrated in Figure 4.7 where the special influences of injecting perforated twisted tape perform. It is indicated that the temperature distribution in the case of twisted tape is better than the temperature distribution in the case of the only helical coil. The temperature distribution of perforated twisted tape shows more turbulence that leads to more heat transfer enhancement. During heat transfer procedures using twisted tape with helical coils, a swirl motion was observed. The technique creates a more intense swirl motion with higher Res. Overall, the heat transmission rate is increased due to the disruption utilized by twisted tape.

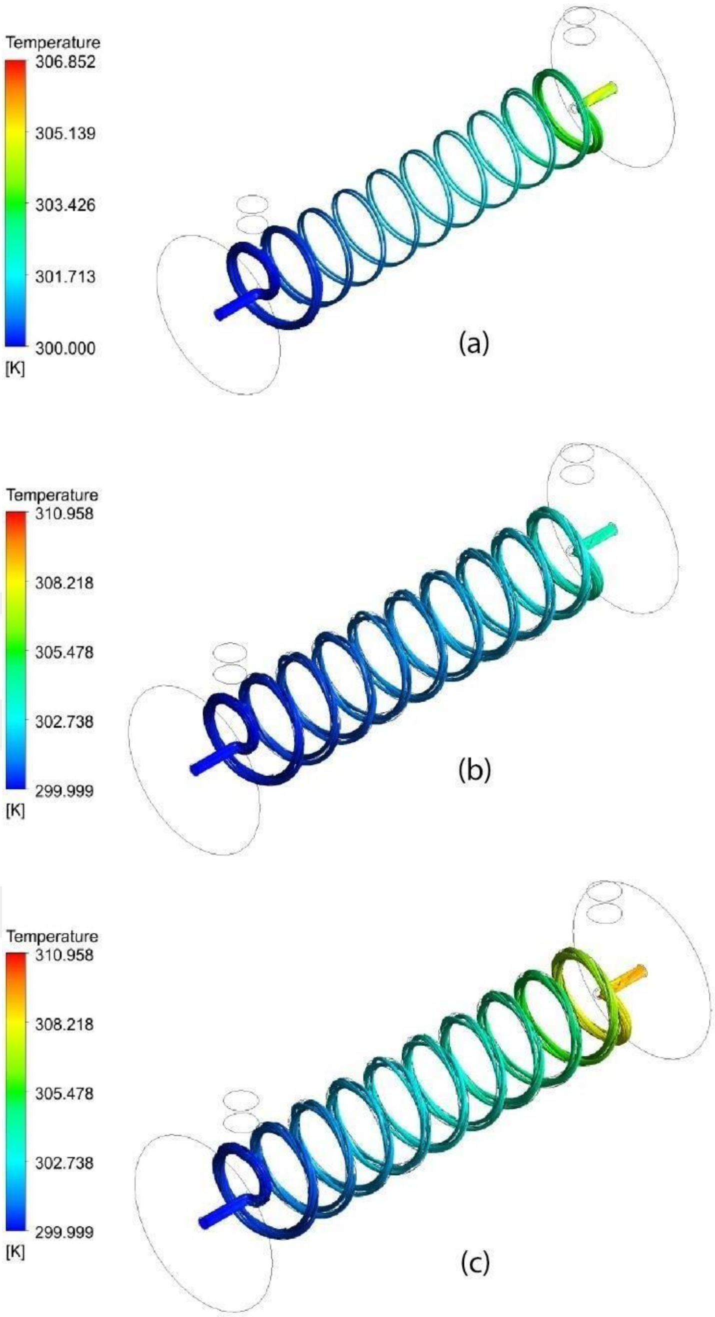

Figure 4.7: Streamlines of temperature distribution of cold water for (a) only helical coil, (b) with twisted tape, and (c) with perforated twisted tape

Figure 4.8 shows the streamlines of velocity distribution where the velocity increases with utilizing the twisted tape. That can be explained as the flow goes over the helical coil the perforated twisted tape force the flow to have twisting passes so that the velocity increase. That leads to enhance the turbulence so that the heat transfer is enhanced from the hot side to the cold side. More mixing between the hot and cold boundary layers inside the helical coil leads to enhance the heat transfer between the layers as well as the higher velocity increases the thermal performance parameters. The holes that are distributed over the surface of the twisted tape decreases the vortex regions so that the temperature distribution is enhanced.

