TURKISH REPUBLIC
ERCIYES UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF MECHANICAL ENGINEERING

NUMERICAL INVESTIGATION OF HEAT TRANSFER AUGMANTION ON ADDING (CUO) NANOPARTICLES TO WATER IN A HELICAL INSERTED TUBE

Prepared by
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Supervisior
Prof. Dr. Veysel ÖZCEYHAN

M. Sc. Thesis

December, 2017
KAYSERİ

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December, 2017
KAYSERİ

SCIENTIFIC ETHICS SUITABILITY

I declare that all information's in this work were obtained in accordance with academic and ethical rules. All results and material that not been at the essence of this work are also transferred and expressed by giving reference as required by these rules and behavior,

Haidar Majeed Hachim

SUITABILITY FOR GUIDE

The MSc / thesis entitled **"Numerical Investigation Of Heat Transfer Augmentation On Adding (Cuo) nanoparticles To Water In a Helical Inserted Tube "** has been prepared in accordance with Erciyes University Graduate Education and Teaching Institute Thesis Preparation and Writing Guide.

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This study entitled **"Numerical Investigation Of Heat Transfer Augmentation On Adding (CUO) nanoparticles To Water In a Helical Inserted Tube"** prepared by Haidar Majeed Hachim under the supervision of **Prof.Dr. Veysel ÖZCEYHAN** was accepted by the jury as MSc. Thesis in Mechanical Engineering department.

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APPROVAL

That the acceptance of this thesis has been approved by the decision of the Institute's Board of Directors with the 26/12/2017 date and 2017/55-19 numbered decision.

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Director of the Institute

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Haidar Majeed Hachim

Kayseri, December 2017

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Erciyes University, Graduate School of Natural and Applied Sciences
Master Science Thesis, December 2017
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ABSTRACT

This quantitative study investigated the turbulent convective heat transfer in horizontal tube through two passive techniques: the first one including nanoparticles (CuO) with different volume concentrations added into the base fluid water with Reynolds number ranging between 4000<Re<14000 and the second one using geometry insert in tube (helical with cross section area airfoil naca 0030) with the coiled wire inserts set up with 0.75 mm separation from inner tube wall with three pitch ratios through CFD and SOLIDWORKS. The pairing of pressure and speed was carried out with SIMPLEC algorithm. The quantitative solution procedure included the investigation of the heat transfer and pressure drop properties by using" Finite Volume Method" with standard "k-w Turbulence Model" to solve the continuity, momentum, energy and turbulence equations in three dimensional domain.

The quantitative results indicated that heat transfer increased with the use of CuO-water nanofluid and helical ribs. This increment was stemmed from the volume concentration, helical pitch rate and Reynolds number. Where heat transfer increased with the decrease of helical pitch ratio and raised both volume density and Reynolds number, the friction factor was almost the same as that utilizing nanofluid and water in smooth tube and augmented with the increased volume concentration and reduced the helical pitch ratio and decreased with the increase in Reynolds number.

Keywords: Heat Transfer Enhancement, Cuo/Water Nanofluid, Helical Wire Coil Insert, Turbulent Flow, Reynolds Number

CUO NANO PARÇACIKLARIN SPİRAL EKLİ TÜP İÇİNDEKİ SUYA EKLENMESİ ÜZERİNE ISI TRANSFER ARTIŞININ SAYISAL İNCELEMESİ

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ÖZET

Bu nicel çalışma yatay tüp içerisindeki türbülanslı taşınımlı ısı aktarımı iki pasif teknik vasıtasıyla incelemiştir: bu tekniklerden ilki $4000<Re<14000$ aralığındaki Reynolds sayısına sahip baz sıvı su içerisine karıştırılan farklı hacim yoğunluklarına sahip nano parçacıkları içermektedir ve ikincisi de CFD ve SOLIDWORKS aracılığıyla 3 dişli adımı oranına sahip iç tüp duvarından 0.75 mm ayrışma ile kurulan sarılı kablo ekleri olan tüpteki (kesit alanı kanatlı naca 030 ile sarmal) geometri ekini kullanmaktadır. Basınç ve ivmenin eşleştirmesi SIMPLEC algoritması ile gerçekleştirilmiştir. Nicel çözüm süreci ısı transferi ve basınç düşüş özelliklerinin devamlılık, ivme, enerji ve türbülans denklemlerini 3 boyutlu alanda çözmek amacıyla standart "k-w Türbülans Modeli" içeren "Sonlu Hacim Metodu" kullanılarak incelenmesini içermiştir.

Nicel sonuçlar CuO su nano akışkan ve sarmal dişlerin kullanımıyla ısı transferinin arttığını göstermiştir. Bu artış hacim yoğunluğundan, sarmal adım oranından ve Reynolds sayısından kaynaklanmıştır. Sarmal adım oranının düşüşüyle birlikte ısı transferinin arttığı ve hem hacim yoğunluğunu hem de Reynolds sayısını artırdığı noktada, sürtünme katsayısı pürüzsüz tüpte nano akışkan ve su kullananınkiyle hemen hemen aynıdır ve artan hacim yoğunluğu ile yükselmiş ve sarmal adım oranını azaltmış ve Reynolds sayısındaki artış neticesinde azalmıştır.

Anahtar Kelimeler: Isı transfer artışı, Cuo/Su Nano akışkan, Sarmal kablo Bobin Eki, Türbülanslı Akım, Reynolds Sayısı

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LIST OF SYMBOLS

Cp	: Specific heat (J/kg K).
Cuo	: Cupper Oxide.
D	: Diameter of a tube (m).
f	: friction factor.
h	: heat transfer coefficient (W/m2.K).
hE	: Heat transfer coefficient with inserts (Enhanced).
hNE	: Heat transfer coefficient without inserts (Non-Enhanced).
K	: Thermal conductivity (W/m. K).
L	: Length (m).
L1	: Entrance Section length (m).
L2	: Test Section length (m).
L3	: Exit Section length (m).
Nu	: Nusselt number.
Pr	: Prandtl number.
Re	: Reynolds number.
Tb	: Bulk temperature of a fluid (k).
Tin	: Inlet thermal temperature (K).
Ts	: Surface temperature (K).
Tw	: Temperature at the wall (K).
V	: Fluid velocity (m/s).
Δp	: Pressure drop (Pa).
$\dot{q}$	: Heat flux of the tube (W/m2).

Greek symbols

η	: Performance enhancement coefficient.
μ	: Dynamic viscosity (kg/m s).
ρ	: Density (kg/m3).
Φ	: Nanofluids volume fractions.

Subscripts

bf : Base fluid.

W : Water.

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CHAPTER 1

1.1. Introduction

As a result of the global energy crisis, which is one of the most crucial problems due to the large and continuous rise in the knowledge of consumption and the rising shortage of energy resources as well as the high cost, researchers have been working to foster the efficiency of thermal systems and diminish the size and thus energy consumption rates. Heat transfer is one of the most significant natural phenomena which researchers have studied and developed through two techniques: passive techniques and active techniques. All researchers opt for passive techniques as they don't need energy and are quite simple in geometrical modifications. One of the most important factors influencing the development of any thermal system is the coefficient of heat transfer and pressure drop. This is obtained by reducing the thermal resistance of the boundary layer and by increasing the disturbance in the fluid flow. This disturbance diminishes the resistance of this layer. The helical coil-tube are utilized in industries and power sectors due to its compact structural design, larger heat transfer surface area and higher heat transfer capability.

One of the most crucial problems that researchers encounter is that the increased fluid disturbance used to raise the heat transfer by reducing the resistance of the secondary layer results in a large drop in the pressure, which leads to an increase in the cost of pressure. Therefore, the researchers should evaluate the potential benefit of raised heat transfer and the expense of reducing the pressure drop by increasing the pump pressure.

1.2. Heat Transfer Enhancement

Heat transfer is one of important goals which research studies focus because of its uses and try to increase the heat transfer by employing a number of methods that are developed by them. There are two major techniques of heat transfer augmentation one of which is called passive technique in which there is no power input to raise the heat transfer, but it is built up during the production process whereas the second kind is called active technique and this technique requires some mechanical or electrical power input during the operation. Also, two or more of passive and active techniques can be used together and that is called compound technique which is employed to produce a larger augmentation than using one passive or active technique independently. In this study, there are two factors that are overcome through passive techniques. The first increase in heat transfer is obtained by using nanoparticles. This aims to change the properties of the fluid and improve the coefficient of heat transfer. The water as a base fluid has a high specific heat and a low thermal conductivity unlike nanoparticles. When using the helical insert, it aims to break the layer adjacent to the wall, which diminishes the heat transfer and also to increase the surface area of heat transfer as illustrated in Figure 1.1.

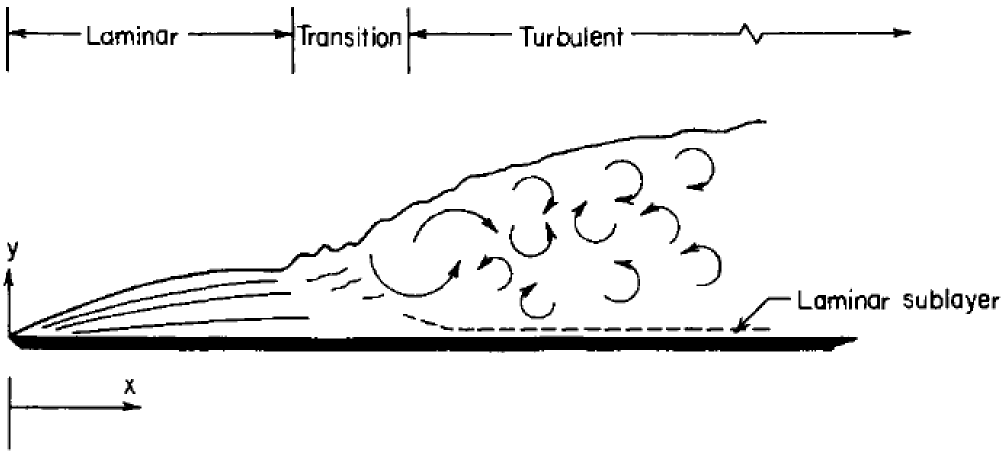

Figure 1.1. Laminar, transition and turbulent boundary layer current regimes in current over flat plate [1], [117]

1.3. Classification of enhancement techniques

According to Manglik [2], there are sixteen different techniques to enhance the heat transfer that can be classified in two groups as follows:

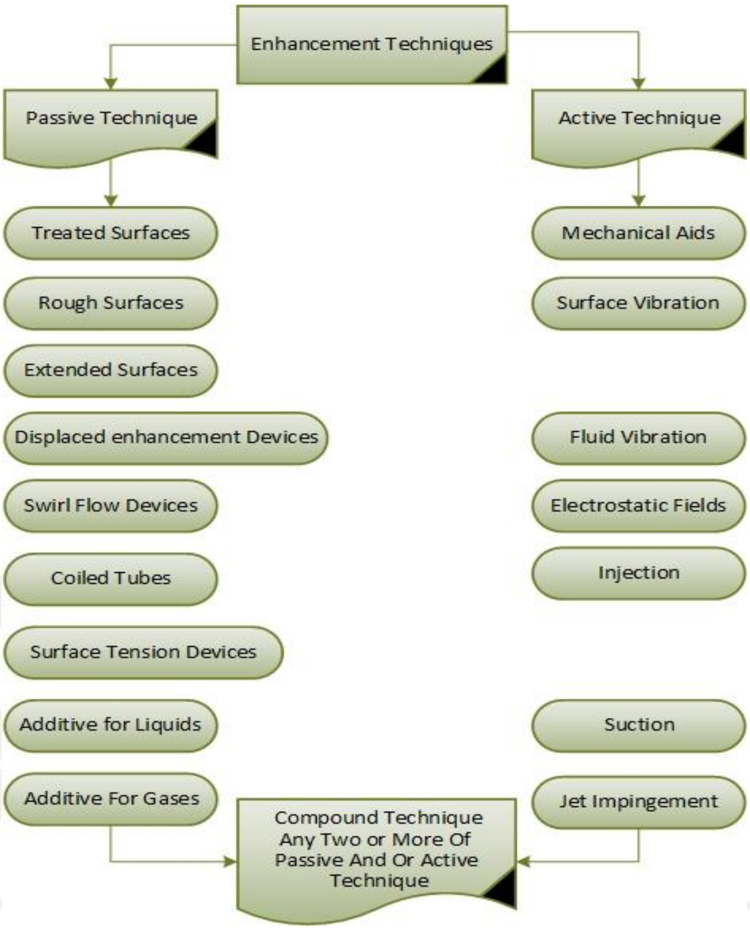

Figure1.2. Heat transfer enhancement techniques

1.3.1. Passive techniques

Passive techniques focus on the flow inside the channels. In these techniques, external power is not required; rather geometry or surface of the flow channel will be modified to raise the heat transfer parameters. The inserts and rough surfaces will be utilized to foster the swirl in the flow, which results in a rise in the heat transfer enhancement. In case of extended surfaces, influential heat transfer area on the side of the extended facet will be raised. Passive techniques are a useful method due to the lower cost of installment and compact size of the heat exchangers. Some of passive techniques are outlined below by Pirbastami [3]:

1-**Treated surface** is the heat transfer surface that has affine –scale shift to their finish or coating. The shift could be continuous or discontinuous, where the roughness is quite smaller than what influences single-stage heat transfer, and they are mainly utilized for boiling and condensing tasks.

