T.C.

ALTINBAS UNIVERSITY

Institute of Graduate Studies

Mechanical Engineering

EXPERIMENTAL AND NUMERICAL STUDY OF HEAT TRANSFER IN DOUBLE-PIPE HELICAL HEAT EXCHANGER USING NANO-LIQUID

Ali Zaeem Fezea ALDAHLAH

Master of Science

Supervisor

Asst. Prof. Dr. Ibrahim KOÇ

Istanbul, 2021

EXPERIMENTAL AND NUMERICAL STUDY OF HEAT TRANSFER IN DOUBLE-PIPE HELICAL HEAT EXCHANGER USING NANO-LIQUID

by

Ali Zaeem Fezea ALDAHLAH

Mechanical Engineering

Submitted to the Graduate School of Science and Engineering

in partial fulfillment of the requirements for the degree of

Master of Science

ALTINBAŞ UNIVERSITY

2021

The thesis titled "**EXPERIMENTAL AND NUMERICAL STUDY OF HEAT TRANSFER IN DOUBLE-PIPE HELICAL HEAT EXCHANGER USING NANO-LIQUID**" prepared and presented by "Ali Zaeem Fezea ALDAHLAH" was accepted as a Master of Science Thesis in Mechanical Engineering.

____

Asst. Prof. Dr. İbrahim KOÇ

Supervisor

Thesis Defense Jury Members:

Asst. Prof. Dr. Ibrahim KOÇ	Faculty of Engineering and Natural Sciences, Altınbaş University, Turkey	__________________
Asst. Prof. Dr. Serdar AY	Faculty of Engineering and Natural Sciences, Altınbaş University, Turkey	__________________
Asst. Prof. Dr. Haydar UYANIK	Graduate school of Applied Sciences, KTO Karatay University, Turkey	__________________

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Approval Date of Institute of Graduate Studies:
____/____/_____

I confirm that all of the material in this paper follows the academic standards and ethical behavior. As I've declared and in accordance with these laws and regulations, I have thoroughly mentioned and referenced any work that was done outside of this piece.

Ali Zaeem Fezea ALDAHLAH

DEDICATION

This is for you, mom. I want to thank you for all you have done for me over the years, for believing in me and encouraging me to be my best, and for all the things you have given me, everything you taught me, and for just being there. You've inspired me to be the person I am today. You've made my dream a reality, and it's something that I'm eternally grateful for.

ACKNOWLEDGEMENTS

I really want to express my gratitude to everyone who has supported me during this journey, especially through the often-long intervals. I'd I really want to say thanks to my adviser, Asst. Prof. Dr. İbrahim KOÇ, since they've been my guidance even being at the crux of a great part of my work, even though I didn't think I could find my way out of being lost. I'd want to take the time to thank my advisor, who always motivates me, which significantly improved the quality of this work. Also, I want to show my thanks to this institution for welcoming me during the years and firmly establishing itself as my home. I am grateful to my parents, who I want to be and whose views and education are constant inspirations to keep questioning things, to my family, who are always loving and unwavering, and to my country, which serves as a constant reminder of strength and self-reliance.

ABSTRACT

EXPERIMENTAL AND NUMERICAL STUDY OF HEAT TRANSFER IN DOUBLE-PIPE HELICAL HEAT EXCHANGER USING NANO-LIQUID

ALDAHLAH, Ali Zaeem Fezea

M.Sc., Mechanical Engineering, Altınbaş University,

Supervisor: Asst. Prof. Dr. İbrahim KOÇ

Date: 09/2021

Pages: 64

In this study, convection heat transfer coefficient and friction factor in double-pipe helical heat exchanger are investigated using nano-liquid of silicon dioxide and water as a base liquid experimentally and numerically. Parallel and counter flows inside the double-pipe helical heat exchanger with variations of Reynolds from 3400 to 11400 are studied. The experimental setup is used to complete all the studies under different conditions. Different concentrations of nanofluids of silicon dioxide with water (eg. 0.0625%, 0.125%, 0.25%, 0.5%) and pure water are investigated. The findings reveal that the heat transfer coefficient is increases with the rise of Reynolds number and nanofluids concentration where the 0.25% concentration achieved the maximum enhancement in parallel and contour flow with numbers 5.5 to 19 $kW/m^2{\cdot}K$ and 7 to 25 $kW/m^2{\cdot}K$, respectively. Nusselt number enhanced with the increase of Reynolds number for all cases since the water velocity growth more turbulence levels increase. The Nu of the parallel and contour flow is from 36 to 95 and 45 to 123, respectively. The 0.25 Vol% concentration reaches the optimal Nu enhancement of a double-pipe helical heat exchanger. Friction factor reduce with the rise of Reynolds number where the highest friction factor value is achieved in the case of 0.5% nanofluid concentration. The pressure drop increased with the rise of solid particles concentrations as the resistance of water fluid flow grows with the increase of pressure drop. The streamlines and contours of temperature, velocity, and pressure inside the inner tube and annulus tubes are investigated. It is concluded that the 0.25% concentration of nanofluids is the optimum concentration for enhancement heat transfer inside the double pipe heat exchanger.

Keywords: Heat exchanger, Silicon dioxide Nanofluids, Double-pipe helical heat exchanger

TABLE OF CONTENTS

Pages

LIST OF TABLES

Pages

LIST OF FIGURES

Pages

LIST OF ABBREVIATIONS

CFD	:	Computational Fluid Dynamics
NTU	:	Number of Transfer Units
DPIE	:	Double-Perforated Inclined Elliptic
OHTC	:	Overall Heat Transfer Coefficient

LIST OF SYMBOLS

A_s	:	Surface area, m^2
M	:	Mass flow rate, kg/s
D_h	:	Hydraulic diameter, m
T	:	Temperature, ◦C
Q	:	Heat transfer rate, W
U	:	Convective heat transfer coefficient, J/kgK
v	:	Velocity, m/s
h	:	Tape height, m
w	:	Tape width, m
d	:	Hole diameter, m
f	:	Friction factor, a dimensionless quantity
C_p	:	Specific heat, J/kgK
g	:	Gravity acceleration, m/s^2
p	:	Pressure, Pa
Nu	:	Nusselt number, a dimensionless quantity
ρ	:	Density of water, kg/m^3
k	:	Thermal conductivity, W/mK
Re	:	Reynolds number, a dimensionless quantity

SUBSCRIPTS

out : Out

in : In

ave : Average

cw : Cold water

hw : Hot water

as : Annulus side

it : Inner tube

Nu : Nusselt number

GREEK SYMBOLS

ΔP	:	Pressure drop, pa
μ	:	Viscosity, Ns/m^2
ρ	:	Density of water, kg/m^3

1. INTRODUCTION

Helically spun tubes warmth exchangers are one of the best-known hardware in several mechanical functions ranging from solar power, nuclear, Sources include chemical, food, and other substances. The helical coil is utilized for the heat transmission of nuclear power stations due to the coefficients of heat transfer in this kind are larger. This is in instance needed if chemical processes have considerable reaction thermal content, and produced heat needs to be quickly transported to maintain the reaction temperature. More than by utilizing straight tubes, the warmth switching surface may also be delivered per unit of area, since it has a compact structure. The tubes form a Secondary stream that reaches the prevailing axial flow path on a day-to-day basis. The secondary diaphragm Fluid's Pattern enhances the thermal switch load and the external fluid hits at a speed greater than that of the inside fluid because of its impact. This extra float improves the transmission of warmth between liquid and surface. And they provide a compact area with larger heat switch coefficients for a higher heat switch. Double- pipe helix coil benefits from the secondary flux of the glide in the annulus [1]. Several investigations have shown that helically coiled tubes are the most suitable tubes for temperature switching applications [2], [3],[4], and [5]. Centrifugal pressure owing to tube curvature, which helps to fuse the fluid and beautify the heat transmission by generating secondary streams (fluxes perpendicular to the axial direction). Therefore, the use of curved tubes in processes of laminar drift warmth change may be quite useful in straight tube warmth exchangers. These circumstances may emerge for highly viscous foods which including pastes or purees to be heated and cooled, in the food processing sector, or for merchandise that is susceptible to excessive tensile forces. Most of the investigations including helical curls and warmth trade have zeroed in on two significant limit conditions; consistent divider temperature and steady warmth motion [6] Notwithstanding, these limit conditions are absent in generally liquid to- liquid warmth exchangers.

1.1 DOUBLE PIPE HELICAL HEAT EXCHANGER

Undoubtedly, one notable easiest and plenty often used heat exchangers is double pipe heat exchanger as seen in Figure 1.1. It is widely utilized in chemical, food, and petroleum industries as well as in the power generation sector. Many accurate researchers believe that that this kind of heat exchanger is utilized for HP applications, given that it has a relatively small diameter. They are also important when it comes to a broad variety of temperatures. The fact that such heat exchangers contribute substantially to pasteurization, reheating, preheating, digester heating and heating operations is also well reported. Due to its cheap design and maintenance costs, many small companies also utilize DPHEs [8].

Figure 1.1 Photo of double pipe helical heat exchanger [7]

1.2 APPLICATION OF DOUBLE PIPE HELICAL HEAT EXCHANGER

Many different types of applications are available, and the simple and functional design makes it difficult to explore all of them. Some are as follows [36] :

- high temperature and pressure equipment such as boilers and compressors
- design of industrial systems that involves cooling and heating

- Oil distillation
- Conditioning systems
- water treatment systems

1.3 DIFFERENT FLOW SCHEMES

Hot and cold fluids in twin pipe heat exchangers often flow concentrically in parallel and counter flow arrangements. the liquids initially flow in the same direction Flowing liquids in the opposite direction is called counterflow [8] as illustrated in Figure 1.2.

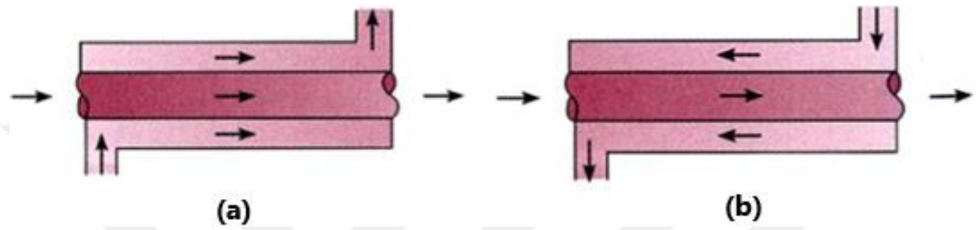

Figure 1.2 Variations in the flow (a) Parallel flow. (b) Counter flow [8]

1.4 ADVANTAGES AND DISADVANTAGES OF DOUBLE PIPE HEAT EXCHANGERS

Double pipes are one of the easiest heat exchanger designs, and because of this, it is uncomplicated to construct and maintain. Despite certain gadgets having benefits and drawbacks, almost all of them have something to offer.

1.4.1 Advantages of Double Pipe helical Heat Exchangers

While other complex types of heat exchangers may have certain distinct advantages, this kind of exchanger offers several unusual benefits. The most noteworthy advantages of twin pipe heat exchangers are the following [35] :

- Lowering capital expenses with improved performance.
- The structure is considerably smaller than the shell and tube, making it simple to maintain, yet the heat transmission is sufficient.

- Popularity is a great asset since the components are standard, and thus the repair and maintenance is quick and simple.
- The design is versatile, allowing additional components to be added and removed simply.
- compression and combustion at high pressure and temperature.
- It is designed with the flexibility to enable extension without the need of an expansion joint.

1.4.2 Disadvantages of double pipe helical heat exchangers

So that properly assess the pros and cons of this style, you need be aware of its design faults, such as [35] :

- Counter-flow designs cannot include them, although certain applications may. While the use of assets in parallel flow is allowed, it does not imply that assets cannot be used simultaneously.
- This kind of heat transfer transmission has less restrictions than other designs and should be utilized in low heat-related applications.
- This kind is more prone to leakage.

1.5 HEAT TRANSFER RAISING TECHNIQUES

Techniques for improving heat transmission may be divided into three major groups:

1.5.1 Active method

Technique provides an external heat transfer mechanism without utilizing mechanical effort. Predictable instances may include use of magnetic fields to enhance flow separation, use of surface or flow vibration to cause flow disruption, and also the implementation of electromagnetic fields. While other research on DPHEs has been conducted, it is said that certain studies have examined this technique. A greater number of transfer units (NTU) and efficiency were attained as the speed of rotation increased [8].

1.5.2 Passive method

This technique does not require outside assistance to improve heat transmission. In general, different surface and geometric changes are critical for the industry. These techniques, which have often been used in DPHEs, include twisting tapes, stretched surfaces, wire coils, and many other types of turbulators [37] .