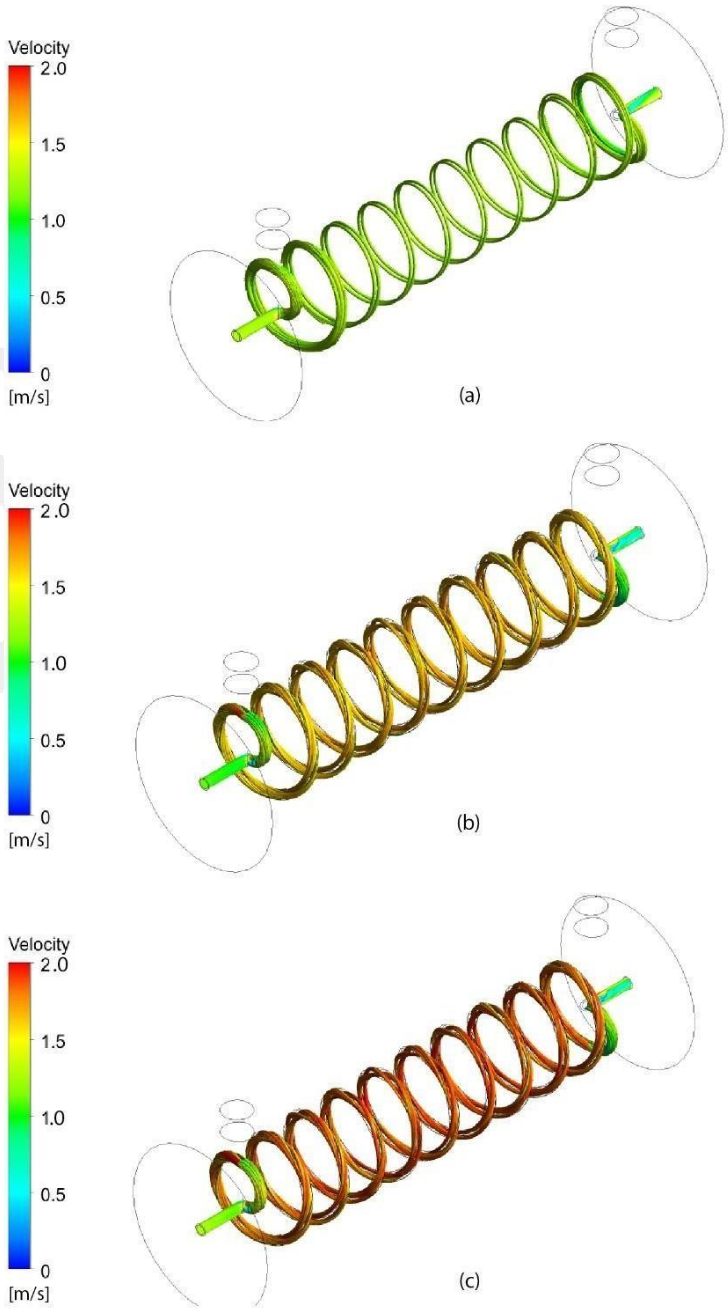

Figure 4.8: Streamlines of the velocity distribution of cold water for (a) only helical coil, (b) with twisted tape, and (c) with perforated twisted tape

Figure 4.9 shows the influence of twisted and perforated twisted tape on the pressure distribution inside the helical coil. It is indicated that the twisted tape has the maximum increase in ΔP. The ΔP in the case of the perforated tape is less than the ΔP in the case of twisted tape. This can be explained as the twisted tape is inserted inside the helical coil the resistance of fluid flow increase. The holes of perforated twisted tape allow the fluid to go smoothly and decrease the eddy zone so that the flow resistance decrease comparing to twisted tape without holes.