2-**Rough facet** is usually the surface modification that promotes the turbulence in the current field, majorly in the single stage currents, and do not raise the heat transfer facet area. And it is provided in two methods: Integral method, where the roughness is integrated on the facets and made by machining or restructuring. The other is the non-integral method, which is implemented by placing roughness close to the facet to raise the heat transfer. Both methods are generally facet modifications that raise the turbulence flow

3-**Extended facets** expand the heat transfer area which raises the heat transfer parameter. The plain fin may just increase the area, but specially structured extended facets can raise the heat transfer coefficient, as well. In applications for gases, mostly extended facets are employed to provide both higher heat transfer parameter (h) and area (A). As the heat transfer coefficient of liquids is higher than gases, shorter fin height is utilized for fluid application. Segmented fins on the facet leads to a separation in the boundary layer. Thus, after each separation a new boundary will be formed and improve the heat transfer rate.

4-**Displaced enhancement device** is placed into a flow channel and moves the fluid through the tube and removes it from the core towards the surface with lower or higher temperatures. The aim of this technique is to increase the fluid mixing, which results in improved energy transport. Inserts like conical ring device, metallic mesh, disks and wire inserts are counted as the displaced enhancement devices.

5-**Swirl flow devices** produce and superimpose swirl or secondary recirculation on the axial current in a channel. They involve helical strip or cored screw-type tube inserts, twisted ducts, and different forms of shifted (tangential to axial direction) current arrangements, and they can be employed for single-stagestage as well as dual-stagestage flows.

6-**Coiled tubes** render slightly more compact heat exchangers. The tube curvature caused by coiling causes secondary currents, which promotes higher heat transfer parameters in single-stagestage currents as well as in many regions of boiling.

7-**Facet tension devices** include wicking or grooved facets, which lead and enhance the flow of liquid from condensing facets to boiling facets.

8-**Additives for liquids** contain the inclusion of solid particles, soluble trace additives, and gas bubbles in single-stagestage currents, and trace additives, which usually compress the facet tension of the liquid for boiling systems.

9-**Additives for gases** contain liquid droplets or solid particles, which are mixed in single-stagestage gas currents in either a dilute stagestage (gas–solid suspensions) or dense stagestage (fluidized beds).

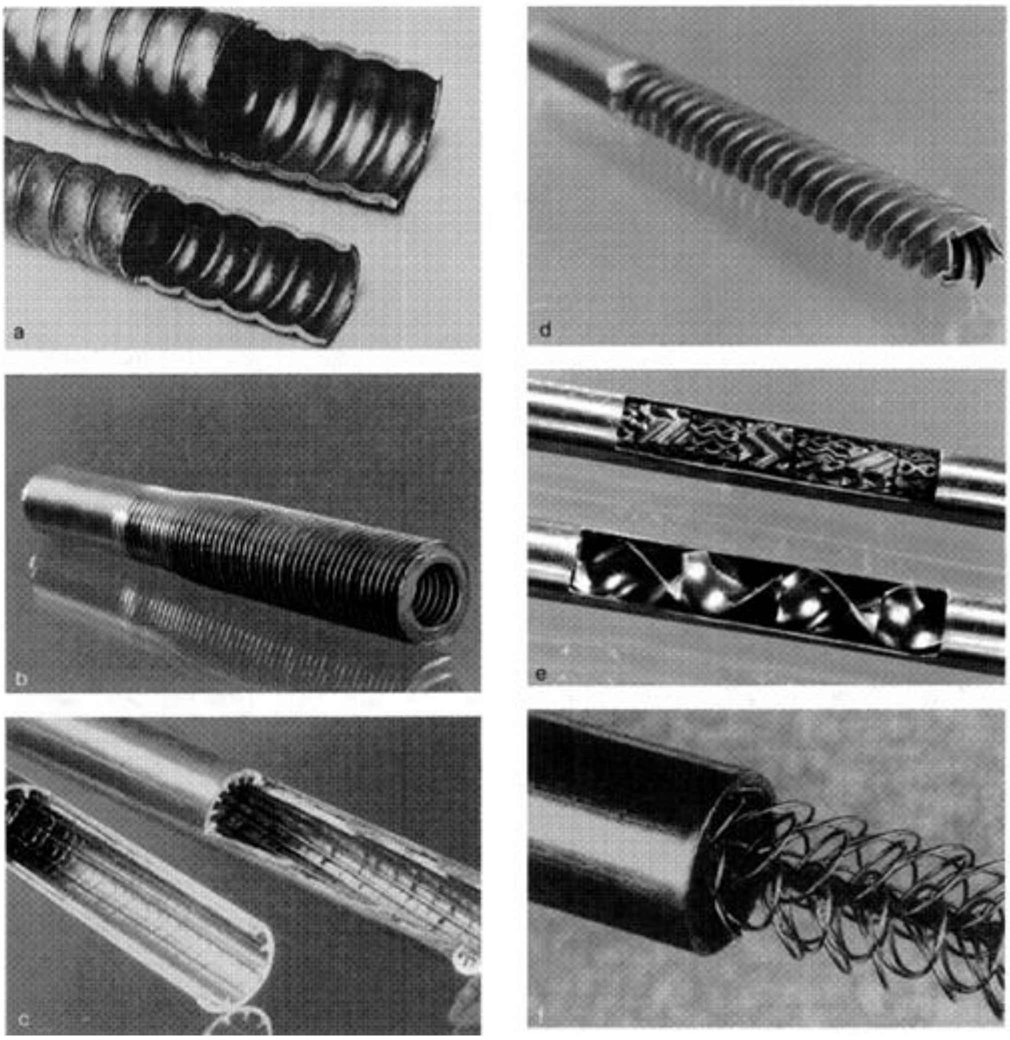

Figure 1.3. Enhanced tubes for augmentation of single-stage heat transfer. (a) Corrugated or spirally indented tube with internal protuberances. (b) Integral external fins. (c) Integral internal fins. (d) Deep spirally fluted tube. (e) Static mixer insert. (f) Wire-wound insert [4].

Figure 1.4. Twisted tae insert with different twist ratio [21]

1.3.2. Active techniques

These techniques necessitate exterior power to promote the heat transfer rate. Active techniques are complicated because of their design and higher cost of the devices compared to the passive methods. Hence, their application is limited. Some of active technique methods are presented below.

1-**Mechanical aids** involve devices that are rotated or stirred by mechanical methods. For example, rotator heat exchanger ducts are commercially utilized and facet scrapers are used for stirring the fluids in chemical processes for viscous fluid.

2-**Facet vibration** is applied to improve the heat transfer with low or high frequency such as piezoelectric devices.

3-**Fluid vibration or fluid pulsation** is where pulsation is formed in the fluid itself rather than on facets. It is useful for single stage flowse.

4-**Electrostatic fields** which could be in the form of electric or magnetic fields, or a constitution of both from DC or AC sources can be employed in heat exchange systems including dielectric liquids. Based on the application, they can foster greater bulk liquid mixing and induce forced convection (corona “wind”) or electromagnetic pumping to improve the heat transfer.

5-**Injection** supplies gas or fluid through a porous heat transfer facet into the liquid flow. This method is utilized for single stagestage heat transfer processes.

6-**Suction** is employed to remove the vapor or fluid from porous facets.

7-**Jet impingement** is used for both dual stage and single stage heat transfer processes. In this method, single stage fluid is forced normally or in a perpendicular or diagonal direction towards the heat transfer facet.

1.3.3. Compound technique

A compound enhancement technique is a combination of more than one enhancement method (either from active or passive) to enhance the thermal performance of heat exchanger devices.

1.4. Advantage of heat transfer enhancement

Manglik **[2]**, Bianco et al. **[6]** and Nikam et al. **[7]** outline the advantages of heat transfer enhancement in detail as follows:

1-It makes the equipment compact.

2-It achieves a high heat transfer rate employing minimized pumping power.

3-It minimizes the expense of energy and material.

6- It increases the efficiency of process and system.

7- It designs the optimum heat exchanger size.

8- It reduces the volume and weight.

9- It if for given temperature difference improved heat transfer.

11- It provides effective utilization of energy – minimum operating cost.

1.5. Why should passive techniques be preferred?

In addition to the advantages, Manglik **[2]** and Vanaki et al. **[8]** summarize the reasons why passive techniques should be opted below:

1. These techniques usually employ simple facet or geometrical modifications to the current channel by integrating inserts or supplementary devices.

2. It does not require any exterior power inputs.

3. Insert production process is elementary and these techniques can be easily used in an available heat exchanger.

4. Passive insert configuration can be determined according to the heat exchanger's operation circumstance.

5. It is utilized in the design of compact heat exchangers.

6. It is applicable both in heat exchanger and in solar air heater and cooling of electronic elements (heat sink).

1.6. Nanofluids

According to some researchers, [9], [10], [11], nano fluids are suspensions of nanoparticles in the base fluid. Nanoparticles vary in dimensions between 100-2500nm. Particles smaller than 100nmare are called “ultrafine”. As a result of their small dimensions, nanoparticles fluidize easily inside the base fluid without any problems of clogging of channels and erosion in channel walls. The type of nanoparticle used directly relies on the improvement of an essential feature of the base fluid. When the relative facet area of nanoparticles is much larger compared to those of conventional particles, it not only considerably improves the heat transfer capabilities, but also increases the stability of the suspension. Numerous particle materials are used for nano fluid preparation. Al_2O_3, CuO, TiO_2, SiC, TiC, Ag, Au, Cu, and Fe nanoparticles are commonly employed in nano fluid research. Carbon nanotubes are also used thanks to their pretty high thermal conductivity in the longitudinal (axial) direction. Base fluids generally utilized in the preparation of nano fluids are the widespread working fluids of heat transfer practices such as water, ethylene glycol and engine oil. In order to enhance the stability of nanoparticles inside the base fluid, some additives are included into the mixture in small quantities. Bianco et al. [6] argue that nano fluids can be divided into four categories according to the volume concentration (a) Dilute nano fluids ($0<\varphi<0.1\%$), (b) Semi dilute nano fluids ($0.1\%<\varphi<5\%$), (c) Semi concentrated nano fluids ($5\%<\varphi<10\%$) and (d) Concentrated nano fluids ($10\%<\varphi$). Preparing nanofluid is not an easy procedure as nano fluid requires good mixing and stability. There are three ways to achieve stability of suspension against sedimentation. First way is to control the pH value of suspensions. Second one is the addition of facet activators or surfactants and thir one is using ultrasonic vibration

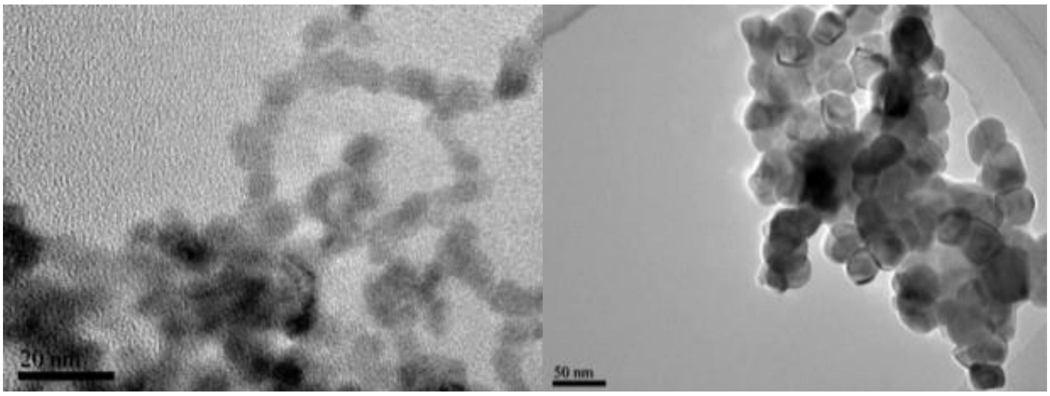

Figure 1.5. TEM photos showing the shape and diameter of the CuO nanoparticles [12].