1.5.3 Compound method

Because of this, it mixes active and passive methods in order to get an improved heat transfer efficiency. This may be considered an example of a multitude of research carried out in heat exchangers because of the usage of fluid vibration and wire coils [8] .

1.6 ENHANCEMENT OF HEAT TRANSFER BY NANOFLUIDS MATERIALS

It's the important methods to improving heat transfer value in heat exchangers is to include solid particles into the medium. The major issues are increases in Pressure decrease, abrasion, clogging, and sedimentation are all problems that may occur, yet it doesn't go unnoticed. When used in contrast to solid particles, utilizing nanofluids increases the amount of heat transmission by around 15%. Nanofluids are used to the aforementioned issues by means of particles with tiny solid sizes and low concentrations. Because of this, a good deal of research Heat exchangers using nanofluids have seen their efficacy explored. A few research have carried out in the last few years on using nanofluids in DPHEs. Some of these research have combined passive methods like nanofluids with heat augmentation techniques, which include conductive, nonconductive, and thermal approaches [8] .

2. LITERATURE REVIEW

2.1 INTRODUCTION

Haraburda [9] illustrated a mechanisms for determining the exterior warmth motion However, the estimates were based on observable connections to assist with flow across an array non-cascading circular cylinders that were not staggered. Except in single-stage applications, using warmth move coefficients does not enhance counts, and when temperature differences are small, the warmth move coefficients are vulnerable. When using "Wilson's plots" for translation, extreme caution should be exercised [7]. The outcomes got to rely upon factors other than the precision of the estimations and it is hard to evaluate the exactness of the determined outcomes. For temperature distinction estimations of around 1 K or littler, more consideration is required than found by and by; often the cases for exactness are inappropriate.

Lavric and Lavric [10] has invented a novel heat exchanger in cold and warm liquids travel helical paths that are in tandem. Due the high partial heat transfer rate achieved for low Reynolds numbers, the tests showed its ability to handle critical thermal tasks even for modest driving forces. Another nice thing is that appropriate values for the energetic coefficient were found. A mathematical model was created to simulate this heat exchanger, which provided greater knowledge of the design factors such as spiral step or wall thickness and its performance.

Hoshi and Development [11] The main aim of this experiment was to see whether wire coil and twist tape placed within a circular tube produced a better heat transfer rate and lower pressure drop than standard wire coil and twist tape. The Reynolds number that experimenters employed in their tests varied between 9648 and 18144, whereas the hot and cold fluid inlet temperatures were 750°C and 300°C correspondingly. The testing findings demonstrated that the use of a a twisted tape with a coil wire, as well as plain tube, produced much superior results as opposed to using twisted tape or a wire coil.

Durmuş et al. [12] For example, in a circle heat exchanger, the inner pipe has a snail positioned at the entrance and considered to be a generator of swirls. When doing the experiment setup, In the inner pipe, cool air was conveyed, and in the annulus, hot water was supplied, with both pipes located inside the chamber. Experimental studies were conducted to find out the impact of snails on heat transmission, pressure drop, as well as heat transfer to other objects, Nu's (a value that describes the snail's heat transmission and pressure decrease) were compared to Nusselt numbers (With smooth pipes, a typical correlation is provided for axial flows). Variables include Reynolds number, Prandtl number, and whirl angle, the findings were associated as seen in Figure 2.1. With the Nusselt number increased to up to 120 percent, the 45° swirling angle and counter flow produced swirl flow with a higher Nusselt number. The addition of the snail's swirl flow impact produced a little rise in pressure drop, but the overall effect was insignificant when compared to the heat transfer capacity boost.

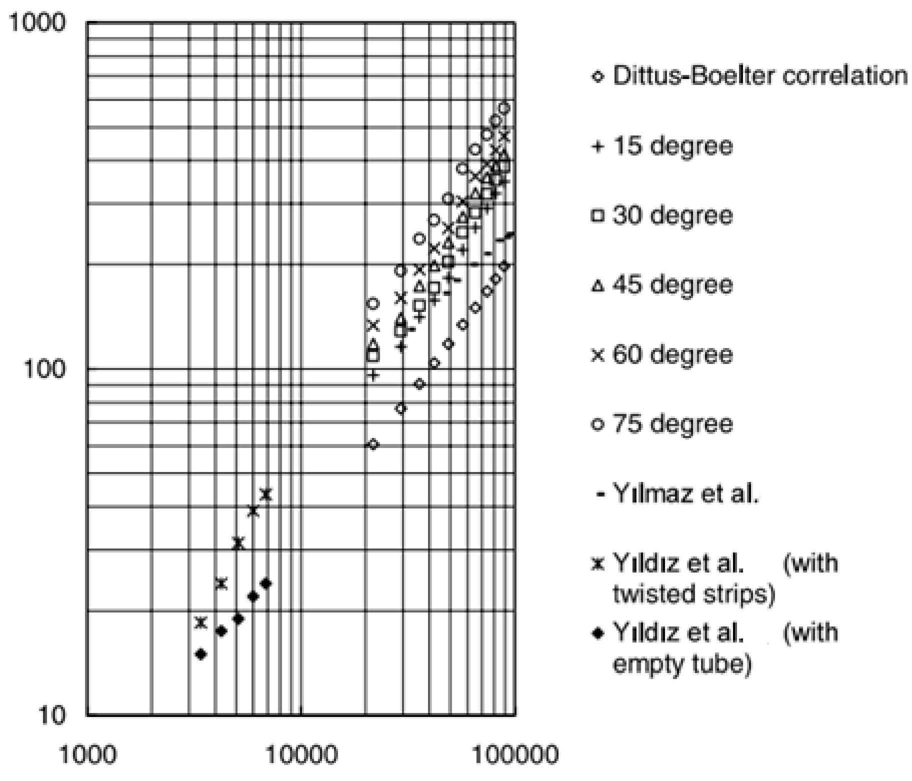

Figure 2.1 The relation between the Nusselt number in the counter-flow and Reynolds number for five different swirling angles [12]

Xuan and Li [13] Analyzed properties of heat transmission and fluid movement of a nanofluid in a tube. For tumultuous flow, the convective and frictional heat transfer coefficients of the sample nanofluids are calculated. When examining these impacts on heat rate and flow, other variables such as amount the Reynolds number and the suspension of nanoparticles are examined in depth. The discovery of a novel kind of convective heat transfer correlation is suggested, which may aid researchers studying heat transfer in nanofluids.

Zhou [14] studied experimentally The heat transfer behavior of copper nanofluids when exposed to sonic cavitation and without. On a heated horizontal copper tube, acoustic and fluid subcooling parameters; a nanofluid concentration have significant effects on improving heat rate. Heat transfer was greatly impacted by the copper nanoparticles and sonic cavitation. With the inclusion of copper nanoparticles, heat transmission still relied on cavitation and subcooling. Heat transfer mechanisms of nanofluids were studied. On the boiling heat transfer effect of nanofluid concentration exemplified by Figure 2.2.

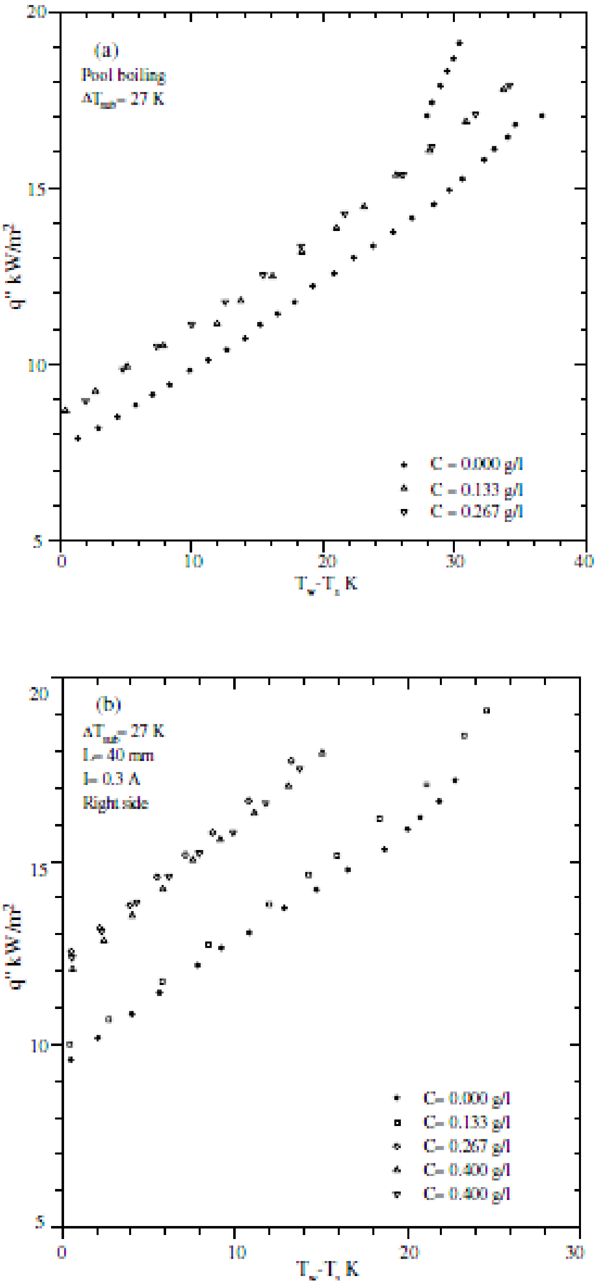

Figure 2.2 The impact of nanofluid on boiling heat transfer: (a) without acoustic waves (I=0) and (b) with acoustic waves I=0.3 [14].

Wongwises et al. [15] the was looked into efficiency of a spiral coil heat exchanger, especially in circumstances of added dehumidification and cooling. A heat exchanger is a metal shell, with a spiral-coiled tube structure. Six concentric spiral-coil tubes make up the spiral-coil unit. A spiral coil with five turns is formed by wrapping a straight tube made from copper and measuring 9.27 millimeters around itself. A working fluid, like air or water, is often utilized in some process. Chilled water travels down the spirally coiled tube, where it enters the outermost turn, and then exits at the innermost turn. The heated air travels via a spiral set of tubes to the shell's perimeter, and then flows radially into the hot air exchanger in the center as seen in Figure 2.3. To estimate the heat transfer characteristics, the Newton-Raphson method is used to solve a theoretical framework that is taking into account conservation of mass and energy technique. The model's findings are in good accord with the current data obtained through an experiment. Spiral coil heat exchanger impacts of different intake circumstances are explored.

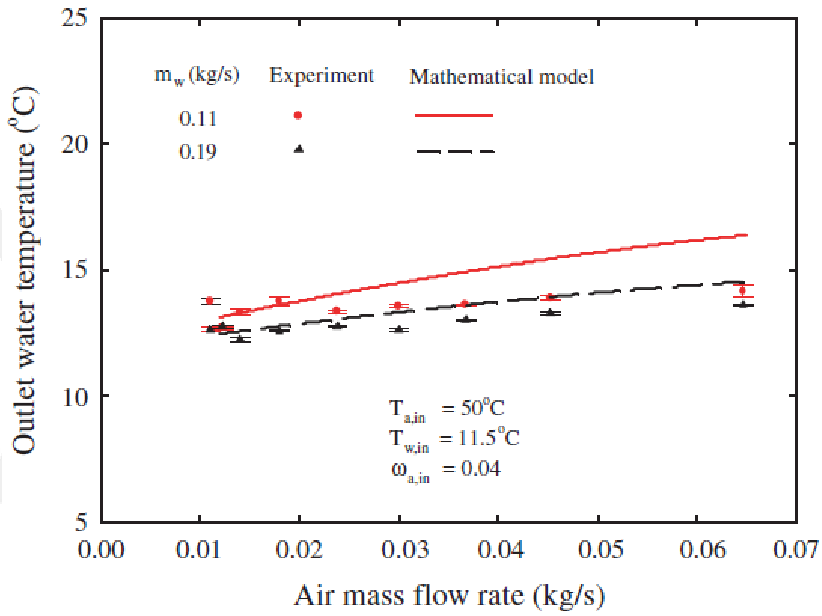

Figure 2.3 Variation of outlet-water temperatures with air mass flow rate for different air temperatures.

Saini et al. [16] Worked with hydrodynamics and heat transfer aspects at the pilot plant size on A study on helical tubes in tubes. For these experiments, the liquid flows counter-clockwise, while the hot and cold fluids are contained in separate areas. In order to encourage the inner tube, semicircular plates were also attached to the external tube to enhance the movement of fluid in the outer area. Heat transmit rates for the inner and outer pipe were computed using Wilson plots. Using the experimental data, plus previously published experimental data, Inner and outer tubes were inspected to determine their Nusselt number and friction factor. The CFD simulations corroborated the experimental results. Even though the boundary circumstances were varied in the current study, a fair comparison was established. The outer Nusselt number and outer Dean number are inversely proportional is illustrated in Figure 2.4.