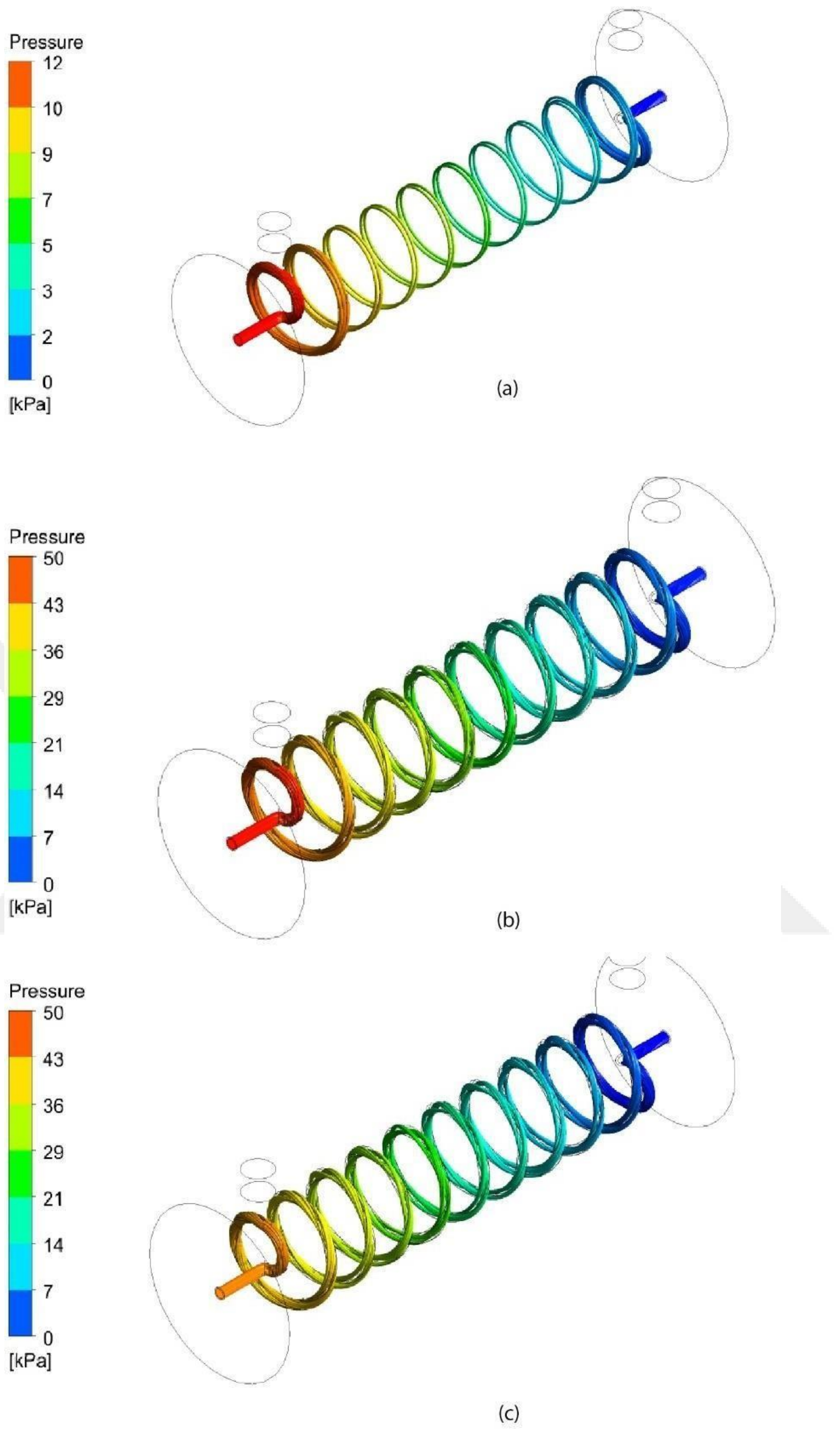

Figure 4.9: Streamlines of pressure distribution of cold water for (a) only helical coil, (b) with twisted tape, and (c) with perforated twisted tape

5. CONCLUSION

In this study, the Finite volume method is utilized to study the effects of twisted tape on HE performance such as *h*, effectiveness, Nu, and ΔP. The numerical results were validated with previous experimental results and there was an excessive agreement between the numerical and experimental results. The range of Res is from 3800 to 18000. Contours and streamlines of temperature and pressure were extracted to have a deep understanding of the fluid motion and heat transfer distribution. The results can be concluded in those points:

i. The *U* increase with the rise of Re where the perforated twisted tape achieved the maximum enhancement of heat transfer achieving the numbers from 966 to 1252 $W/m^2.K$.
ii. The perforated twisted tape has the highest ratio of enhancing Nu following the numbers from 66 to 115.5 and this can be explained as the velocity rises, the turbulence level increases.
iii. HE effectiveness increases with the growth of Re where the perforated twisted tape attained the supreme enhancement of effectiveness reaching the numbers from 0.360 to 0.855.
iv. The twisted tape configuration has the maximum ratio of ΔP increase as the complicity of twisted tape rises the ΔP.
v. Contours and streamlines of hot and cold water cross the HE explains the distributions of temperature, velocity, and pressure.

6. FUTURE STUDY

The investigation of thermal performance and ΔP of helical coil HE with nanofluids and geometrical modification may be advised for the future studies.

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