1.6.1. Preparation methods for Nanofluids [9]

1.6.1.1 Single-step method

In the single step method, the nanoparticles are manufactured and spread simultaneously into the base liquid.

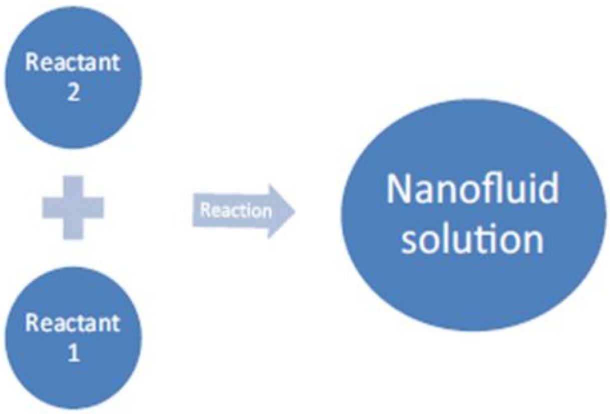

Figure 1.6. Schematic one step method [9]

1.6.1.2. Two-step method

Two-step method is the most widely used method for preparing nano fluids. Nanoparticles, nano-fibers, nano-tubes or other nano-materials employed in this method are first manufactured as dry powders by chemical or physical procedures. Then, the nano-sized powder will be spread into a liquid in the second step through intensive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing and ball milling. Two-step method is the least costly method to manufacture nano fluids in big quantities as nano powder synthesis methods have already been adapted up to industrial production levels. Because of the high facet area and facet activity, nanoparticles are apt to gather. A significant method to improve the stability of nanoparticles in liquids is the use of surfactants. Yet, the functionality of the surfactants under high temperature poses a problem, particularly for high temperatureimplementations.

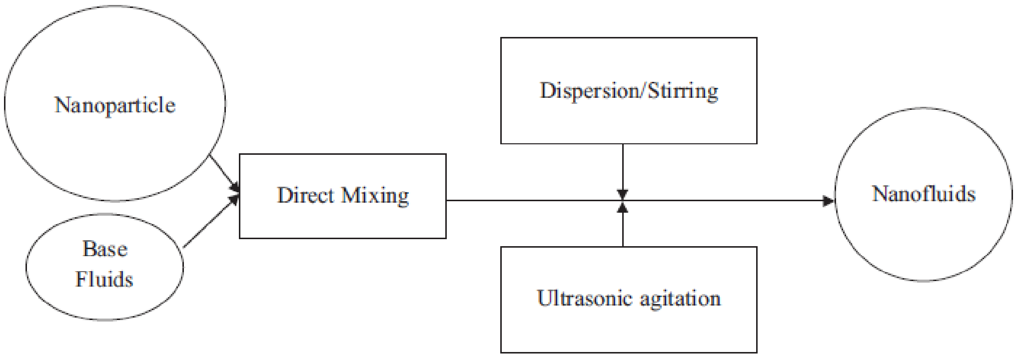

Figure 1.7. Schematic two step method [9]

1.6.2. Thermal conductivity of Nano fluids [11] [9]

The fluids that have been conventionally utilized for heat transfer practices have a pretty low thermal conductivity. Taking into account the rising demands of modern technology, it has been lately suggested that spread of small quantities of nanometer-sized solids in the fluid called nanofluids can foster the thermal conductivity of the fluids. This rise in the thermal conductivity is thought to be stemmed from “Brownian Motion”, Interfacial layer (nano-layer), Volume fraction of particles, effect of nanoparticle clustering and thermophoresis.

1.6.2.1. Brownian motion

The haphazard motion of nanoparticles within the base fluid is termed as Brownian Motion and stemmed from the continuous collisions between the nanoparticles and the molecules of the base fluid. It was discovered that the Brownian motion of nanoparticles at the molecular and Nano scale level is a pivot mechanism running the thermal act of nanoparticle–fluid suspensions ("nanofluids"). The enhancement in the effective thermal conductivity of nanofluids is primarily stemmed from the localized convection caused by the Brownian movement of the nanoparticles.

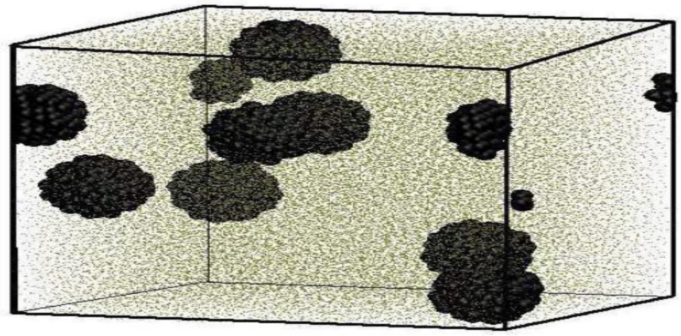

Figure 1.8. Brownian motion of nanoparticles [11]

1.6.2.2. Interfacial layer (nanolayer)

Despite the fact that fluid molecules close to a solid facet create layered structures, little is known about the link between this nano layer and the thermal features of solid/liquid suspensions. It is supposed that the solid-like nanolayer serves as a thermal bridge between a solid nanoparticle and a bulk liquid and thus is pivot to foster the thermal conductivity. Based on this thermally bridging nano layer idea, a structural model of nanofluids that includes solid was proposed. Traditional pictures of solid/liquid suspensions do not consist of this nano-layer. The thermal conductivity of the nano-layer on the facet of the nanoparticle is not known. However, as the layered molecules are in an intermediate physical condition between a bulk fluid and a solid, the solid-like nano-layer of fluid molecules would be supposed to result in a higher thermal conductivity than that of the bulk liquid.

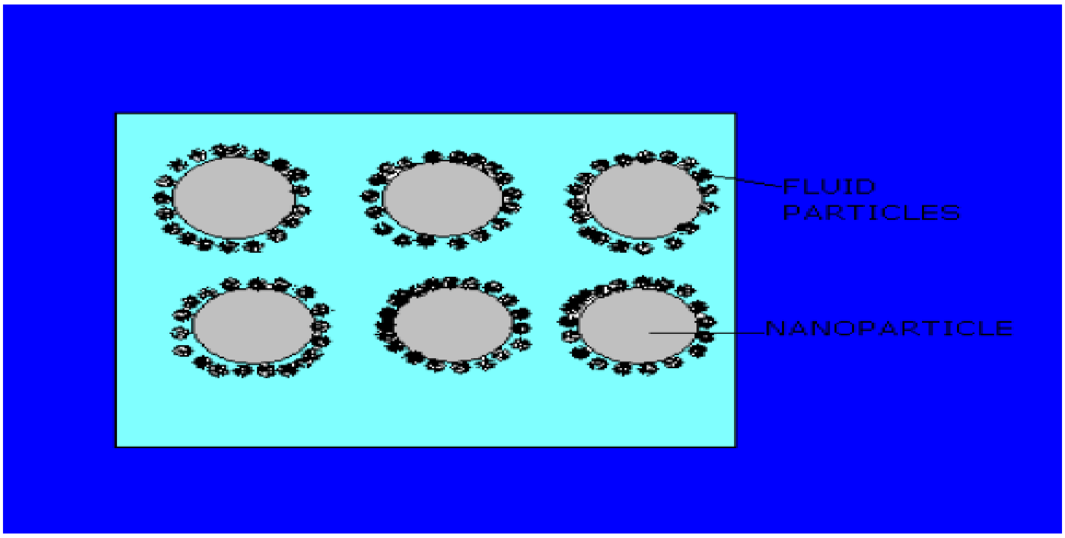

Figure 1.9. Schematic cross section of nanofluids structure with nanoparticles, bulk liquid, and nano-layers at solid/liquid interface [11]

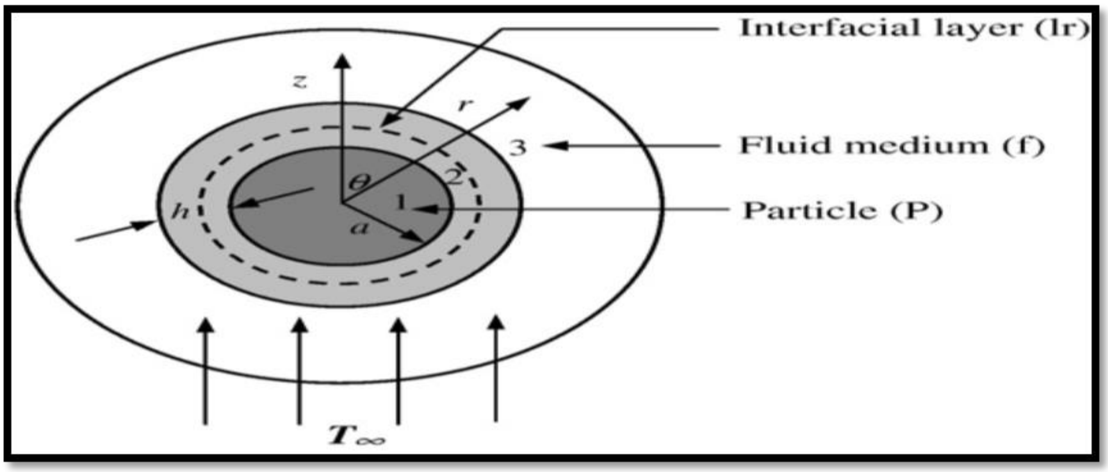

Figure 1.10. Single spherical particle with interfacial layer in a fluid medium [13].

1.6.2.3. Volume fraction

The volume concentration of nanoparticles remarkably influences the rise in the heat conductivity of the nano fluid in comparison with the pure fluid.

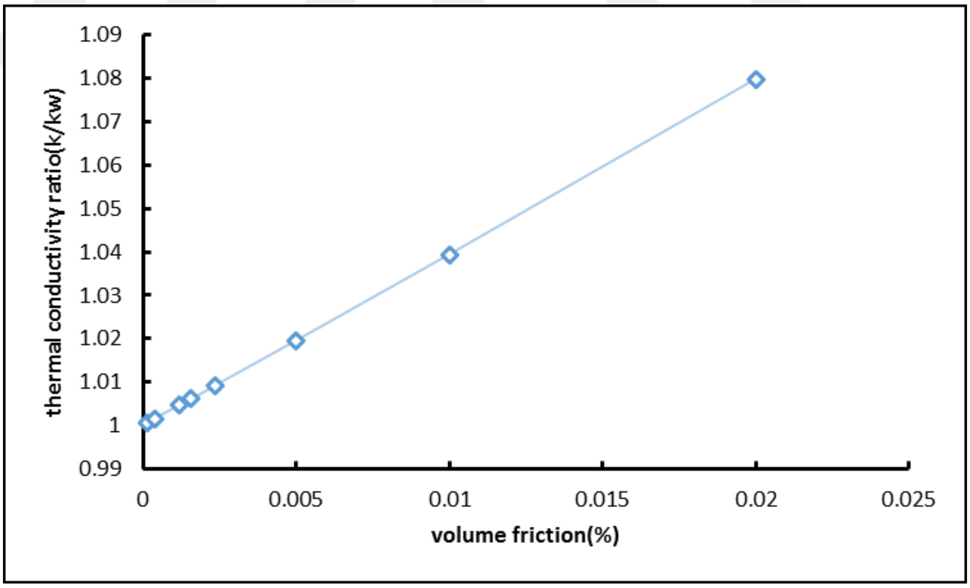

Figure 1.11. Thermal conductivity vs. volume friction

1.6.2.4. Effect of nanoparticles clustering

Clustering renders lower thermal resistance paths and thus influences the thermal conductivity enhancement. To solve this case, particles of smaller dimensions and low volumetric concentrations should be utilized. Effective volume dimensions of a cluster must be bigger than the solid stage volume, allowing more heat to pass through such cluster quickly.

1.6.2.5. Thermophoresis

Thermophoresis or thermo diffusion is the action of molecules in temperature fields. It is usually seen in mixtures of moving particles supplying different reactions to forces of any temperature gradient. Hot region molecules with high energy affect the cold region particles, and thus the particles move in reverse direction to temperature gradient.