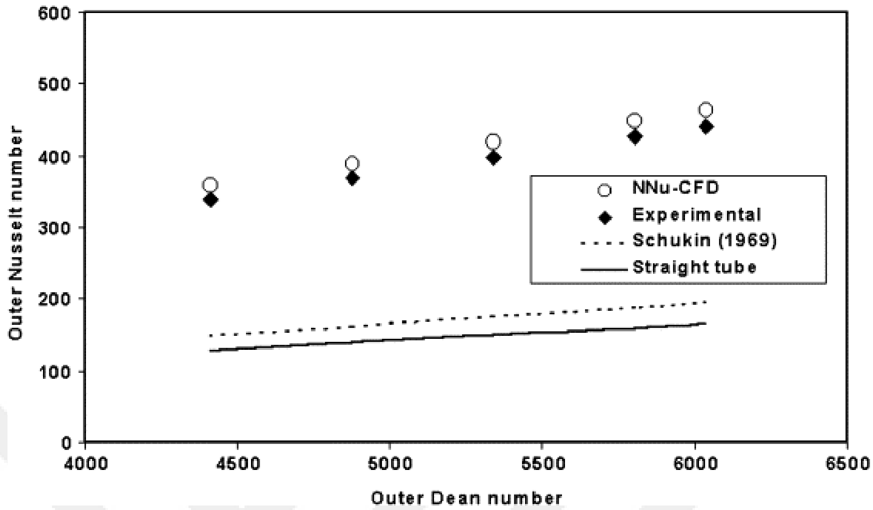

Figure 2.4 Nusselt number versus outer Dean number

Naphon [17] studied The helical-spun heat exchanger's thermal achievement and loss of pressure, including and in the absence of spiral fins. There's a heat exchanger is made out of a cylinder with helical coils on each ends, having diameters that are different. For every coil, the tube is bent to form a helical coil with thirteen turns. Shell side uses cold water while tube side uses hot water. These tests use 0.10 to 0.22 kg/s cold and hot liquid flow rates, as well as 0.02 to 0.12 kg/s flow rates. Both hot and cold water inlets run at a temperature of between 15 and 25 degrees Celsius, whereas inlet temperatures of cold and hot water run from 35 to 45 degrees Celsius. cool water travels through the helical pipes, passes through the heat exchanger, and exits the inner channel. The heated liquid flows from the inner helical-coil tube into the heat exchanger, and it then travels along the helical tube. The working fluid flow and test section input conditions are addressed in relation to the heat transfer characteristics.

Buongiorno et al.[18] investigated a huge information base identified with nanofluids streaming inside straight cylinders and introduced that the fierce warmth move rates of nanofluids can be anticipated precisely with standard single-stage conditions, Helically wound cylinders can be in numerous applications including food preparing, atomic reactors, reduced warmth exchangers, heat recuperation frameworks, substance handling, low worth warmth trade, and clinical gear.

Bhardwaj et al. [19] Heat transfer rates for flow between concentric helix coils, according to a correlation. In order to accommodate the many functional dependent factors, such distance between the concentric and eccentric coils, tube diameter, and coil diameter, CFD data and experimental findings are used to create a mathematical model. "A new correlation for heat transfer coefficient has been created using Numerical Technique, and this new correlation has shown to give an accurate match to the experimental data with an error range of 3–4 %".

T. J. Rennie and V. G. S. Raghavan [20] examined a double-pipe helical heat exchanger to learn how long food must be cooked, and at what temperature and consistency. The flow rates of parallel and counter-flow configurations were explored, in which both low and high flow rates were utilized. Heat and coldness were measured in the inner tube's tubing. First-order kinetics was used to predict homogeneity in the heating and cooling systems. There is an inherent benefit to consistent processing in the effort to provide high-quality products. This paper is the first in a series of studies intended to improve homogeneity in helical heat exchangers with two pipes. Flow rate uniformity in the inner pipes and the outer caused residence time distributions to become more even. Flow rate increased, and thus temperature homogeneity in the inner tube improved. However, altering the annular flow rate for constant inner pipe flow resulted in uniformity problems. Additional examination of the annulus revealed the same findings. Increasing flow rates may cause greater homogeneity in inner pipe heating. The uniformity of the cooling process was shown. helix heat exchangers designed for the preparation of fluid meals should use these results.

Sergis and Hardalupas [21] expressed factually that the greater part of the past investigations demonstrated low warmth move improvement; 11% of the example demonstrated disintegration of the warmth move coefficient and 3% showed no upgrade by any means. Yu et al.[22] additionally expressed that the multifaceted nature and the debate of nanofluid frameworks are identified with the strong/fluid limit layer among As the base fluid is affected by nanoparticles, their large area of contact alters the liquid characteristics, bringing about three-stage frameworks (rather than conventional thought of nanofluids as two-stage frameworks of strong and fluid).

Huminic and Huminic [23] investigated To examine an evaluation of three-dimensional nanofluids in laminar flow and helical heat exchangers with pipes' heat transfer characteristics. This mix is used as the working fluid in which the CuO and TiO2 nanoparticles have a diameter of 24 nanometers and are distributed with a concentration of 0.5 to 3 percent. To ensure equal mass flow rate through the inner pipe and across the annulus, the nanofluid mass flow rate during which the water mass flow rate was adjusted to one-half, full, or twice value. For findings in the study, you can see the extensive range of nanofluids, water temperatures, reported by the statistics given in the article, heat transfer speeds and coefficients are important factors to consider. On display are results on heat transfer coefficients and rates of heat transfer for nanoparticle concentration level and Dean number, respectively. Nanofluids with Water with 2 percent CuO nanoparticles in it, as well as having the same flow rate in the inner tube and annulus, exhibited a 14 percent greater heat transfer rate than pure water. When using nanofluids, the heat transfer efficiency was 19 percent better than when using pure water For nanofluids as well as water, convective heat transfer rate also rose as mass flow rate increased or Dean number. Simulations have been compared to data generated using empirical equations in order to verify the findings.

Hasan et al. [24] Exhibiting the impact of employing louvre strip inserts inserted numerically using different kinds of nanofluids in the helix double-pipe heat exchanger in the heat and flow fields. In this research, the Reynolds numbers range 10.000 to 50.000 is utilized in two distinct configurations for the louvered band inserts (forward and backward). Also examined are the impacts of different angles and slopes of the louvered strip. There are four distinct kinds of nanoparticles, Al2O3, CuOs, SiO2s, ZnOs with varying volume fractions between 1% and 4% and various sizes of 20 nm to 50 nm nanoparticles, distributed into basic fluid (water). By using a forward louvered stripe arrangement with a -level angle of 30° and a lowest pitch of 30 mm, the heat transfer may be increased by 367 to 411 percent. There is a 10x increase in skin friction factor in the enlarged tube compared to the smooth tube, with a value in the 1.28–1.56 range (PEC). Researchers have found the largest quantity of SiO2 nanofluids in the world, followed by Al2O3, ZnO, and CuO, whereas the pure water is Nusselt. The following figures may be obtained. The findings indicate that the number of Nusselt rises when the nanoparticle diameter decreases, while the volume of nanoparticles increases somewhat. The findings show a little variation in the coefficient of skin friction as SiO2 nanofluid nanoparticle sizes vary.

Reddy and Rao [25] experimented with the Heat transfer and friction coefficient of TiO2 nanofluids running through whether or not helical coil inserts in twin pipe heat exchanger. The trials are performed between 4000 and 15000 Reynolds and between 0.0004% and 0.02% within a ranges of volumes. The basic fluid is produced using 40% ethylene glycol and 60% distilled water. A coefficient of heat exchange and friction are increased by 10.73% and 8.73%, especially in comparison to the basis fluid fluids that flow in a tube, in 0.02% of nanofluid volume. In comparison to the fluid base in a pipe with a P/s helical coil insert 2,5 temperature and friction coefficients in comparison to base fluid are increased correspondingly by 13.85% and 10.69% for 0.02 percent nanofluid. There are a comparison between the measured the coefficient of heat transmission and friction factor and the available literature. Researchers have found significant relationships in their experiments between the The friction factor and the Nusselt number. Graphics and tabulations are used to present the results. Any study of uncertainty is also performed and the error of the experiment is ±10%.

Habib et al. [26] Study the increase of the coefficient of heat rates by placing coiled wire around an internal dual-pipe tube surface. As turbulators, insulated cables of 2 mm circular diameter were utilized for creating a coil of various pitches (p = 6, 12, 20 mm). The research for turbulent water flow to each other as well as in the annulus flusses is carried out the heat exchanger tube-to-tube. The cold liquid. Tests were conducted for 4,000 to 14,000 numbers of Reynolds. The experimental findings indicate that significantly increased thermal conductivity coefficients is the consequence of the usage of curved circular wires comparison a Pipes for seamless surfaces directions and counter wasser flows. With number of Reynolds and pitch the mean Nusselt number rises. The heat transfer coefficient of turbulent liquid flow rises with a maximum increase of 400 percent for parallel flow and 450 percent for counter flow throughout all spindle cord pitch ranges. New correlations are given for relative mean nusselt values at various coiled wire pitches.

Solaimany Nazar et al. [27] The performance thermodynamics of a 3D fined pipe spirally baffled heat exchanger working with nanofluids was quantitatively studied Water-based nanofluids at different volume concentrations are used to study copper (Cu), copper oxide (CuO), and carbon nanotubes nanoparticules Temperature distribution and pressure drop are investigated the Reynolds number as a function (Re) and concentration of volume. Heating and pressure reduction were enhanced with a rise in Reynolds number and volume concentration. This results from fact that the volume concentration of CuO/water and the nanofluid's Nu Number rose, while the volume concentration of CNT/Nu water's Number dropped. To simulate Heat exchanger Nusselt number and gradient of pressure, a neural network is used. Probability distributions are well predicted by the neural network.

Bhramara et al. [28] nanofluid Fe3O4 flow in a twin-pipe heat exchanger with a return tube bend was tested for efficient heat transfer convectional heat transfer friction factor. These tubes have a 0.01-millimeter inner tube diameter and 0.04-millimeter annulus tube diameter in this study. There's a return curve at 2.2 meters from the tube's entrance. An inner tube transports the hot iron oxide (Fe_3O_4) nanofluid, while an annular tube transports the cool water. The nanoparticles used in this study had volumes with 0.005% concentrations, 0.015%, 0.035%, and 0.065%, and Reynolds numbers ranging from 15,000 to 30,000. When compared to base fluid data, the a nanofluid flow with a volume concentration of 0.06 percent in an inner heat exchanger tube has a Nusselt number increase of 14.7% at 30,000 Reynolds numbers; the nanofluid pumping penalty is 10%. To quantify the twin pipe heat exchanger's overall performance, the Water and nanofluid heat exchanger efficiency is measured in NTUs.

Alighardashi et al. [29] A double-pipe helical heat exchanger was used to evaluate the heat transfer coefficient of air. There is a copper-wire fin soldered to the outside of the internal tube to enhance the rate of heat transmission. The results of the literature correlations are compared to experimental by varying Reynolds number is determined by mass flow rate and temperature. Also proposed is an approach for obtaining the The internal tube and annulus section heat transfer coefficients of helical heat exchangers with two pipes. that combines two already presented ideas and future fixes, use of comparable diameter instead of hydraulic diameter, as well as other changes. In the annulus portion, heat transmission rates are affected by installed fins, as well as the effects of OHTC mass flow rates for both hot and cold temperatures, are also explored. Finally, the acquired data demonstrate the validity of the proposed connection as well as an increase in OHTC having do with a fin inside the annulus.

Zhang et al. [30] numerically study a heat exchanger with two pipes an outward helically curved tube. It is sought to get the dimension of the shell side by using the specified geometrical characteristics of the corrugated tube as a starting point. Compared to the tube side, the shell side explores and compares the mechanisms of better heat transfer and complex flow characteristics. Heat transmission, pressure drop, as well as energy savings are all taken into consideration while optimizing the flow rates of the tubes and shells. Thermal and pressure fluctuations are found to be the same for shells as for tubes, with heat transmission increasing with decreasing shell diameter. In a thorough study, a shell diameter of 38 mm is the optimum value for achieving low pressure drop and a high heat transfer coefficient. When it comes to finding the optimal flow rate match between the tube and shell, as well because it has two equilibrium solutions: one for the tube and one for the shell, evolutionary algorithms are employed to discover the optimum answer.

Raja et al. [31] experimented with the influence of helical fins on the effectiveness of a heat exchanger with two tubes. In order to analyze and evaluate the operation of plain inner pipe heat exchangers with helical fins, each heat exchanger was investigated and the results were contrasted. The hot fluid flow rate was changed in this experiment from 0.01 kg/s to 0.05 kg/s, while the hot fluid temperature at the input was held constant at 80 °C. The inclusion of fins increases the heat transfer coefficient, as seen in the results. Also, average heat rate transmission and the effectiveness of heat exchanger increase at higher flow rates to 38.46% and 35% apiece.