1.6.3. How did Nano fluid improve the heat transfer?

The points outlined by Xuan and Li [14] indicate that nano fluid improves the heat transfer:

1-by increasing the facet area and heat capacity of the fluid

2-by increasing the thermal conductivity of the fluid

3- The interaction and collision among particles, fluid and the flow facet are massive.

4- The mixing fluctuation and turbulence of the fluid are intensified.

5- The dispersion of nanoparticles flattens the transverse temperature gradient of the fluid.

1.7. Literature Review

1.7.1. Nano fluid in smooth tube

In 1995, Choi [15] coined the term nanofluids by making use of stable suspension of a small quantity of tiny particles, fibers or tubes with size of 1-100 nm. Nanofluid is a mixture of particles and base fluid (like water, ethylene glycol and light oils). Those particles enhance the base fluid features like thermal conductivity to increase the heat transfer coefficient. Experimental investigation proves that utilizing low volume concentration of nanoparticle renders a considerable rise in thermal performance. Thus, many researchers work on nanotechnology [16].

Pak et al. [17] explored the heat transfer and turbulent friction factor for two types of nanoparticles ($\gamma - Al_2O_3$) and TiO_2 with particle diameter of 13 nm and 27nm with water as base fluid. The result indicates that the Nusselt number for turbulent flow rises with increasing both the volume and three types of concentration (3%) was smaller than water about 12% at constant speed.

Li et al. [18] investigated experimentally the heat transfer and friction factor of Cu-water nanofluid in tube for the laminar and turbulent current. The results pointed out that heat transfer rises around 60% for nanofluid with volume concentration of 2 vol% and the friction factor went through almost no change with low volume concentration of nano particle.

Namburu et al. [19] conducted a quantitative study on the heat transfer and pressure drop of three types of nanoparticles (Al_2O_3, SiO_2 and CuO) with mixture of ethylene glycol and water as working fluid in a radial tube under a stable heat flux in turbulent flow regime. With varying volume concentrations between 0 to 6%, the results show that nano fluids with smaller diameter nanoparticles have bigger Nusselt number and viscosity, and heat transfer rises with increasing volume concentration and Reynolds number, and at the same volume concentration and Reynolds number CuO supplies a higher heat transfer performance followed by Al_2O_3 and SiO_2 .Tthe pressure loss rises with the rise in the volume concentration.

Asirvatham et al. [20] explored the heat transfer of CuO nanoparticle flow in radial tube in laminar current regime with volume concentration of 0.003%. The base fluid is de-ionized water with varying mass flow rate (0.0113kg/s to 0.0139kg/s) with inlet temperature of 10C° and 17C°. The results suggested that the heat transfer coefficient rises about 8% more than the base fluid.

Fotukian et al. [16] examined the heat transfer and pressure drop of CuO –water flow in tube under turbulent regime with volume concentration lower than 0.24%. The results sugges that the heat transfer coefficient rises more than base fluid on average 25% and there is no significant variance in heat transfer enhancement ratio with volume concentration under 0.24% whereas the pressure drop is penalty 20%.

Vajjha et al. [21] dwelled on the heat transfer and pressure drop of three types of nanoparticles (Al_2O_3 , CuO and SiO_2) with mixture of 60% ethylene glycol and 40% water as working fluid with varying volume concentration (2-10vol%). The results point out that the heat transfer coefficient rises with increasing volume concentration. At Reynolds number of 7240, the heat transfer coefficient increase about 81.7% for Al_2O_3 at 10% volume concentration and the pressure drop ascends with the increase in the volume concentration at Reynolds number of 6700, and the pressure drop increases about 4.7 times more than the working fluid as a result of the viscosity of nano fluid.

Weerapun et al. [15] examined the heat transfer coefficient and friction factor of TiO2 – water flowing in horizontal double pipe counter current heat exchanger under turbulent flow. The dimensions of the nanoparticle is 21 nm with volume concentration of 0.2-2%. The results showed that the heat transfer rises when Nano fluid is utilized and rises with increasing Reynolds number and volume concentration whereas pressure drop is a bit higher than water and rises with increasing volume concentration.

Eldwin et al. [12] conducted a study focusing on the heat transfer behavior of CuO and water in horizontal tube under turbulent current regime with low volume friction (0.01%). The results indicated that the heat transfer rate and pressure drop are almost the same as water.

Kannadasan et al. [23] explored the heat transfer and friction factor behavior of CuO and water in horizontal heat exchanger in horizontal and vertical position under turbulent current regime. Results revealed that the enhancement of convective heat transfer coefficient and friction factor is nearly the same compared to water and the friction increase when the volume concentration increases at low current.

Dawood et al. [24] studied quantitatively on the heat transfer in laminar regime current in an elliptic annulus with fixed heat flux. The study was conducted with various types of nanoparticles (AL_2O_3, CUO , SiO_2 and ZnO) with varying dimensionss (20 , 40 , 60 and 80 nm) and volume concentration (between 0% to 4%) and water as base fluid. The Reynolds number ranged from 200 to 1000. The results suggested that the SiO2-water renders the highest Nusselt number followed by AL_2O_3-water, ZnO-water and CuO-water.

Vajjha et al. [25] carried out a quantitative study on the heat transfer and pressure drop of two types of nanoparticles (Al_2O_3 and CuO) with mixture of ethylene glycol and water as working fluid in flat tube, with various volume concentrations up to 6%. The results point out that the heat transfer coefficient and friction factor rise with the increasing volume concentration and the highest heat transfer coefficient for Al_2O_3 and CuO at volume concentration up to 3% and 2% respectively.

Abdul Hassan et al. [26] conducted an experimental study on the heat transfer and pressure drop of three types of nanoparticles (Al , Al_2O_3 and CuO) with particles diameter (25nm , 30nm and 50nm) respectively flowing through a regular heated radial tube in laminar current regime with water as the base fluid and various volume concentrations (0.25 to2.5 vol%). The results show that the rise in the heat transfer coefficient for three types of nanofluids (Al , Al_2O_3 and CuO) is 45% , 32% and 25% respectively and there is no penalty drop in the pressure.

Vahidinia1 et al. [27] examined the heat transfer in turbulent regime current in a horizontal tube under a non-uniform heat flux in the upper wall and insulation in the lower wall. The study was conducted with Nano fluid AL_2O_3-water and volume concentration between 0 %and 6%. The results point out that the heat transfer coefficient is higher than the base fluid and raising the volume concentration increases both the heat transfer and shear stress.

Majid et al. [28] studied the heat transfer act of CuO and water in horizontal dual tube counter current heat exchanger under turbulent flow regime. The results indicated that the heat transfer coefficient of nanofluids is higher than base fluid and the Nusselt number. In addition, heat transfer coefficient rises when the volume friction and Reynolds number increase. The pressure drop of nanofluid is higher than base fluid and rises with the increasing volume friction.

Abdolbaqi et al. [29] dwelled on the heat transfer and friction factor of TiO2 in flat tube under stable heat flux and turbulent current with mixture of 20% BioGlucol and 80% water as working fluid at the nanoparticle diameter of 50nm. The volume concentration varied between 0.5-2vol%. The results showed that Nusselt number is higher than working fluid and rises with increasing Reynolds number and operation temperature and indicated that the Nusselt number at volume concentration of 2% was lower than working fluid by 3%. Also, friction factor is higher than working fluid and rises with the increasing volume concentration.

1.7.2. Fluid with insert

Kumar et al. [30] examined the heat transfer and friction power loss by utilizing coiled wire inserted tube with water as working fluid with different pitched coil (1<p/d<5.5) and with three wire diameters (0.052 in. ,0.063in. and 0.072in.) The results point out that heat transfer rises about 280% and the friction power loss rises as well.

Agrawal et al. [31] examined the heat transfer enhancement by employing coiled wire inserts during forced convection of R-22 inside a horizontal tube with three different coil pitches (6.5mm , 10mm and 13mm) and three wire diameters of coil (0.65 mm, 1 mm and 1.5 mm). The results indicated that using helically coiled wire raises the condensing heat transfer coefficient by 100%.

Garcı´a et al. [32] studied the thermal hydraulic act in laminar-transition- turbulent by utilizing coiled wire inserted tube with water and water-propylene glycol mixture at Reynolds number from 80 to 90000 and Prandtl number between 2.8 to 150 with six coil pitches between 1.17<p/d<2.68 and wire diameters between 0.07<e/d<0.1. The results suggest that in turbulent current, pressure drop rises nine times and heat transfer rises four times in comparison with smooth tube. At low Reynolds number, there is no effect of wire coil. At transition to critical Reynolds number down to 700, heat transfer rate rises to 200% with stable pumping power.

Eiamsa-ard et al. [33] dwelled on the heat transfer coefficient and friction factor in heat exchanger fitted with neatly space twisted and cold and hot water was employed as working fluid. In addition, they were inserted in the test section in two different cases: first, fully length typical twisted tape and twisted tape with various free spaces. The results suggest that the heat transfer and friction factor increase.

Naphon et al. [34] investigated the heat transfer and pressure drop in a horizontal dual pipe with coiled wire in which the inner and outer diameter of micro fin tube are 8.92mm and 9.52mm respectively. The inlet cold and hot water temperature vary between 15 and 20 C° and between 40 C° and 45C°. The results pointed out that the coiled wire insert has a considerable increase in not only the heat transfer but also the friction factor.

Akhavan-Behabadi et al. [35] conducted an experimental study on the increment of pressure drop during the condensation of R-134a vapor inside a horizontal tube in heat exchanger including a dual pipe counter current through coiled wire with various coil pitches (5mm , 8mm , 10mm and 13mm) with different wire diameters (0.5 mm, 0.7 mm, 1 mm and 1.5 mm). The results revealed that the pressure drop rises to 1600% in the range of 260.

In a similar vein, Promvonge [36] examined the heat transfer enhancement and friction factor when utilizing helically wire coil and twisted tape together with air as the working fluid in a radial tube under a regular heat flux. The impact of the helical and twisted were tested for Reynolds number ranging from 3000 to 18000. The results suggested that employing wire coil and twisted tape renders a dual rise in the heat transfer compared to the smooth tube and a considerable increase in the pressure drop.

Akhavan–Behabadi et al. [37] also examined the heat transfer enhancement and the pressure drop during flow boiling of R-134a via coiled wire inserted horizontal evaporator with various coiled pitches (5mm ,8mm ,10mm and 13mm) and different coiled diameters (0.5 mm, 0.7 mm, 1 mm and 1.5 mm). The results showed that the heat transfer enhancement rises with high increase in the pressure drop.

Gunes et al. [38] explored the heat transfer and pressure drop with coiled wire inserted tube in a turbulent current regime. The coiled wire has equilateral triangular cross section and insert independent from the tube wall. The experiments were conducted with three pitch ratios (P/D = 1, 2 and 3) and two ratios of equilateral triangle length side to tube diameter (a/D = 0.0714 and 0.0892) at a margin (s) of 1 mm from the tube wall in the range of Reynolds number from 3500 to 27,000. Regular heat flux was implemented to the external facet of the tube and air was the base fluid. The results suggest that using coiled wire inserts result in a considerable increase in the heat transfer and pressure drop and Nusselt number rises with the increase in Reynolds number and wire thickness and the decrease of pitch ratio.

Gunes et al. [39] also examined the heat transfer and pressure drop with coiled wire inserted tube in turbulent current regime. The coiled wire was placed separately from the tube wall with two different distance (s=1 and 2). The experiments were practiced with three pitch ratios (P/D = 1,2 and 3) at the range of Reynolds number from 4105 to 26,400. Regular heat flux was implemented to the exterior facet of the tube and air was the base fluid. The results revealed that utilizing coiled wire inserts lead to a considerable rise in the heat transfer and pressure drop, and the Nusselt number and friction factor rise with the decreasing pitch ratio and margin.

Akhavan-Behabadi et al. [40] also dwelled on the heat transfer coefficient through coiled wire inserts during the heating of engine oil inside a horizontal tube. Seven coiled wires with the pitches of 12-69mm and two wire diameters of 2mm and 3.3mm are employed. The results indicated that using wire coil inserts with lower wire diameter provides a sound performance at low Reynolds number and decrease in the coil pitch results in a rise in the heat transfer coefficient.

Eiamsa-ard1 et al. [41] examined the heat transfer and friction factor through tandem wire coil in square duct with regular heat flux with Reynolds number ranging from 4000 to 25000. The results revealed that employing wire coil with short free space length causes a considerable rise in the heat transfer and friction factor and the full length wire renders a higher heat transfer and friction factor.

Yang San et al. [42] explored the heat transfer and pressure drop data for air current and water current in smooth tubes with coiled-wire inserts. The wire diameter-to-tube to inner diameter ratio (e/d) range from 0.0725 to 0.134 and coil pitch-to-tube to inner diameter ratio (p/d) range from 1.304 to 2.319. The results point out that the Nu value slightly rises with the e/d value whereas it relatively rises with a decrease in the p/d value. Besides, the Nu value considerably rises with the Re value.

Similarly, Keklikcioglu et al. [43] examined the heat transfer and friction factor through coiled wire with equilateral triangular cross section area with stable side length (e=6mm) with three pitch ratios (P/D=1 ,2 and 3) and the edge of triangle was directed to face the incoming air. The coiled wire was located independently from tube wall at two distances (1mm and 2mm). Reynolds number ranged from 3429 to 26663. The results suggested a remarkable rise in the heat transfer and friction factor.

Sharafeldeen1et al. [44] studied the heat transfer and pressure drop via a coiled wire inserted tube in turbulent current regime in the range of Reynolds number from 14400 to 42900 and the wire diameter ratio ($0.044<e/d<0.133$) and coil pitch ratio of $1<p/d<5$ with regular heat flux. Air serves as the working fluid. The results indicate that both heat transfer and pressure drop rise.

1.7.3. Nanofluid flow with insert

With a different perspective, Sharma et al. [45] examined the heat transfer and friction factor of Al_2O_3 nanoparticle with volume concentration of 0.1% and water as the base fluid at a current in tube with twisted tape insert with ratio of H/D=5 in transition current regime. According to the results, the heat transfer rises when both Reynolds number and volume concentration increased. Also, the heat transfer ascends about 13.77% with nano fluid (Al2O3) at 0.1% volume concentration and Reynolds number 3000 and about 23.69 % at Reynolds number of 9000. When utilizing twister tape insert with Al2O3 at the same volume concentration (0.1%), the heat transfer rises about 36.96% at Reynolds number of 3000 and about 44.71 % at Reynolds number of 9000.

In a similar vein, Chandrasekar et al. [46] also studied the heat transfer and pressure drop of Al_2O_3 nanoparticle with dimensions diameter of 43nm and volume concentration at 0.1% and water as the base fluid at a current under stable heat flux in horizontal tube with and without wire coil insert. Two pitch ratios (2 and 3) of wire coil were employed in a laminar current regime. The results revealed that Nusselt number rises about 12.24% at Reynolds number of 2275 when using Nano fluid only. Furthermore, it ascends about 15.91 % and 21.53 % when using nano fluid with two wires coiled. The pressure drop of nano fluid is almost the same as that of water and increases when employing wire coil.

Pathipakka et al. [47] quantitatively explored the heat transfer of Al2O3/water Nano fluid with varying volume concentrations (0.5% , 1% and 1.5%) current in a tube with twisted inserts with different twist ratios (2.93 , 3.91 and 4.89) under a regular heat flux. The test was conducted with Reynolds number between 200 and 2100. The results point out that the heat transfer ascends 31.29% with 1.5% nanofluid volume concentration and twisted pitch ratio of 2.93 at Reynolds number 2039.

Suresh et al. [48] investigated the heat transfer and friction factor act of CuO and water with volume friction of 0.1% , 0.2% ,0.3% in plain and helically dimpled tube under turbulent current regime with stable heat flux. According to the results, the heat transfer rate rises and the friction factor is almost the same as plain tube with the increase in Nusselt number.

Heat transfer and pressure drop of CuO/water nanoparticle were explored by Wongcharee et al. [49] employing various volume concentrations (0.3% , 0.5% and 0.7%). The test was fulfilled with Reynolds number between 830 to 1990 at nano fluid current within a radial tube with two kinds of twisted tape first of which includes alternate axis (TA) with stable twisted ratio y/w of TA at 3 and second of which includes typical twisted tape (TT). The results implicitly pointed out that using CuO nano fluid with twisted alternate (TA) renders a higher Nusselt number and thermal performance, and the twister alternate TA is about 89% more influentialthan typical twisted. Wongcharee et al. [50] also examined the heat transfer and friction factor act of CuO and water (with volume friction 0.3% , 0.5% ,0.7%) with three different twist ratios under turbulent current regime. The results revealed that the heat transfer rate rises with increasing volume concentration nanoparticle and decreasing twist ratio. In addition, the heat transfer, friction factor, thermal performance were higher when using them together than employing one technique.

Kannadasan et al. [51] compared the heat transfer and pressure drop of CuO/water nano fluid in helically coiled heat exchanger held in horizontal and vertical positions in turbulent current regime with two volume concentrations (0.1% and 0.2%). The current on the tube side varies (0.03-0.075 kg/s). The results suggest that the heat transfer coefficient and friction factor rise with increasing volume concentration in both vertical and horizontal positions. Moreover, Nusselt number seems to ascend 36% and 45% at two different volume concentrations (0.1% and 0.2%) respectively in horizontal position, whereas the Nusselt number ascends 37% and 49% at the same volume concentration in vertical position. The friction factor rises in both positions to 7% and 21% at volume concentration of 0.1% in horizontal position and to 12% and 25% at the same volume concentration in vertical position.

Rabienataj et al. [52] explored the heat transfer and pressure drop of SiO_2 nanoparticle with dimensions diameter of 30 nm and 3 different volume concentration (0%, 0.5% and 1%) and water as the base fluid. The current in plain tube and five helical corrugated tubes with different height and pitch fluctuated. The test was conducted with Reynolds number ranging from 5000 to 15000. The results suggested that including nanoparticle raises the heat transfer, and the friction factor is almost the same. Moreover, raising the corrugated height and lowering the corrugated pitch increases the impact of nano particle on the heat transfer.

Hashmi et al. [53] explored the heat transfer and pressure drop of CuO nanoparticle with varying weight concentrations (0.5%, 1% and 2%) flow within a horizontal helical tube under a stable heat flux with oil as the base fluid. The test was conducted with Reynolds number between 10 and 100. The results point out that the heat transfer employing helical tube is more effective than utilizing nano fluid.Besides, the heat transfer rises more when combining the two techniques,where the heat transfer rises about 17.7% with CuO nano fluid flow on straight tube with weight concentration of 2%, and increases about 30.4% with CuO nano fluid at the same weight concentration, but in the helical tube.

Saeedinia et al. [54] also focued on the heat transfer and pressure drop by using CuO nanoparticle with oil as the base fluid flow in tube with various wire coiled inserts under a stable heat flux in laminar current regime. Also, the nanoparticle volume concentration ranges from 0.07% to 0.3%, and the coiled wire diameter is between 0.9-1.5mm and pitches vary (25-35mm). The test was implemented with varying Reynolds number (20-110). The results outline that the heat transfer coefficient ascended about 45% and penalty about 63% in the pressure drop at the highest Reynold number and wire coil.

Naik et al. [55] examined the convective heat transfer and friction factor through CuO nanoparticle with diameter of 50 nm and varying volume concentration (0.025% , 0.1% and 0.5%) flowing in plain tube and with twisted tape inserts with twist ratios of $0 < H/D < 15$ under stable heat flux with the mixture of water 70% and propylene glycol 30% as the base fluid. In addition, the study was conducted with Reynolds number ranging from 1000 to 10000. According to the results, the heat transfer rises with CuO nano fluid up to 27.95% with volume concentration of 0.5% in plain tube whereas it increases up to 76.06% with the same volume concentration and with twisted tap insert ratio of 5 at the same Reynolds number. The friction factor rises to 10.08% with CuO nanofluid in plain tube, and to 26.57% with CuO nanofluid and twisted tape.

Maddah et al. [56] explored the impact of Al_2O_3 nanoparticle with volume concentration ranging from 0.2% to 0.9% with water as the base fluid flow in dual pipe heat exchanger with twisted tape. The test was conducted with Reynolds number ranging from 5000 to 21000. Also, the twist ratio changed along a twist depending on the geometrical progression ratio of GPR reducer (RGPR<1) or increaser (IGPR>1). The results point out that the heat transfer with twisted tape and nano fluid rises about 1.03 to 4 times compared to the plain tube, and also friction factor increases about 1.4-2.8 times.

Sultan [57] also examined the heat transfer and friction factor of two types of nanoparticles (Ag and ZrO_2) with oil as the base fluid. The current in the heat exchanger with and without fins was under laminar current regime. The volume concentration of nanoparticles varies (1%, 2%, 3%, 4% and 5%). According to the results, it can be stated that Silver with oil renders the highest heat transfer in comparison with Oxide Zirconium. The heat transfer coefficient rises with nano fluid (Ag) and (ZrO_2) for heat exchanger with fins 38.5%, 25.33%, and yet without fins 22.41% and16.26% respectively at volume concentration of 5%. Moreover, the friction factor increased through the use of nano fluids.

Rakhsha et al. [58] conducted an experimental and quantitative study dwelling on the heat transfer and pressure drop of CuO Nano fluid flow in side helical coiled tube with 4-6 turns at stable wall facet temperature in turbulent current regime the volume concentration of nanoparticle of 0.1% with particle dimensions of 68nm, with water as the base fluid. Quantiative results suggest that the heat transfer and pressure drop rose about 6-7% and 9-10% respectively. And experimental results revealed that the heat transfer increased about 16-17% whereas pressure drop rises about14-16%. The overall results indicated that the heat transfer and pressure drop rise as the Reynolds number and curvature ratio increase.

Bunker et al. [59] also examined the heat transfer and friction factor of CuO nanoparticle with water as the working fluid with various volume concentrations (0.01% , 0.15% and 0.02%) flow in plain tube and tube with helical coiled insert with two pitch ratios (p/d=2 and 4). The test was performed with Reynolds number ranging from 4000 to 10000. The results outlined that the heat transfer and friction factor rise with the increase in the volume concentration and decrease the pitch ratio for coiled. In addition, the heat transfer with nano fluid and helical coiled insert is higher than employing one technique and the friction factor rise through the use of nano fluid and helical coiled than plain tube.

1.8 Scope and Objectives

The major aim of this study is to investigate quantitatively the utilization of passive techniques both the CuO nanoparticles and helical inserted with airfoil cross section area under turbulent current regime. The details of the study's objective are as follows:

1- To study the impact of CuO nanoparticle with different volume concentration (0.015% , 0.039% , 1% and 2%) in heat transfer enhancement with water as a base fluid,

2- To study the impact of helical inserted in heat transfer enhancement with three pitch ratios (p/d=3 ,4 and 5),

3- To study the impact of helical inserted and CuO nanoparticle in heat transfer enhancement with water,

4- All the studies were carried out with various Reynolds Number range (4000 , 6000 , 8000 , 10000 , 12000 and 14000) to explore the effects of Reynolds number.

1.9. Thesis organization

This thesis consists of four chapters which are outlined below.

Chapter 1 is of a brief introduction of heat transfer enhancement, classification of enhancement techniques, advantage of enhancement, on two kinds of passive techniques (nanofluid helical coiled wire insert and compound technique) and objective of the present study.

Chapter 2 formulates the problem with necessary governing equation, makes the independence test for two cases (smooth tube and tube with insert).

Chapter 3 presents the results obtained from the simulation in ANSYS program and discusses them in graphical forms.

Chapter 4 includes the conclusions from the quantitative results and recommendation for future studies.

1.10. Summary of Chapter

Most of the researchers who dwelled on the rise in the heat transfer enhancement by employing passive techniques proposed a set of conclusions. Heat transfer enhancement increased when both the Reynolds number and volume concentration increased and also ascended when both nanoparticle sized and pitch ratio of inserts decreased.

CHAPTER 2.

METHODOLOGY

In this study, turbulent flow heat transfer of CuO/ water Nano fluid has been quantitatively investigated by using CFD in a horizontal tube with helical insert inside the test section with cross section area as airfoil (0030) as depicted in Figure 2.1. This quantitative study adopted six values for the Reynolds number varying from 4000 to 14000 with four volume concentrations of nanofluid (0.015%, 0.039%, 1% and 2 %), and the two phase mixture models are employed for the simulation. under the boundary condition stable heat flux (25000 W/m2). The coupling of the pressure and speed was obtained through SIMPLIC algorithm.