Sharma et al. [32] Double-distilled water and a mixed surfactant were used to study CNT nanofluid, with the Surfactant/CNT ratio maintained at 1. As part of an investigation of the The characteristics of water in both the hydrodynamics and heat transfer aspects, as well as the solution's heat transfer properties and surfactant's influence on water, are all dependent on the water molecules and their various phases. is used. Additionally, and nanofluid of CNT surfactant and water thermo-physical properties were studied. Surfactant-water solution and water had the same viscosity, while the surfactant-water solution had a little increase in density. Reynolds number raises friction factor in water, and nanofluid of CNT surfactant and water. Heat transfer coefficient of CNT nanofluid is 62.62% higher than that of water when Reynolds number is multiplied by 5. The heat transfer coefficient of a and nanofluid of CNT surfactant and water. CNT nanoparticles have a major impact in enhancing nanofluidic heat transfer rate in comparison to water.

Hatami et al. [33] investigated heat rate and thermal efficiency of the new Double-Perforated Inclined Elliptic (DPIE) turbulators in dual-pipe heat exchangers. The range of Reynolds under a turbulent flow system was between 5,000 and 18,000. The angle of inclination for the elliptical inserts, and the diameter of perforation (d) vary from 15° to 25°, respectively 0,5 mm < d< 1,5 mm. Swirl generators with perforations may raise flow disturbances substantially and break the thermal limit layer to accelerate the transmission of heat without considerable effect on friction loss. Experiments have shown that the average number of Nusselt turbulators has been enhanced by 217.4 percent compared to the pipe without swirl generators. The re-circulation via the elliptical turbulator's hole increases the fluid mix between the walls and the central region. For DPIE swirl generators with d/b = 0.25 and α= 25o, a maximum heat efficiency value of 1.849 was achieved. For dual-perforated elliptic turbulators when the friction factor is d/b = 0.25, increased by 14.0% compared with conventional elliptical inserts without holes. The heat transmission was found to be enhanced by approximately 39.4% utilizing With d/b = 0.25, DPIE inserts are used unlike the usual strips that are devoid of louvres In contrast to current turbulators of Reynolds numbers, the suggested new turbulators have a considerably higher thermal efficiency, as well as ease of installation and low manufacturing costs.

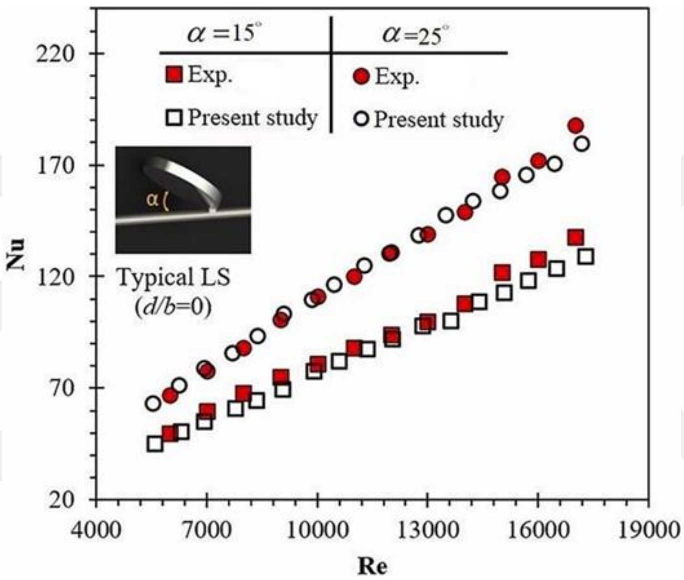

Figure 2.5 The relationship between the Reynolds number and the Nusselt number [33].

2.2 SCOPE OF THIS STUDY

It is found through previous various investigations that a double-pipe helical heat exchanger is used in many applications because of simple construction and maintenance. More studies carried out an investigation on geometrical modifications on the heat exchangers such as baffle configurations and fins shapes. Very few studies have looked at the impact of Nano-liquids on enhancing thermal exchange with twin pipe heat exchangers These results are based on experimental and numerical simulation of the heat transfer and pressure decrease in a helical heat exchanger with a nano-liquid (silicon dioxide and water). Parallel and counter flow inside the heat exchanger with variations of Reynolds are investigated. The experimental setup is used to complete all the studies under different conditions.

3. EXPERIMENTAL STUDY

3.1 EXPERIMENTAL SETUP

The system consists of a cold fluid circuit and a hot fluid circuit. Water is used as a cooling liquid, tap water is used and placed in a reservoir and flow control valves are used to regulate flow rate, when the water is supplied by the pump and then to the flow meter to find out the amount of flow and passes a flexible tube to the heat exchanger. The water temperature degree is calculated at entry and exit from the heat exchanger utilizing K-type thermocouples as illustrate in Figure 3.1.

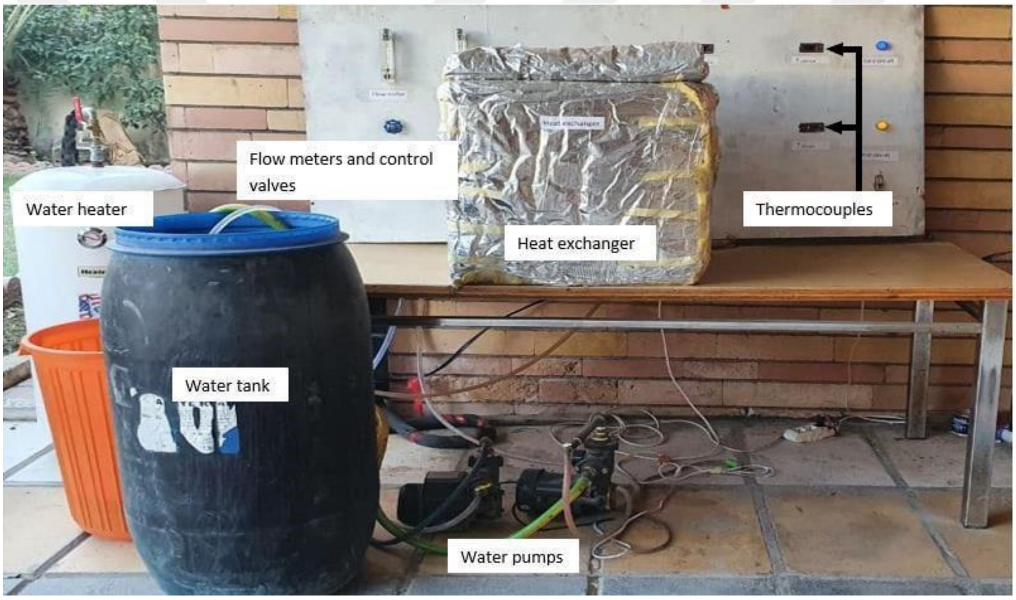

Figure 3.1 Photo of the experimental setup

The hot water circuit consists of a tank containing water that is pumped to a heater to be heated to a certain temperature and then to a valve to control the flow and to the flow meter and it enters the heat exchanger and the entry and exit temperatures are calculated employing thermocouples of type K placed at the entrance and exit of the exchanger thermocouple as seen in Figure 3.2. The inner tube will be used for hot water and nano-fluid, and the outer tube is used for water. The heat exchanger is installed on a wooden table, as well as the digital thermometer, flow meter, control valve, and PowerPoint on a white wooden board.

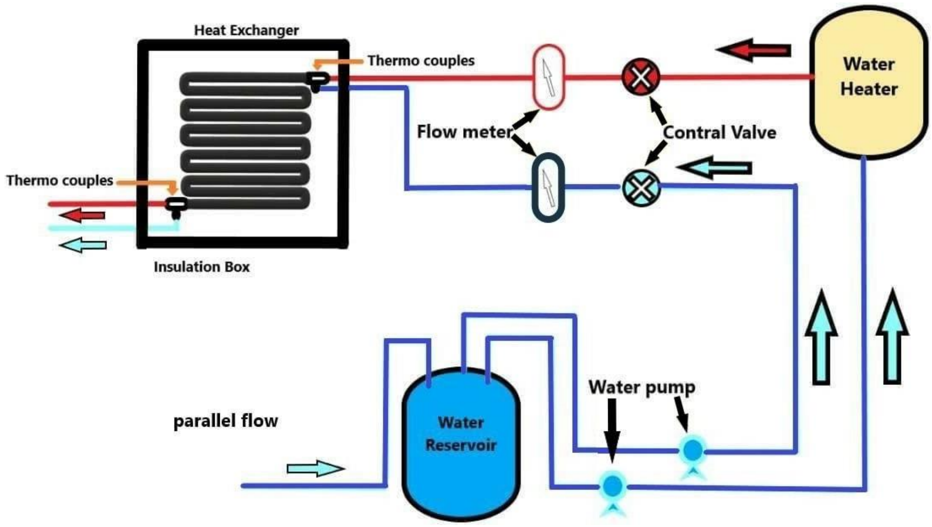

Figure 3.2 A schematic view of experimental study

Figure 3.3 shows a photo of a double spiral tube heat exchanger made of copper where the dimensions of inner and annulus radius are illustrated in Figure 3.4 and Table 1. Cold water thread through the outer pipe, while hot water or nano-fluid passes through the inner pipe. Thermocouples are installed at the inlet of the inner tube and the annular tube, as well as at the outlets of the two tubes. The heat exchanger is isolated by placing it in a wooden box with dimensions (54 x 54 x 54)cm, and the box is insulated from inside and outside with glass wool. Glass wools have thermal conductivity values ranging from between 0.023 and 0.040 W/m·K. The stainless steel T-tubes fitting are attached to each tube, where they are installed at the entrance to each tube of the heat exchanger, nevertheless, the thermocouples on one side and the other hand the flexible tubes are connected.

Figure 3.3 Photo of double-pipe helical heat exchanger

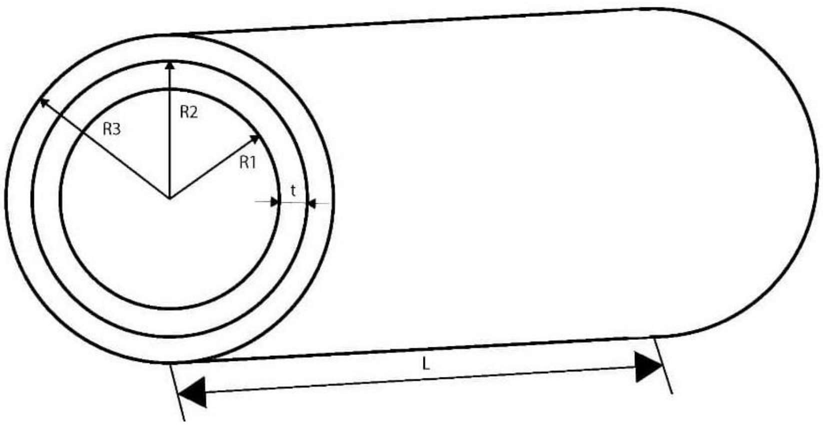

Figure 3.4 Tube dimensions

Table 1 Dimensions of inner and outer tubes of heat exchanger

Dimensions	Inner tube (mm)	Outer tube (mm)
R1	8	15.5
R2	9	17.0
R3	11	19.0
t	1	1.5
L	8300	8300.0

3.2 BASIC EQUATION OF DOUBLE PIPE HELICAL HEAT EXCHANGER

On order to determine how much heat is exchanged between cold water in annulus side and hot water in the inner tube, we use the following formulas:

$$Q = \dot{M}_{cw}\, Cp_{,cw}\, \left(T_{cw,out} - T_{cw,in}\right) \quad (1)$$

$$Q = \dot{M}_{hw}\, Cp_{,hw}\, (T_{hw,in} - T_{hw,out}) \quad (2)$$

where the $M_{(cw,ho)}$ is mass flow rate of cold and hot water respectively, the $Cp_{(cw,ho)}$ is the specific heat of cold and hot water respectively. The average heat can be calculated by [30]:

$$Q_{ave} = \frac{Q_{as}+Q_{it}}{2} \quad (3)$$

The heat balance deviation $\frac{Q_{as}+Q_{it}}{2}$ must be less than 5% and that achieved in all experimental tests. The convective heat coefficient (*U*) can be determined from [34]:

$$U = \frac{Q_{ave}}{A_s F \Delta T_m} \quad (4)$$

Where *F* is the correlation factor, ΔT_{Lm} is the logarithmic-mean temperature difference

The inner tube outer surface area can be indicated by:

$$A_s = n\pi DL \quad (5)$$

Where *n* is the number of tubes, and it equals one and logarithmic mean temperature difference equals

$$\Delta T_{Lm} = \frac{\left(T_{hw,out}-T_{cw,out}\right)-\left(T_{hw,in}-T_{cw,in}\right)}{ln\frac{(T_{hw,out}-T_{cw,out})}{(T_{hw,in}-T_{cw,in})}} \quad (6)$$

The Reynolds number (Re) can be calculated by the following equation [35] :

$$Re = \frac{\rho VD}{\mu} \quad (7)$$

Where *v* is the velocity and *ρ* is the density and μ is the viscosity and the Nusselt number can be calculated by:

$$Nu = \frac{h\, D_h}{k} \quad (8)$$

D_h is the hydraulic diameter and k is the thermal conductivity and h is the heat transfer coefficient. The friction factor *(f)* depends on the pressure drop and geometry of the tube and can be calculated by [35]:

$$f = \frac{\Delta p}{\rho \frac{1}{D_h}\frac{v^2}{2}} \quad (9)$$

3.3 EXPERIMENTAL RESULTS

3.3.1 Parallel flow performance

For the parallel flow scheme, It's easy to see that, the coefficient of heat transfer grows with the rise of Reynolds number and nanofluids concentration as seen in Figure 3.5 It is indicated that the effects of adding solid nanoparticles for water are obvious as the enhancement of heat transfer coefficient in case of 0.0625 Vol.% and 0.125 Vol.% concentrations. The 0.25 Vol.% achieves the maximum enhancement of heat transfer coefficient of double-pipe helical heat exchanger following the numbers from 5.5 to 19 $\mathrm{kW/m^2{\cdot}K}$. The 0.5 Vol.% concentration has less heat transfer coefficient values but near to the 0.25 Vol.%. That can be explained as adding more nanoparticles to the water inside the hot side after 0.25 Vol.% has very small effects on heat transfer comparing to the effects of 0.25 Vol.%.