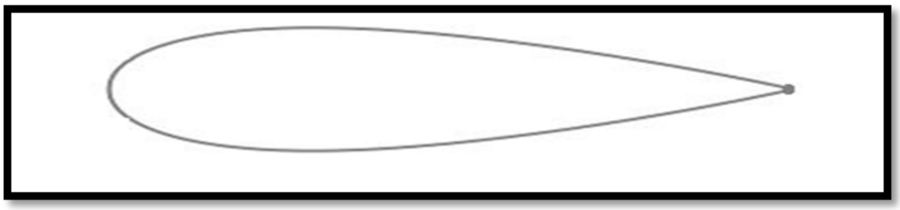

Figure 2.1. cross section airfoil (0030) of helical

2.1. Heat Transfer Fluid Flow

According to Cengel and Ghajar [60], flow in the tube can be laminar or turbulent based on the flow condition. At low speed, the flow is laminar and turns turbulent when speed rises above the critical value. Under most convenient condition, the flow in the tube is laminar at Reynolds value less than 2300 and completely turbulent at Reynolds number above 4000. Turbulent flow is crucial in practice due to its higher heat transfer coefficient as illustrated in Figure (2)

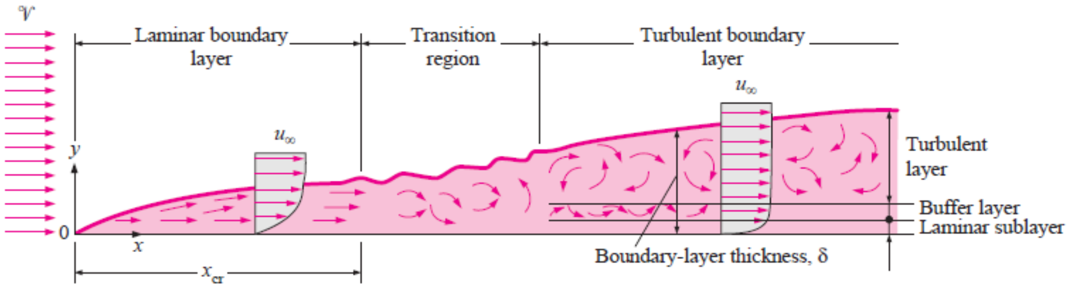

Figure 2.2. Different flow regimes. [60]

2.2. Parameters

1- Mean bulk of CuO/water temperature(T_b)[60]

$$T_b = \frac{(T_i + T_o)}{2} \tag{1}$$

2- Heat transfer coefficient (h): It is identified as the proportion of heat transfer difference between a solid facet and a fluid per unit facet area per unit temperature variance. [60]

$$h = \frac{q}{T_s - T_b} \tag{2}$$

3- Nusselt number (Nu): The Nusselt number refers to the improvement of heat transfer through a fluid layer due to convection relative to conduction across the same fluid layer [60].

$$Nu = \frac{h * d}{k} \tag{3}$$

4- Reynolds number is a dimensionless number consisting the physical properties of the flow. In other words, it's the ratio of inertial forces to viscous forces [60].

$$Re = \frac{\rho . v . d}{\mu} \tag{4}$$

1- *Pressure Drop* is the variation between the pressures at the entrance and the exit of the tube bank. It is a measure of the resistance that the tubes provide to flow over them [60].

$$\Delta P = \frac{f\, v^2 \rho l}{2d} \tag{5}$$

Thermal conductivity (k) is identified as a measure of the ability of material to conduct heat [60].

Prandtl Number is a dimensionless number representing the relative thickness of the speed and thermal boundary layers [60].

$$\Pr = \frac{molecular\ diffusivity\ of\ momentum}{molecular\ diffusivity\ of\ heat} = \frac{v}{\alpha} = \frac{\mu C_p}{K} \quad (6)$$

2- Thermal performance factor is specified as the rate of the enhanced convective heat transfer coefficient h_E to the non-enhanced one h_{NE} at the same pumping power [50].

$$\eta = \left(\frac{h_E}{h_{NE}}\right) \quad (7)$$

2.3. Procedure of Study

1. We draw the geometry (smooth tube) by using solid work program.

2. Then, generate general mesh via ANSYES 14.5.

3. We select the turbulent flow type by comparing the Nusselt number of the result (smooth tube +water base fluid) with dittus-boelter Nusselt number correlation and friction factor with Blasius correlation. We opt for the turbulent flow k-omega standard for all the study.

4. We have run independence test for the first case's smooth tube to produce mesh and analyze the flow with water and nanofluid with various volume concentrations (0.015%, 0.039%, 1% and 2%)

5. We have run independence test for second case's tube with helical insert with variant pitch ratios (P/D=3, 4 and 5) to generate mesh and analyze the flow with water and nanofluid with same volume concentrations.

6. We calculate all the quantitative solutions.

7. We analyze all the results and write the conclusion and suggestion.

Figure (3) outlines the procedure of the study.

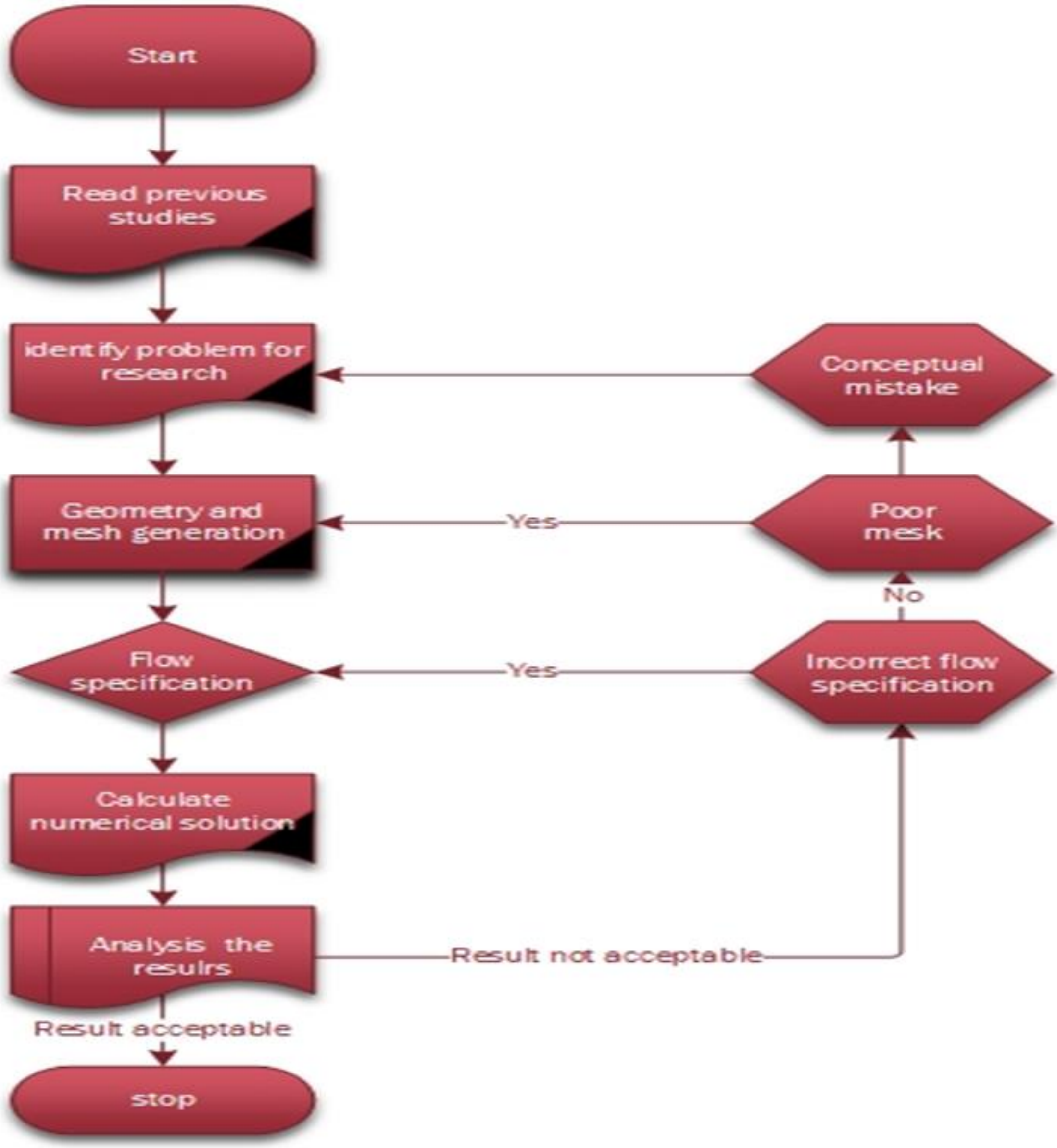

Figure 2.3. Flow chart of the CFD analysis process

2.4. Geometry

The geometry of the flow area was created in Cartesian (X, Y, Z) coordinate, with the pipe axial centerline along the Z axis. The geometry included a straight pipe 40 mm in diameter and 1600 mm in length with three sections: 400mm inlet section (for inflow), 200mm outlet (for outflow) and 1000mm test section wall. This pipe length sufficed to maintain a completely developed flow throughout the whole area under the boundary conditions employed in the study as depicted in Figure 4.

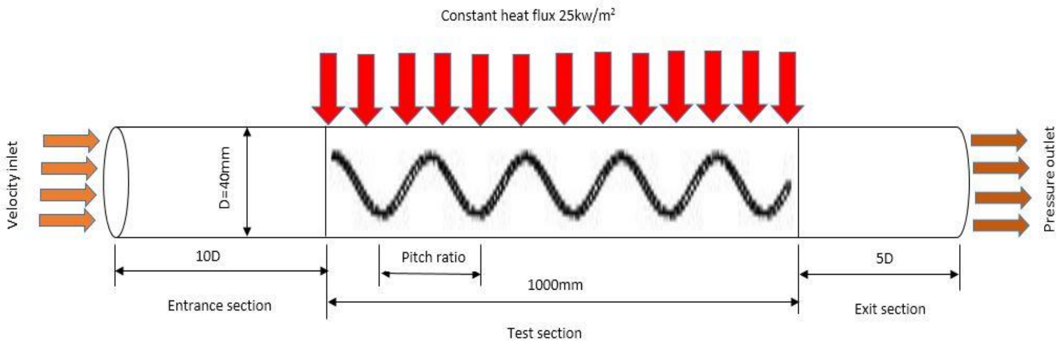

Figure 2.4. Schematic of quantitative study

2.5. Boundary Condition and Assumptions

1-Steady State

2-Newtionion Fluid

3- Incompressible

4-No slip (Speed close to Wall =Zero)

Table 2.1. Boundary condition

Details	Value
Tube diameter	40mm
Enter section length	10D
Test Section	1000mm
Exit section	5D
Heat flux	25kw/m^2
Inlet Temperature	288K
Reynolds number	4000<Re<14000
Speed inlet	Reckoned by Reynolds number
Type of NACA	0030
Pressure outlet	Zero
Volume concentration	0.015%, 0.039%, 1%, 2%
Pitch ratio P/D	3, 4 and 5 as shown in Figure (5)

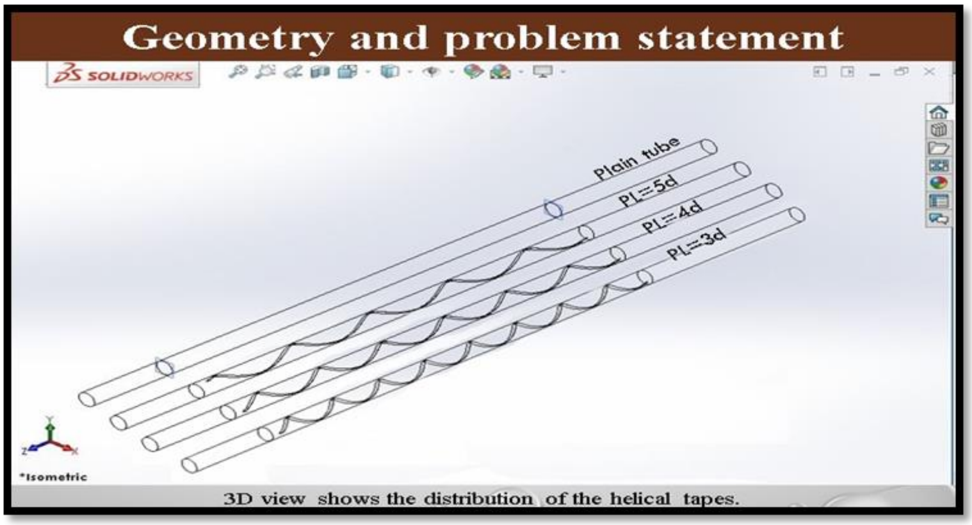

Figure 2.5. Geometry and problem statement

2.6. CFD Definition

As Eesa pointed out [61], Computational Fluid Dynamics (CFD) is the use of computer-based simulation to analyze the systems including fluid flow, heat transfer and related incidents such as chemical reaction. A quantitative model is first formed through a set of mathematical equations that identify the flow. These equations are then sorted out via a computer program so as to receive the flow variables throughout the flow domain. Since the emergence of the digital computer, CFD has attracted huge attention and been commonly employed to investigate different aspects of the fluid dynamics. The development and application of CFD have went through remarkable progress, and thus it has become a influential means in the design and analysis of engineering and other processes which engages in the analysis of heat transfer increase for fluid flowing through pipes employing CFD. Using CFD for modeling the heat and fluid flow is a sound tool for estimating the equipment performance. CFD supplies a convenient tool to examine the detailed flows and heat exchange process, which occurs within the tube, friction factor and Nusselt number. In the early 1980s, computers have become powerful for general-purpose.