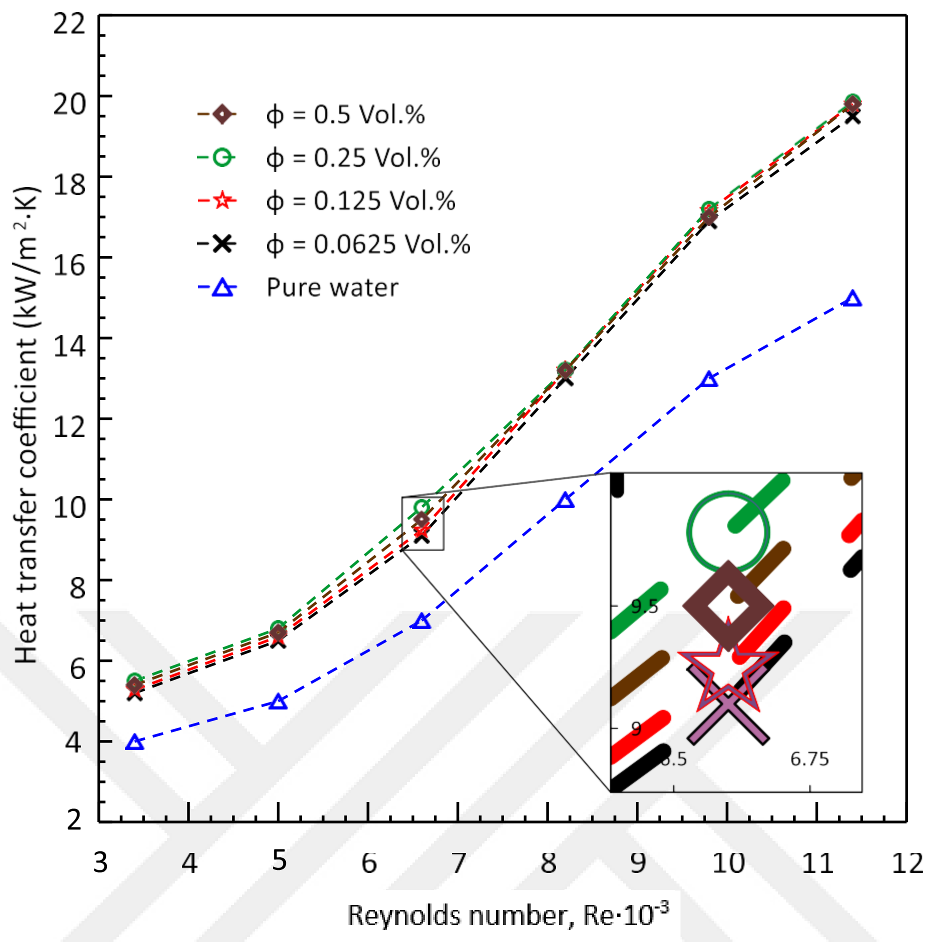

Figure 3.5 Heat transfer coefficient versus Reynolds number for different concentration and pure water

Nusselt numbers in cases of pure water as well as 0.0625 Vol.%, 0.125 Vol.%, 0.25 Vol.% and 0.5 Vol.%. Concentrations are investigated in Figure 3.6 for Reynolds number range from 3400 to 11400. It can be detected that the Nu enhanced with the rise of Reynolds number in every instance since the water velocity growth more turbulence levels increase. Following the numbers 36 to 95, a 0.25 Vol.% concentration reaches the optimal Nu enhancement of a double-pipe helical heat exchanger. The Nu values are lower in the 0.5 Vol.% concentration, but they are close to the 0.25 Vol.% concentration. This can be demonstrated by the fact that applying additional nanoparticles to the water within the hot side after 0.25 Vol.% had very little impact on heat transfer compared to the results of 0.25 Vol.%.

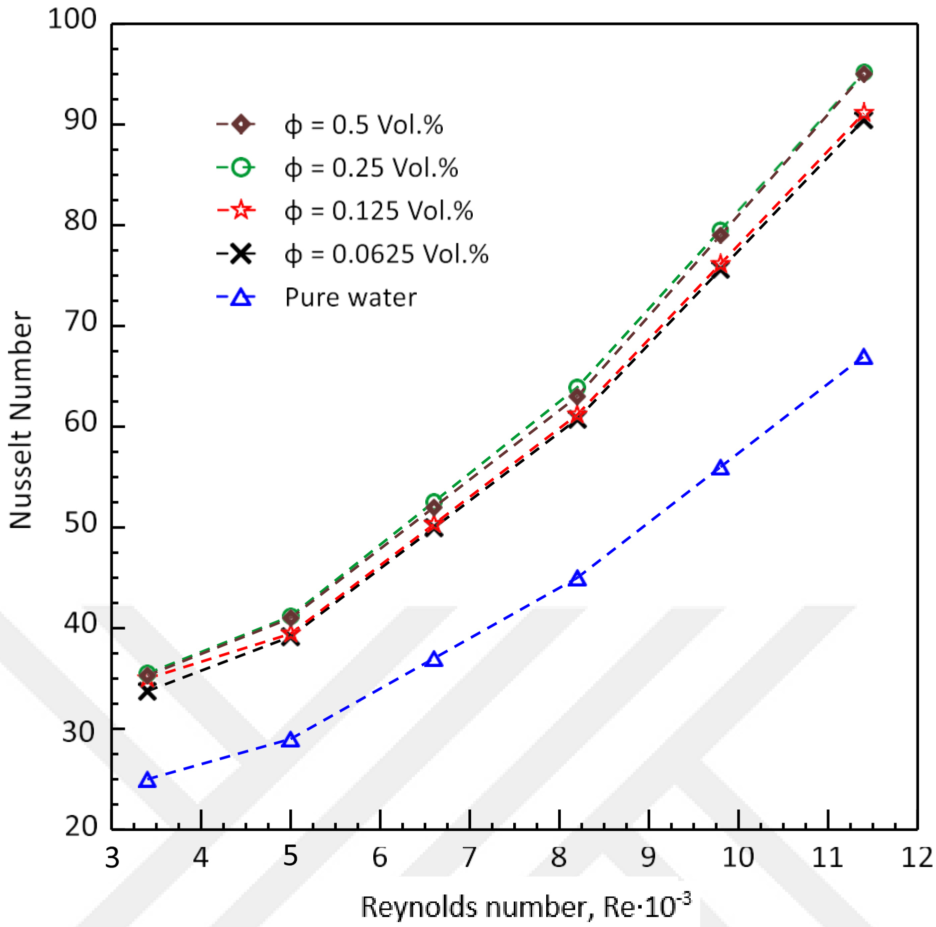

Figure 3.6 Nusselt number versus Reynolds number for different concentration and pure water

The relation between friction factor and Reynolds number for the pure water and various nanoparticle concentrations is seen in Figure 3.7 It can be detected that the friction factor reduces with the rise of Reynolds number. The maximum value of friction factor is achieved in the case of 0.5 Vol.% nanofluid concentration where the pressure drop rise with the increase of solid particles concentrations. The resistance of water fluid flow grows with the increase of pressure drop.

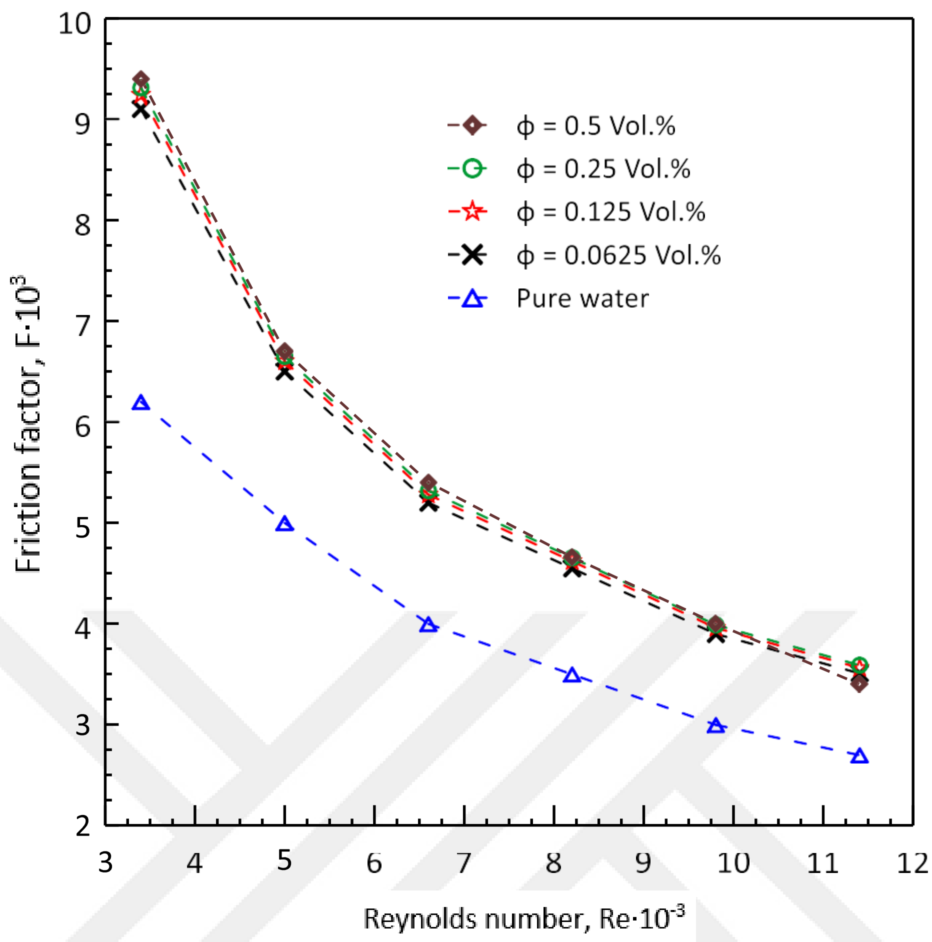

Figure 3.7 Friction factor versus Reynolds number for different concentration and pure water

3.3.2 Counter flow performance

The relation between the overall heat transfer coefficient and Reynolds number is investigated in Figure 3.8 for pure water and different nanoparticles concentration where the heat transfer is enhanced with the rise of the Reynolds number. It is indicated that values of heat transfer coefficient in case of counter flow scheme are higher than those in case of parallel flow scheme. The 0.25 Vol.% solid particles concentration has the maximum percentage of heat transfer enhancement comparing to other concentrations and pure water.

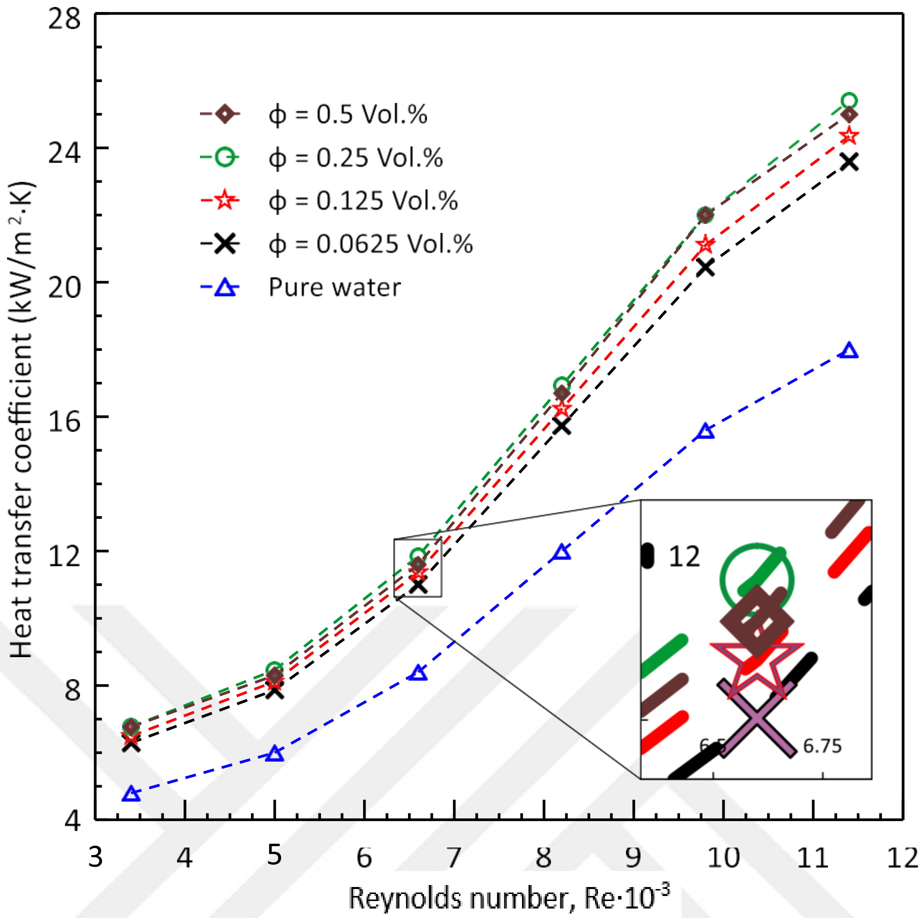

Figure 3.8 Heat transfer coefficient versus Reynolds number for different concentration and pure water

The relation between the Nusselt number and Reynolds number is investigated in Figure 3.9 for pure water and various nanoparticle concentrations where the Nusselt number improved with the growth of the Reynolds number. The Nusselt numbers of counterflow patterns are better than those in the case of parallel flow patterns. The 0.25 Vol.% concentration achieves the highest rate enhancement of Nusselt number from 45 to 125 comparing to other concentrations and pure water.

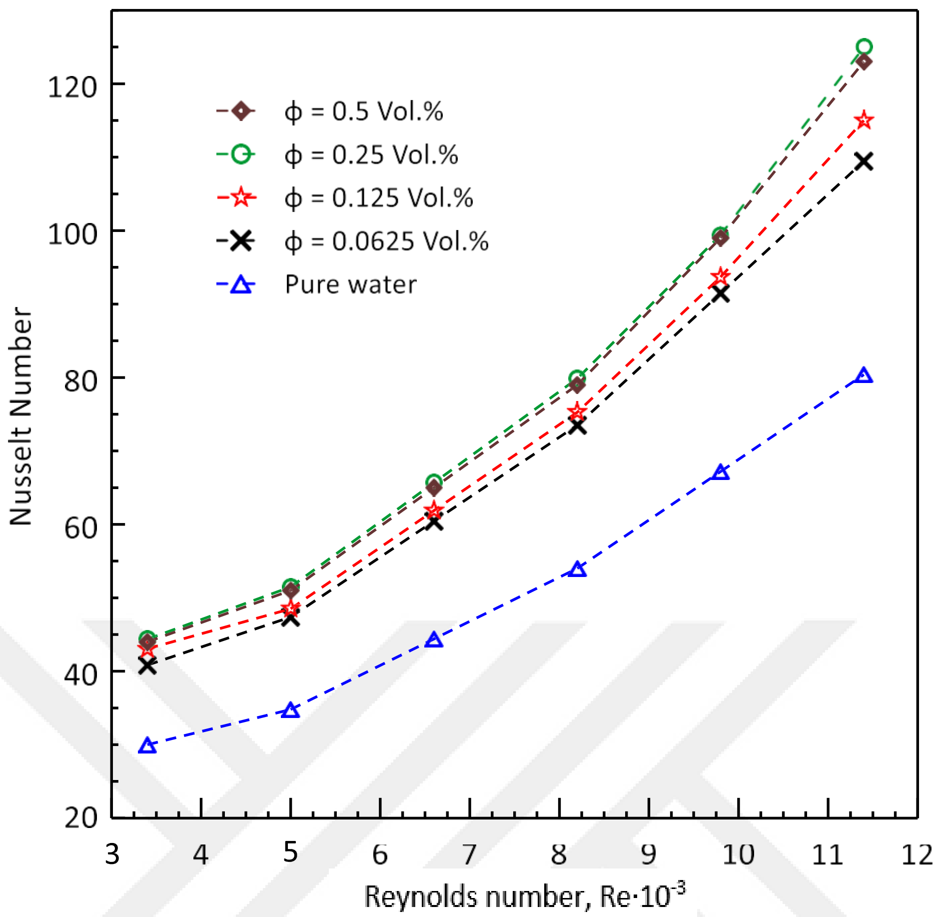

Figure 3.9 Nusselt number versus Reynolds number for different concentration and pure water

The relation between friction factor and Reynolds number for the pure water and various nanoparticles concentrations (0.0625 Vol.%, 0.125 Vol.%, 0.25 Vol.%, 0.5 Vol.%) is explained in Figure 3.10 It can be noticed that friction factor reduce with the increase of Reynolds number where the maximum values of friction factor are achieved in the case of 0.5 Vol.% nanofluid concentration where the pressure drop increased with the rise of solid particles concentrations.

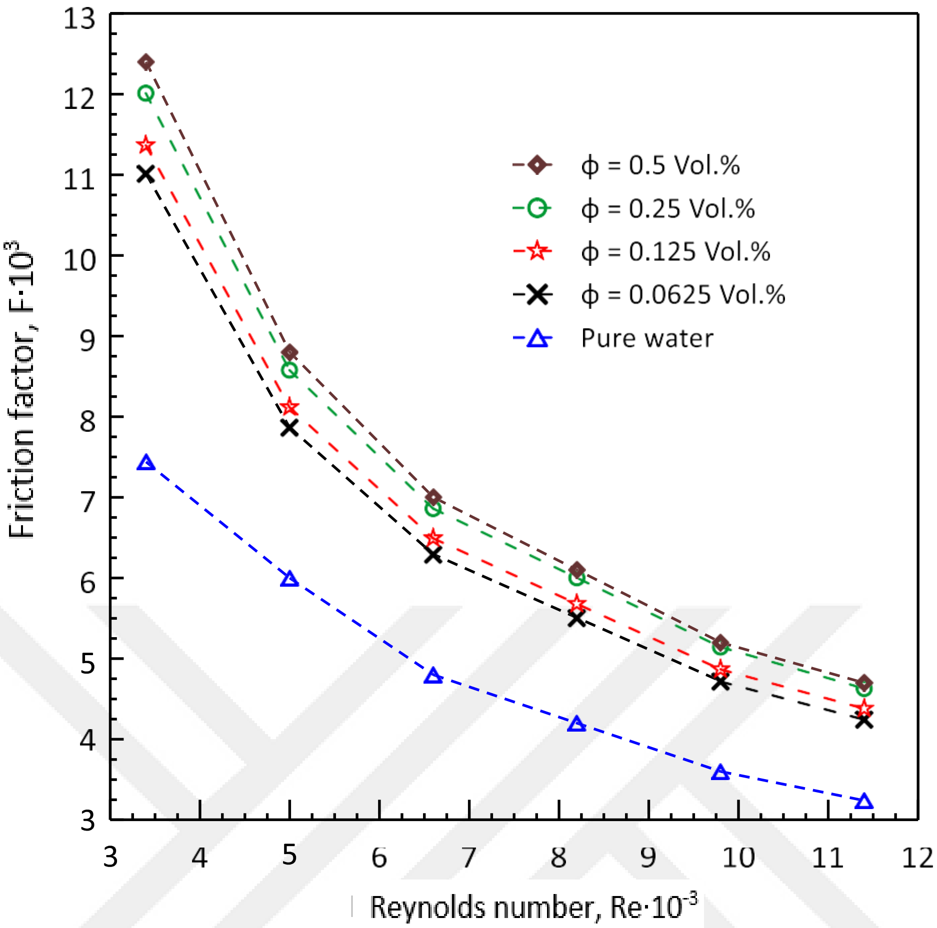

Figure 3.10 Friction factor versus Reynolds number for different concentration and pure water

4. NUMERICAL STUDY

4.1 NUMERICAL MODEL

The domains of cold water, hot water, and tube domains performed in cad software are investigated in Figure 4.1 for the parallel flow. In the inlets and outlets of hot and cold water for the double-pipe helical heat exchanger.

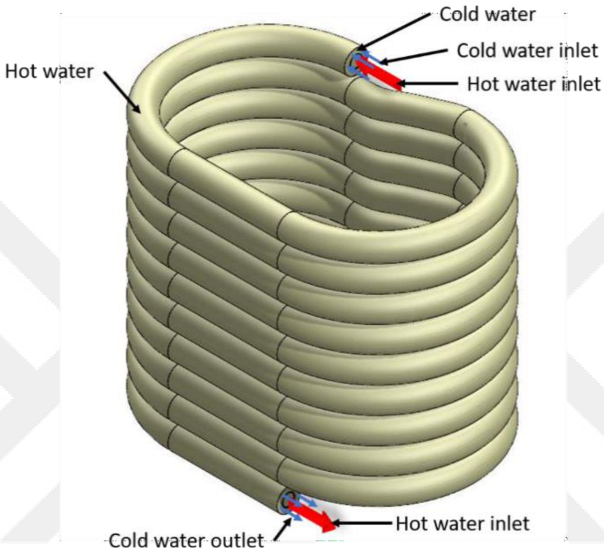

Figure 4.1 Numerical model with cold and hot water domains

4.2 MESH GENERATION

Finite element method is utilized for mesh generation in the heat exchanger Figure 4.2 shows the grid distribution in the three domains of the mesh utilized in the current numerical investigation. Hexahedron grid is chosen for grid generation.

Figure 4.2 3D model for mesh generation

Three mesh conditions are used to check the mesh independence with 1212521, 1575214, and 2058244 numerical elements till the result differences are less than 1%. The error percentage of convective heat transfer coefficient and friction factor are illustrated in Table 2.

Table 2 The error percentage of heat transfer coefficient and friction factor

Meshing elements number	**h error %**	**F error %**
1212521	1.415%	1.534%
1575214	1.026%	1.112%
2058244	0.085 %	0.095 %

4.3 MODEL VALIDATION

Comparing the numerical results and experimental results is attained as seen in Figure 4.3 and Figure 4.4. The Nusselt number and friction factor were chosen to show the performance of the twin-pipe heat exchanger, and the numerical findings confirmed that the experimental and numerical findings were identical. For Nusselt number and friction factor, the average discrepancies between simulation and experiment findings are roughly 3.01% and 4.21%, respectively. Nusselt number and friction factor have maximum differences of 5.21% and 7.32 %, respectively. Apart from the inherent experimental and simulation mistakes, the discrepancies seem tolerable in general. The numerical simulation model under consideration is shown to be effective and accurate in this study.