2.6.1. Validation of CFD Models

According to Eesa [61], validation of CFD models is often needed to evaluate the precision of the computational model. This assessment can facilitate the development of sound CFD models. Validation is obtained by comparing CFD results with existing experimental, theoretical or analytical data. Validated models become established as reliable, while those which fall short in the validation test require modification and revalidation.

2.6.2. Advantages of CFD [61]

Eesa outlines the advantages of CFD as follows:

1. Ability to run the systems where the controlled experiments are not applicable.

2. While the range of data that experiments can supply might sometimes be restricted because of the equipment or technique constraints, CFD can supply a variety of extensive data as no similar limitations generally exist.

3. The complex physical interactions that take place in a flow case can be modelled simultaneously as no restricting suppositions are generally required.

4. CFD can offer extensive flow visualization. Indeed, in many industrial practices CFD is more prevalently employed as a flow visualization means than a source of certain computational data.

2.6.3. Valdition of turbulance models [62]

The turbulent can be categorized into several types. These types can not be implemented haphazardly to all cases of disturbance. Yet, several determinants must be regarded to determine the appropriate type for our problem that we intend to solve. These determinants include physical of the flow, the established practice for a certain set of problems, the level of precision needed, the existing computational resources and the available time for simulation.

These types can be classified into 2 main categories as presented in Figure 8:

1- K-ω Model

i- Standard K-ω Model

ii- Shear Stress Transport (SST) K-ω Model

2- K-Ɛ Model

i- Standard K-Ɛ Model

ii- Renormalization-group (RNG) K-Ɛ Model

iii- Realizable K-Ɛ Model

In present study, we opt for Standard K-ω Model as it provided us the nearest result from Dittus-Boelter correlation for Nusselt number and Blasius correlation for friction factor as illustrated in Figure 6 and 7.

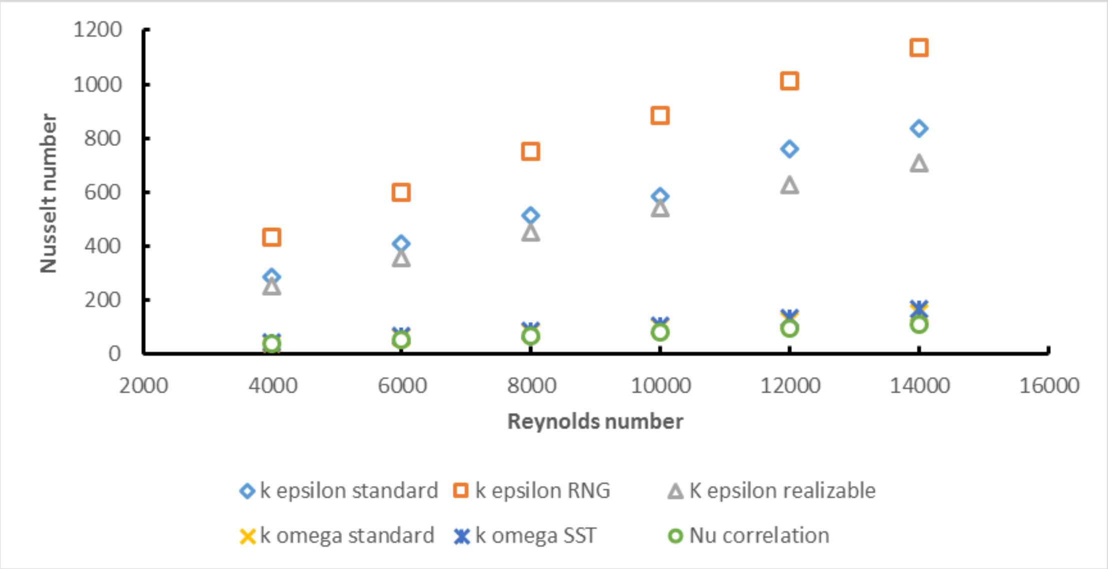

Figure 2.6. Compression of turbulence model with the impact of Reynolds and Nusselt number

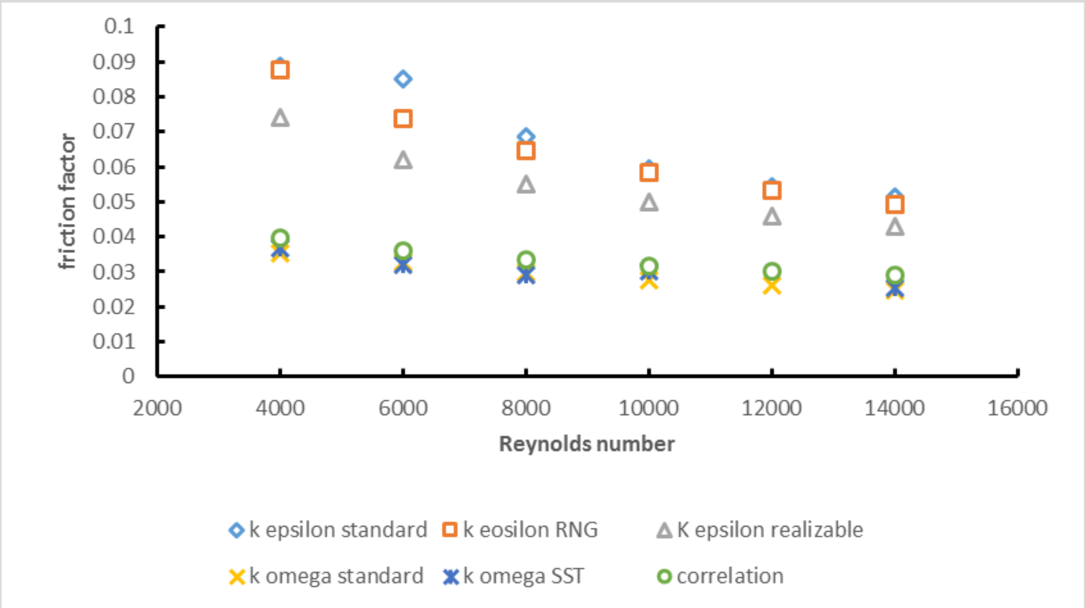

Figure 2.7. Compression of turbulence model with the impact of Reynolds and friction factor

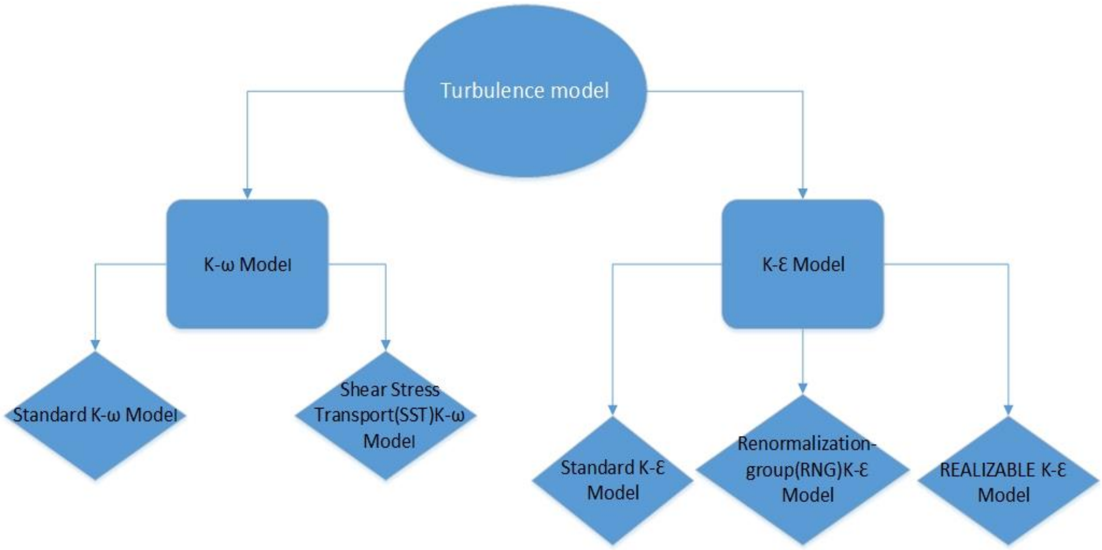

Figure 2.8. Types of turbulance models

2.6.4. Nanofluid simulation techniques[6]:

Quantitative simulation of nanofluid is one of the significant tools to estimate the fluid dynamic and thermal nanofluid behavior and this ability of quantitative simulation enables us to think in different design options and avoid high cost in experimental means. Also, according to the investigations conducted, nano fluids' features are influenced by a number of components such as gravity, Brownian motion, Brownian diffusion, friction force between the fluid and nanoparticles, sedimentation, dispersion, layering at the solid-liquid interface, ballistic phonon transport and thermophoresis. In various quantitative studies, some of these components are considered and some others have been neglected. This can be a case of the variances in the results of various quantitative solutions [70]. There are three different models to identify the governing equation in order to simulate Nanofluid convective as follows:

1. Single phase model

2. Discrete-Phase Model

3. Mixture model

2.6.4.1. Single Phase Model

Kakaç, S., Pramuanjaroenkij [63], Ghatage et al. [64] defines this model as the combination of nanoparticle and base fluid with mixed features between the nanoparticle and base fluid. In addition, all motion and energy equations for pure fluid can be directly employed to nanofluid. One of the main concerns in this simulation is the evaluation of nanofluid thermophysical features; especially, viscosity and thermal conductivity.

2.6.4.2. Discrete-Phase Model

The twofold approach seems as a sound model to identify the nanofluid flow.Indeed, the slip speed between the fluid and particles might not be zero as a result of some components such as gravity, friction between the fluid and solid particles, Brownian forces, Brownian diffusion, sedimentation and dispersion. The twofold approach supplies a field specification of the dynamics of each phase or, alternatively, the Lagrangian trajectories of individual particles m with the Eulerian specification of the fluid flow area.

2.6.4.3. Mixture model

In this model, the nanoparticle features and the behavior are regarded independent from the base fluid features and behavior. And nanoparticles and base fluid are regarded as two different phases with variant momentum.

2.7. Governing Equation

The analysis of heat transfer in this study is implemented through continuity, momentum and energy proposed by Kakaç, S., Pramuanjaroenkij [63].

Continuity equation:

$$\nabla . (\rho_m \, \overrightarrow{v_m}) = 0 \tag{8}$$

Momentum equation

$$\nabla . (\rho_m \vec{v}_m \vec{v}_m) = -\nabla P + \nabla . [\mu_m (\nabla \vec{v}_m + \nabla \vec{v}_m^T)] + \nabla . \left(\sum_{k=1}^{n} \emptyset_k \rho_k \vec{v}_{dr,k} \vec{v}_{dr,k} \right) \tag{9}$$

Energy equation

$$\nabla . \sum_{k=1}^{n} (\emptyset k \, \vec{v}_k (\rho_k \, h_k + p)) = \nabla . (k_{eff} \nabla T) \tag{10}$$

2.8. Mesh

According to Patel [65], when sorting out the fluid flow problems quantitative, the facets, boundaries and spaces around and between the boundaries of the numerical area have to be designed usable by computer including tetrahedral, hexahedral, prismatic, or pyramidal cells. This can be realized by some arrangements of regularly and irregularly spaced nodes around the computational area known as the “Mesh”.

2.9. Grid Independence Test

Rashidi et al. [66]state that the quantitative method is an approximation method that includes an error ratio compared to the experimental methods in order to lower the error rate and make the results more logical. The independent check is implemented through several types of mesh and observing the values of the similar elements in which the value of the Nusselt is equal or close. Following this, the corresponding mesh of the values of equal or convergent Nusselt are chosen as illustrated in Figure (9), Figure (13) and Figure (14).