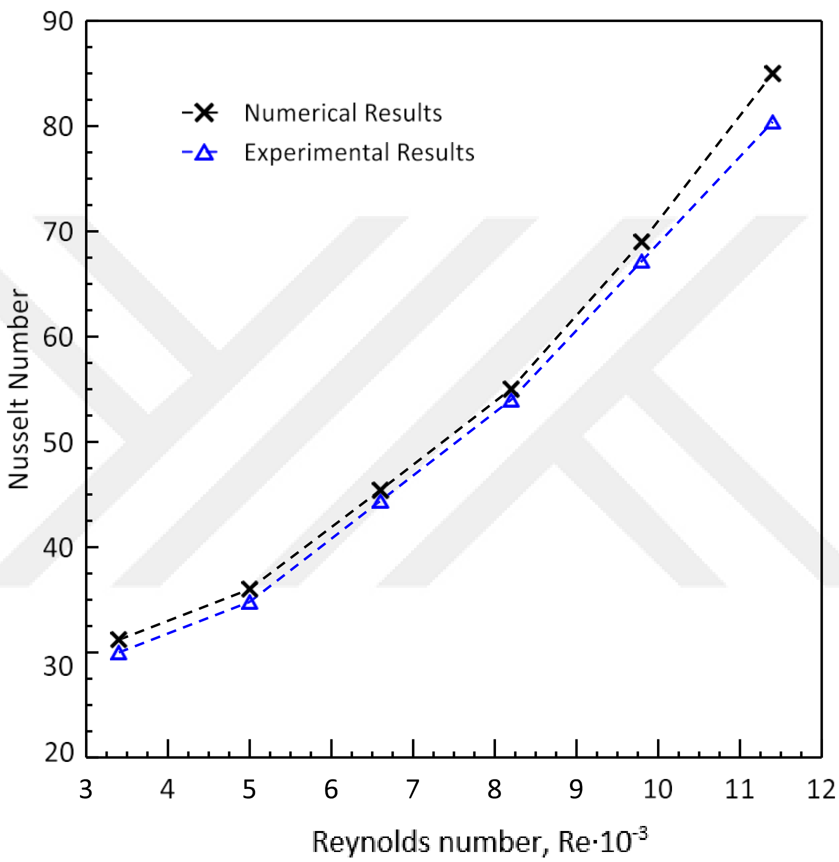

Figure 4.3 Comparing between experimental and numerical results of Nusselt number

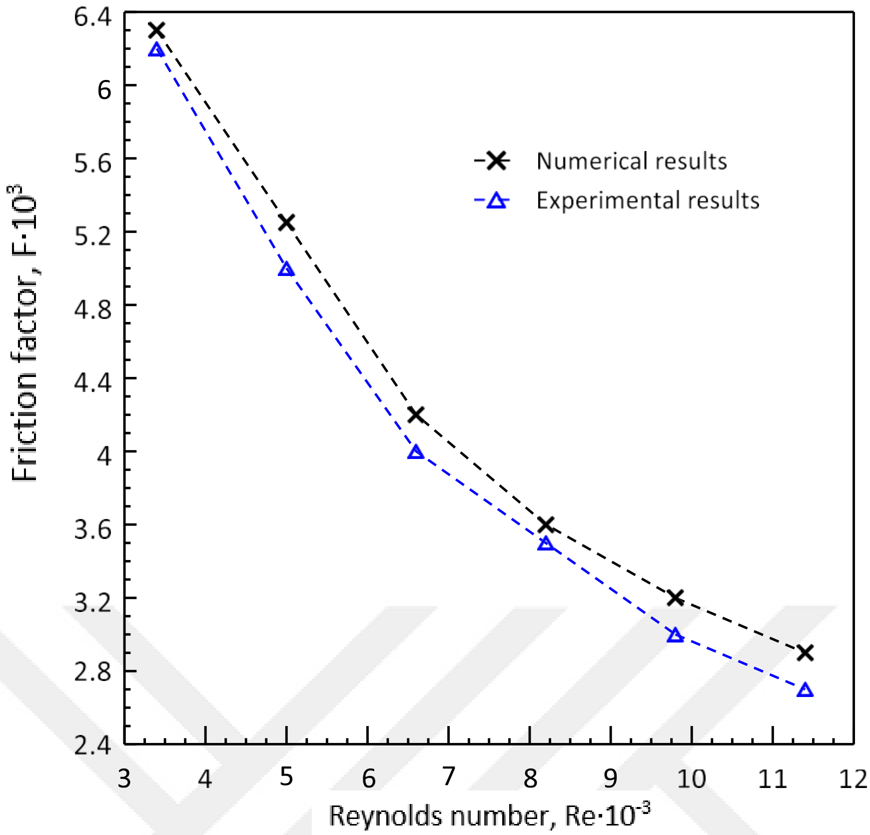

Figure 4.4 Comparing between experimental and numerical results of friction factor

4.3 ANALYSIS AND DISCUSSION OF NUMERICAL RESULTS

4.3.1 Temperature distribution

The temperature distribution of cross-section inside the double pipe heat exchanger is investigated in Figure 4.5. The temperature in the hot side decreases as the heat transfer from the hot side to the cold side.

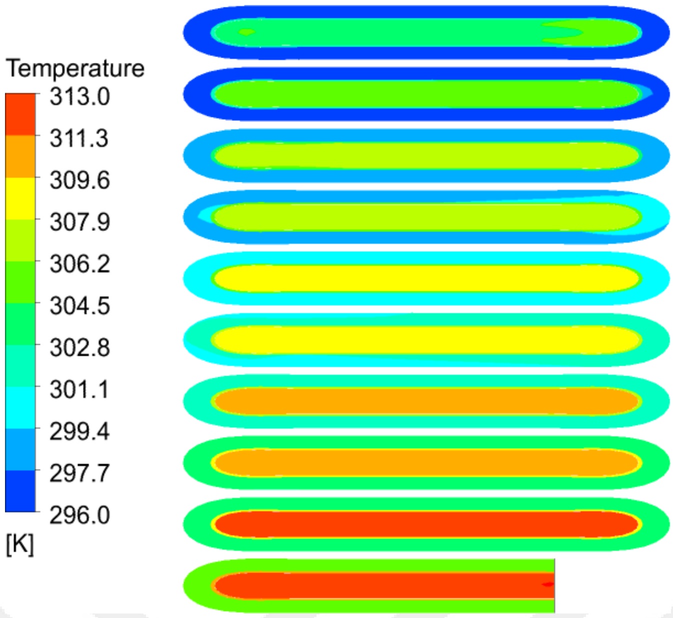

Figure 4.5 Contours of temperature distribution across the heat exchanger

Streamlines of temperature distribution of hot water with Silicon dioxide particles are illustrated in Figure 4.6. The temperature of the hot mixture of water and nanoparticles decrease until the temperature reaches 307 K.

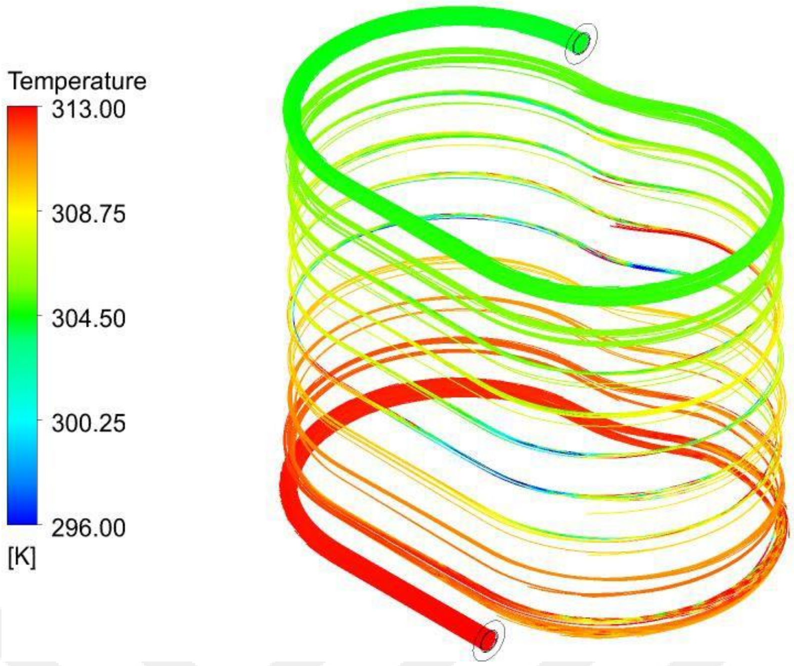

Figure 4.6 Streamlines of temperature distribution of hot water with silicon dioxide particles

4.3.2 Fluid flow structures

The velocity distributions in shapes of streamlines and contours are seen in Figure 4.7 and Figure 4.8. It is indicated that the velocity inside the inner tube is higher than the annulus side where the velocity increase with adding nanoparticles to the water. The turbulence enhanced as the velocity increase so that the heat transfer improved.

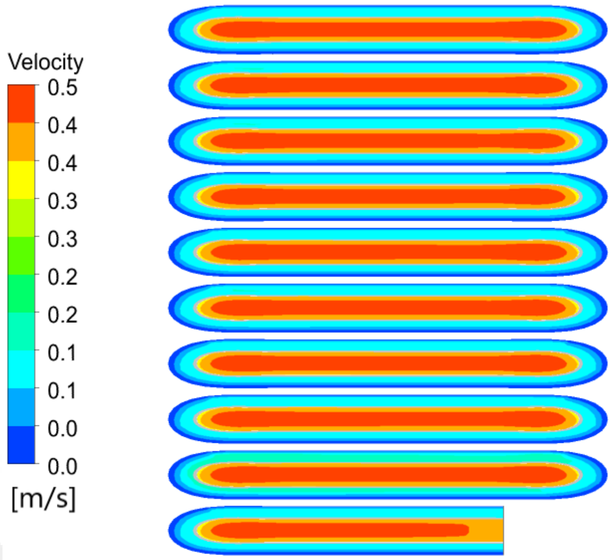

Figure 4.7 Contours of velocity distribution across the heat exchanger

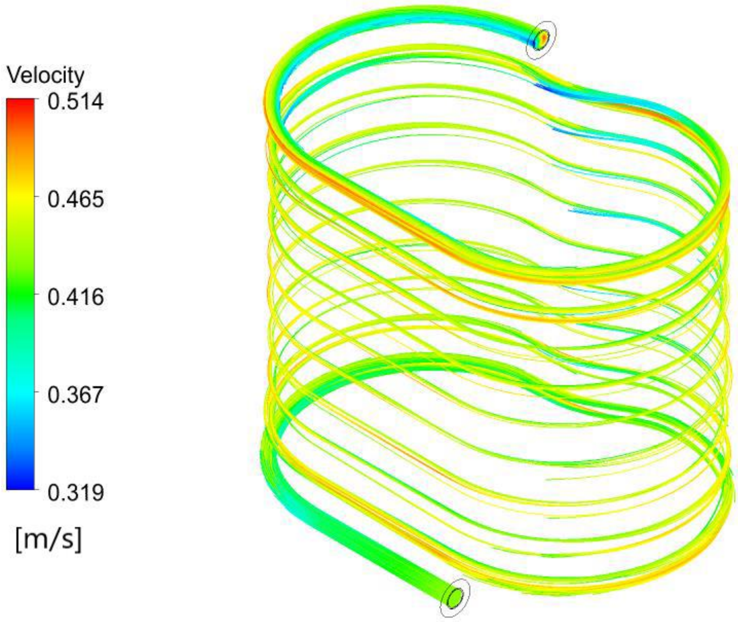

Figure 4.8 Streamlines of the velocity distribution of hot water with silicon dioxide particles

4.3.3 Pressure distribution

The pressure distributions for the cold and hot sides are illustrated in Figure 4.9 and Figure 4.10 where the pressure drop on hot side is greater than the cold side. The effect of adding nanofluids in the inner tube can be observed as the pressure drop increase in the inner tube.

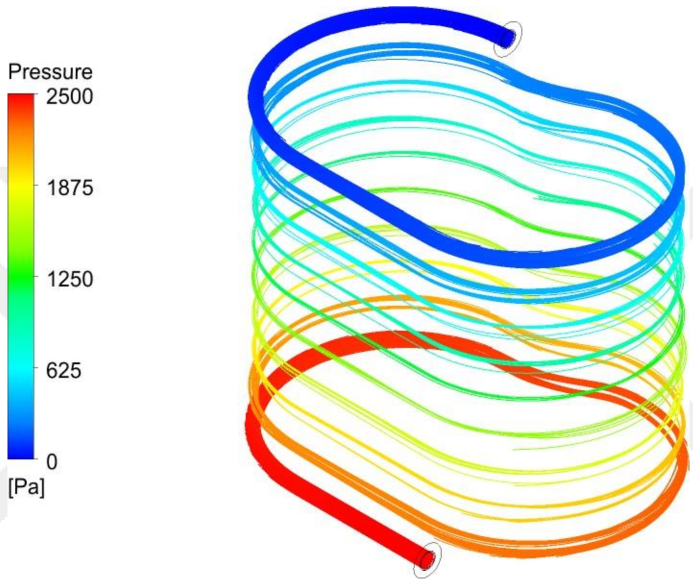

Figure 4.9 Streamlines of pressure distribution of hot water with silicon dioxide particles

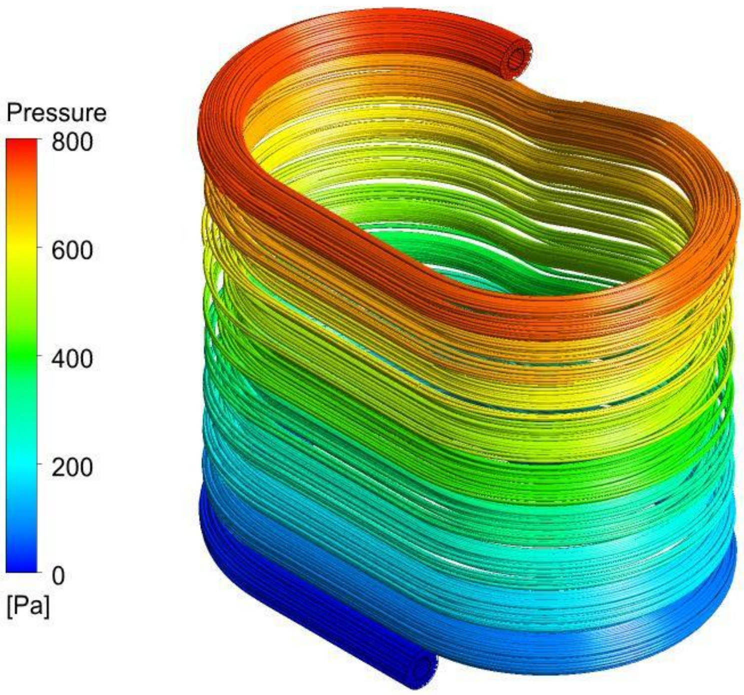

Figure 4.10 Streamlines of pressure distribution of cold water

5. CONCLUSION

In this study, the influences of adding silicon dioxide to water on the heat transfer and friction factor in a double-pipe helical heat exchanger are investigated experimentally and numerically. Parallel and counter flow schemes in the heat exchanger with variations of Reynolds from 3400 to 11400 are studied. Different concentrations of nanofluids of silicon dioxide with water (e.g., 0.0625 Vol.%, 0.125 Vol.%, 0.25 Vol.%, 0.5 Vol.%) and pure water are investigated, and the results can be concluded in these points:

i. The heat transfer coefficient increases with the rise of Reynolds number and nanofluids concentration where the 0.25 Vol.% concentration achieved the maximum enhancement in parallel and contour flow with numbers 5.5 to 19 $kW/m^2 \cdot K$ and 7 to 25 $kW/m^2 \cdot K$, respectively.

ii. Nusselt number enhanced with the increase of Reynolds number for all cases since the water velocity growth more turbulence levels increase. The Nu of the parallel and contour flow are from 36 to 95 and 45 to 123, respectively. the 0.25 Vol.% concentration reaches the optimal Nu enhancement of a double-pipe helical heat exchanger

iii. friction factor falls as the Reynolds number increases, with the highest value of friction factor was reached at a nanofluid concentration of 0.5 vol.%. The pressure drop increased with the rise of solid particles concentrations as the resistance of water fluid flow grows with the increase of pressure drop.

iv. The streamlines and contours of temperature, velocity, and pressure inside the inner tube and annulus tubes are investigated.

v. It is concluded that the 0.25 Vol.% concentration of nanofluids is the ideal concentration for enhancement heat transfer inside the double pipe heat exchanger.

REFERENCES

[1] A. A. Hussain, A. S. J. J. o. E. Golam, and S. Development, "Experimental and Numerical Study of the Heat Transfer Coefficients of Double Pipe Helically Coiled Heat Exchanger," vol. 20, 2016.

[2] S. Berger, L. Talbot, and L. J. A. r. o. f. m. Yao, "Flow in curved pipes," vol. 15, pp. 461-512, 1983.

[3] L. Janssen, C. J. I. J. o. H. Hoogendoorn, and M. Transfer, "Laminar convective heat transfer in helical coiled tubes," vol. 21, pp. 1197-1206, 1978.

[4] D. J. C. E. S. Ruthven, "The residence time distribution for ideal laminar flow in helical tube," vol. 26, pp. 1113-1121, 1971.

[5] C. E. Kalb and J. J. A. J. Seader, "Fully developed viscous—flow heat transfer in curved circular tubes with uniform wall temperature," vol. 20, pp. 340-346, 1974.

[6] D. Prabhanjan, G. Raghavan, T. J. I. c. i. h. Rennie, and m. transfer, "Comparison of heat transfer rates between a straight tube heat exchanger and a helically coiled heat exchanger," vol. 29, pp. 185-191, 2002.

[7] J. W. J. E. T. Rose and F. Science, "Heat-transfer coefficients, Wilson plots and accuracy of thermal measurements," vol. 28, pp. 77-86, 2004.

[8] M. Omidi, M. Farhadi, and M. Jafari, "A comprehensive review on double pipe heat exchangers," Applied Thermal Engineering, vol. 110, pp. 1075-1090, 2017/01/05/ 2017. Available: https://www.sciencedirect.com/science/article/pii/S1359431116316222

[9] S. S. J. C. E. Haraburda, "Three-phase flow? Consider helical-coil heat exchangers," vol. 102, p. 149, 1995.

[10] E. D. Lavric and V. Lavric, "The steady state analysis of the twin helix heat exchanger," in European Symposium on Computer Aided Process Engineering-10. vol. 8, S. Pierucci, Ed., ed: Elsevier, 2000, pp. 439-444.

[11] H. A. J. J. o. E. Hoshi and S. Development, " Experimental investigation of enhancement heat transfer of insert twisted tape of circular cut with wire coil in double pipe heat exchanger," vol. 22, pp. 1-33, 2001.

[12] A. Durmuş, A. Durmuş, and M. Esen, "Investigation of heat transfer and pressure drop in a concentric heat exchanger with snail entrance," Applied Thermal Engineering, vol. https://www.sciencedirect.com/science/article/pii/S1359431101000783

[13] Y. Xuan and Q. J. J. H. t. Li, "Investigation on convective heat transfer and flow features of nanofluids," vol. 125, pp. 151-155, 2003.

[14] D. W. Zhou, "Heat transfer enhancement of copper nanofluid with acoustic cavitation," International Journal of Heat and Mass Transfer, vol. 47, pp. 3109-3117, 2004/07/01/ https://www.sciencedirect.com/science/article/pii/S001793100400081X

[15] P. Naphon, S. J. E. T. Wongwises, and F. Science, "A study of the heat transfer characteristics of a compact spiral coil heat exchanger under wet-surface conditions," vol. 29, pp. 511-521, 2005.

[16] V. Kumar, S. Saini, M. Sharma, and K. D. P. Nigam, "Pressure drop and heat transfer study in tube-in-tube helical heat exchanger," Chemical Engineering Science, vol. 61, https://www.sciencedirect.com/science/article/pii/S0009250906000893

[17] P. Naphon, "Thermal performance and pressure drop of the helical-coil heat exchangers with and without helically crimped fins," International Communications in Heat and Mass Transfer, vol. 34, pp. 321-330, 2007/03/01/ 2007. Available: https://www.sciencedirect.com/science/article/pii/S0735193306002119

[18] W. Williams, J. Buongiorno, and L.-W. J. J. o. h. t. Hu, "Experimental investigation of turbulent convective heat transfer and pressure loss of alumina/water and zirconia/water nanoparticle colloids (nanofluids) in horizontal tubes," vol. 130, 2008.

[19] R. Kharat, N. Bhardwaj, and R. J. I. J. o. T. S. Jha, "Development of heat transfer coefficient correlation for concentric helical coil heat exchanger," vol. 48, pp. 2300-2308, 2009.

[20] T. J. Rennie and V. G. S. Raghavan, "Numerical analysis of the lethality and processing uniformity in a double-pipe helical heat exchanger," Chemical Engineering and Processing: Process Intensification, vol. 49, pp. 672-679, 2010/07/01/ 2010. Available: https://www.sciencedirect.com/science/article/pii/S0255270110001236

[21] A. Sergis and Y. Hardalupas, "Anomalous heat transfer modes of nanofluids: a review based on statistical analysis," Nanoscale Res Lett, vol. 6, p. 391, May 19 2011. Available: https://www.ncbi.nlm.nih.gov/pubmed/21711932

[22] E. V. Timofeeva, W. Yu, D. M. France, D. Singh, and J. L. Routbort, "Nanofluids for heat transfer: an engineering approach," Nanoscale Res Lett, vol. 6, p. 182, Feb 28 2011. Available: https://www.ncbi.nlm.nih.gov/pubmed/21711700

[23] G. Huminic and A. Huminic, "Heat transfer characteristics in double tube helical heat exchangers using nanofluids," International Journal of Heat and Mass Transfer, vol. 54, https://www.sciencedirect.com/science/article/pii/S0017931011002973

[24] H. A. Mohammed, H. A. Hasan, and M. A. Wahid, "Heat transfer enhancement of nanofluids in a double pipe heat exchanger with louvered strip inserts," International Communications in Heat and Mass Transfer, vol. 40, pp. 36-46, 2013/01/01/ 2013. Available: https://www.sciencedirect.com/science/article/pii/S0735193312002552

[25] M. Chandra Sekhara Reddy and V. Vasudeva Rao, "Experimental investigation of heat transfer coefficient and friction factor of ethylene glycol water based TiO2 nanofluid in double pipe heat exchanger with and without helical coil inserts," International Communications in Heat and Mass Transfer, vol. 50, pp. 68-76, 2014/01/01/ 2014. Available: https://www.sciencedirect.com/science/article/pii/S0735193313002133

[26] A. Zohir, M. Habib, and M. J. E. h. t. Nemitallah, "Heat transfer characteristics in a double-pipe heat exchanger equipped with coiled circular wires," vol. 28, pp. 531-545, 2015.

[27] M. Saeedan, A. R. Solaimany Nazar, Y. Abbasi, and R. Karimi, "CFD Investigation and neutral network modeling of heat transfer and pressure drop of nanofluids in double pipe helically baffled heat exchanger with a 3-D fined tube," Applied Thermal Engineering, vol. 100, pp. 721-729, 2016/05/05/ 2016. Available: https://www.sciencedirect.com/science/article/pii/S1359431116300758

[28] N. T. Ravi Kumar, P. Bhramara, B. M. Addis, L. S. Sundar, M. K. Singh, and A. C. M. Sousa, "Heat transfer, friction factor and effectiveness analysis of Fe 3 O 4 /water nanofluid flow in a double pipe heat exchanger with return bend," International Communications in Heat and Mass Transfer, vol. 81, pp. 155-163, 2017/02/01/ 2017. Available: https://www.sciencedirect.com/science/article/pii/S0735193316303633

[29] D. Majidi, H. Alighardashi, and F. Farhadi, "Experimental studies of heat transfer of air in a double-pipe helical heat exchanger," Applied Thermal Engineering, vol. 133,

https://www.sciencedirect.com/science/article/pii/S135943111736814X

[30] W. Wang, Y. Zhang, K.-S. Lee, and B. Li, "Optimal design of a double pipe heat exchanger based on the outward helically corrugated tube," International Journal of Heat and Mass Transfer, vol. 135, pp. 706-716, 2019/06/01/ 2019. Available: https://www.sciencedirect.com/science/article/pii/S0017931018348853

[31] S. Sivalakshmi, M. Raja, and G. Gowtham, "Effect of helical fins on the performance of a double pipe heat exchanger," Materials Today: Proceedings, vol. 43, pp. 1128-1131, 2020/09/25/ 2021. Available: https://www.sciencedirect.com/science/article/pii/S2214785320364452

[32] K. Singh, S. K. Sharma, and S. M. Gupta, "An experimental investigation of hydrodynamic and heat transfer characteristics of surfactant-water solution and CNT nanofluid in a helical coil-based heat exchanger," Materials Today: Proceedings, vol. 43, pp. 3896-3903, 2021/02/09/ 2021. Available: https://www.sciencedirect.com/science/article/pii/S2214785321000602

[33] M. E. Nakhchi, M. Hatami, and M. Rahmati, "Experimental investigation of performance improvement of double-pipe heat exchangers with novel perforated elliptic turbulators," International Journal of Thermal Sciences, vol. 168, p. 107057, 2021/10/01/ 2021. Available: https://www.sciencedirect.com/science/article/pii/S1290072921002210

[34] Z. Wu, L. Wang, and B. Sundén, "Pressure drop and convective heat transfer of water and nanofluids in a double-pipe helical heat exchanger," Applied Thermal Engineering, vol. 60, pp. 266-274, 2013.

[35] M. Imran, G. Tiwari, A. J. I.-I. J. o. I. S. Yadav, Engineering, and Technology, "CFD Analysis of Heat Transfer Rate in Tube in Tube Helical Coil Heat Exchanger," vol. 2, 2015.

[36] “What Is Double Pipe Heat Exchanger: Types. Working Principles | Linquip.” Industrial Manufacturing Blog | Linquip, Industrial Manufacturing Blog | linquip, 3 Mar. 2021, https://www.linquip.com/blog/double-pipe-heat-exchangers/.

[37] Thejaraju, R., and K. B. Girish. "A Comprehensive Review on Design and Analysis of Passive Enhancement Techniques in Double Pipe Heat Exchanger." power 2: 2.