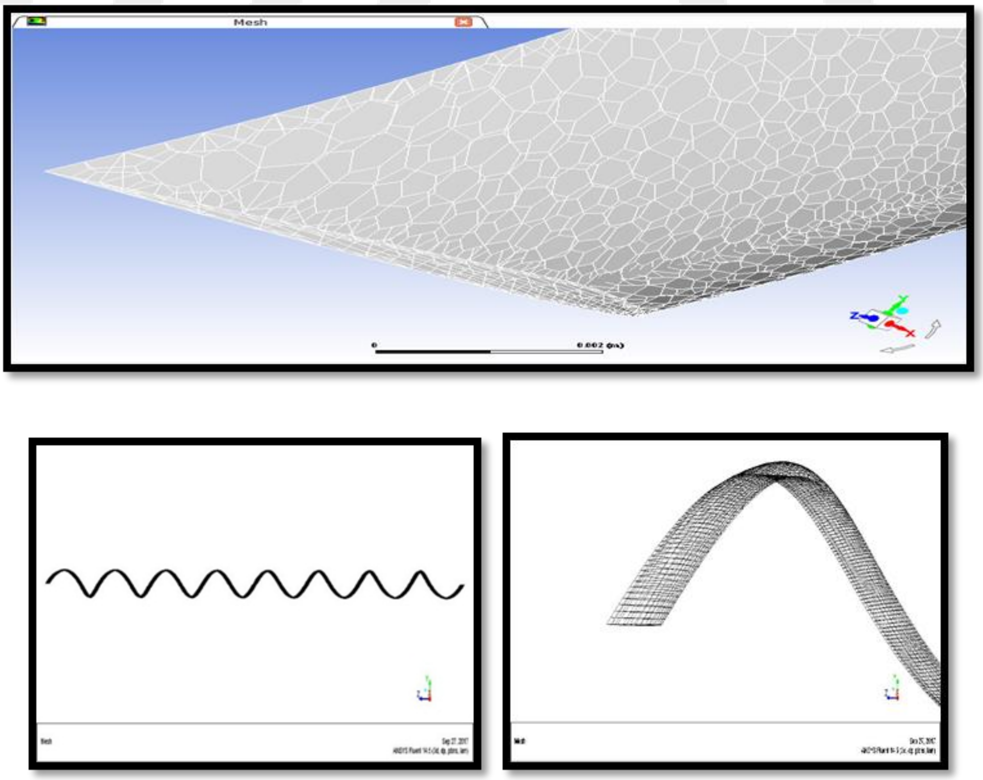

Figure 2.9. Schematic of helical in ANSYS with airfoil

2.9.1. Independence Test for Smooth tube

The independence test for the first case with smooth pipe depicted in Figure 10 indicate that the value of Nusselt number is almost the same in elements 3, 4 and 5 and we opt for mesh no 4.

Table 2.2. Mesh sensitivity results

	No of Element	Nu	f
1	303398	525.9	0.030124
2	430730	184.25	0.026985
3	1755349	121.99	0.026728
4	1988576	121.97	0.026647
5	2186119	121.35	0.026632

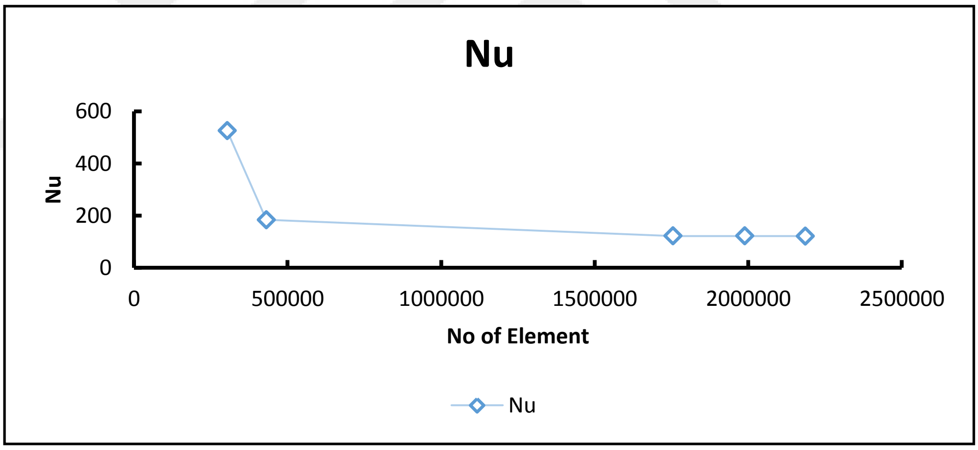

Figure 2.10. Grid Independence Study for The Simulation Of Smooth tube

2.9.2. Independence Test for Tube with helical insert

The independence test of second case with smooth tube with helical visualized in Figure 11 and Figure 12 reveal that the value of Nusselt number is almost the same in elements 2, 3and 4 and we opt for mesh no 2.

Table 2.3. Mesh sensitivity results

No of Element	Nu	f
2900390	68.97	0.057213
3549661	54.9	0.05326
3557123	54.98	0.053078
3573517	55	0.053078

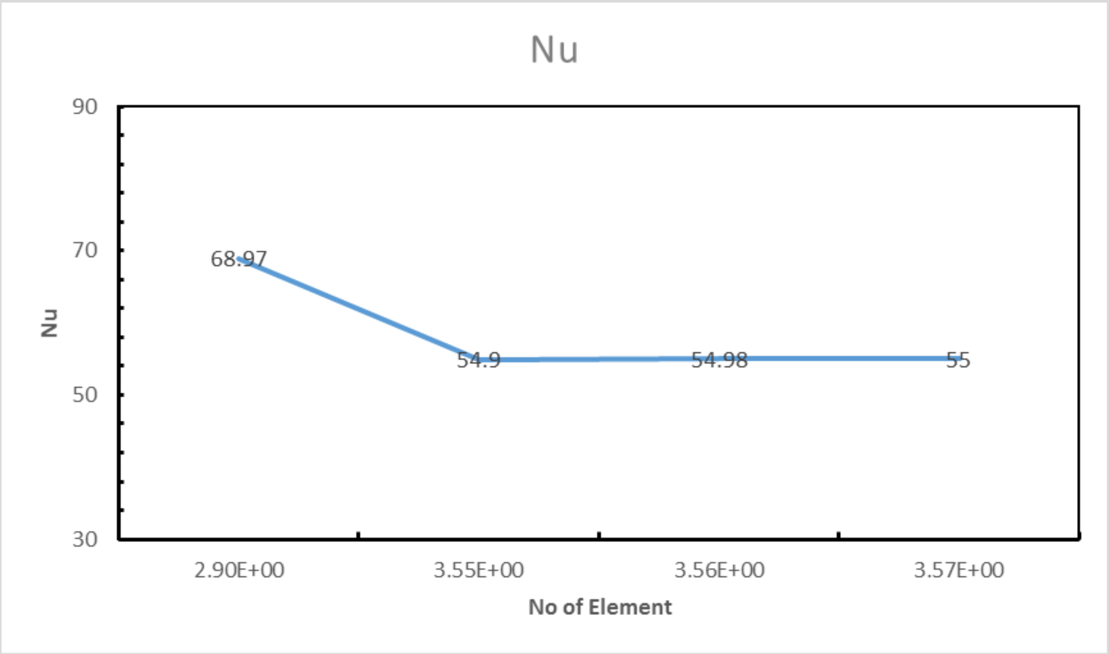

Figure 2.11. Grid Independence Study for the Simulation of Tube Helical Wwith Nusselt Number

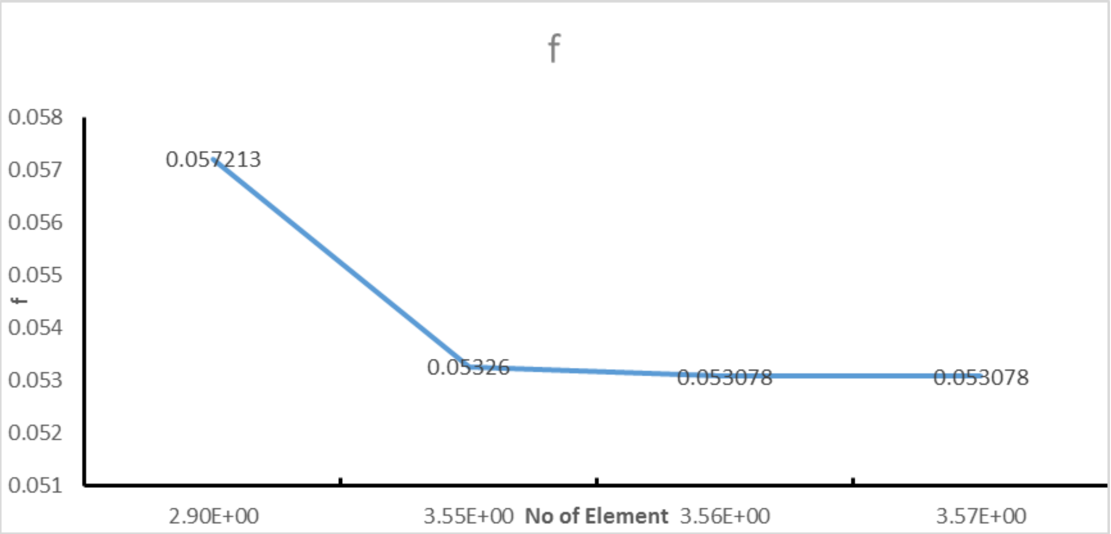

Figure 2.12. Grid Independence Study for the Simulation of Tube Helical with Friction Factor

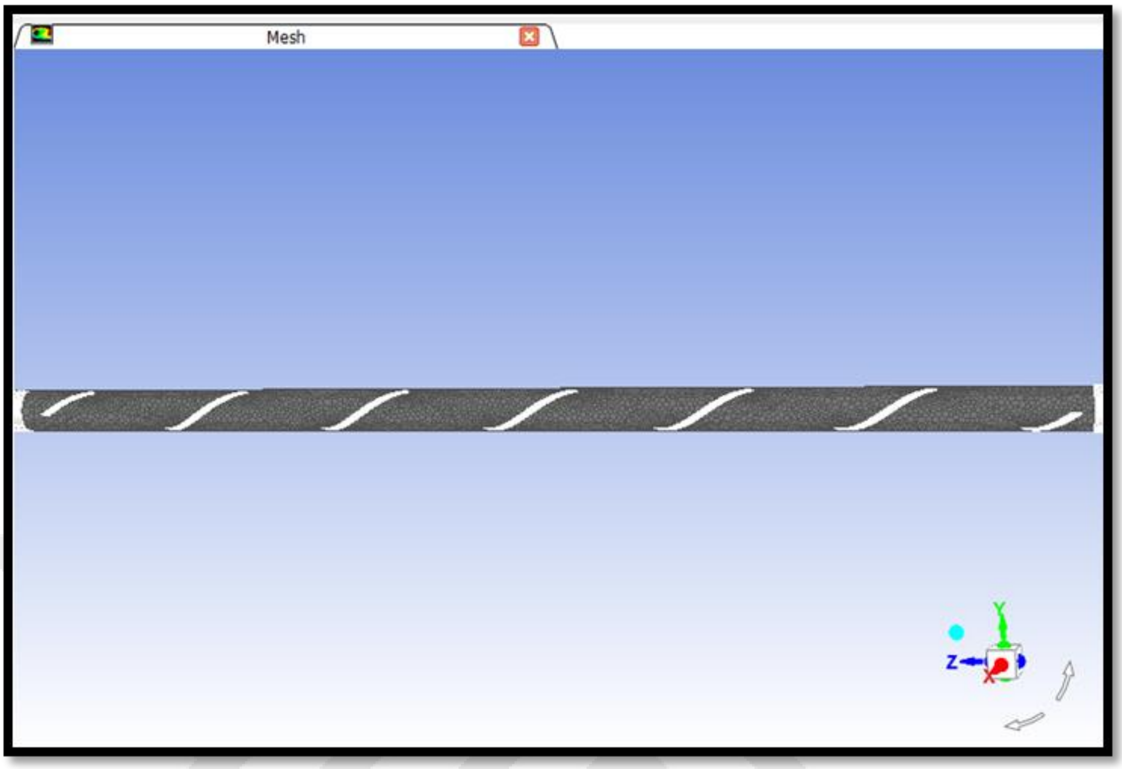

Figure 2.13. Tube with helical mesh

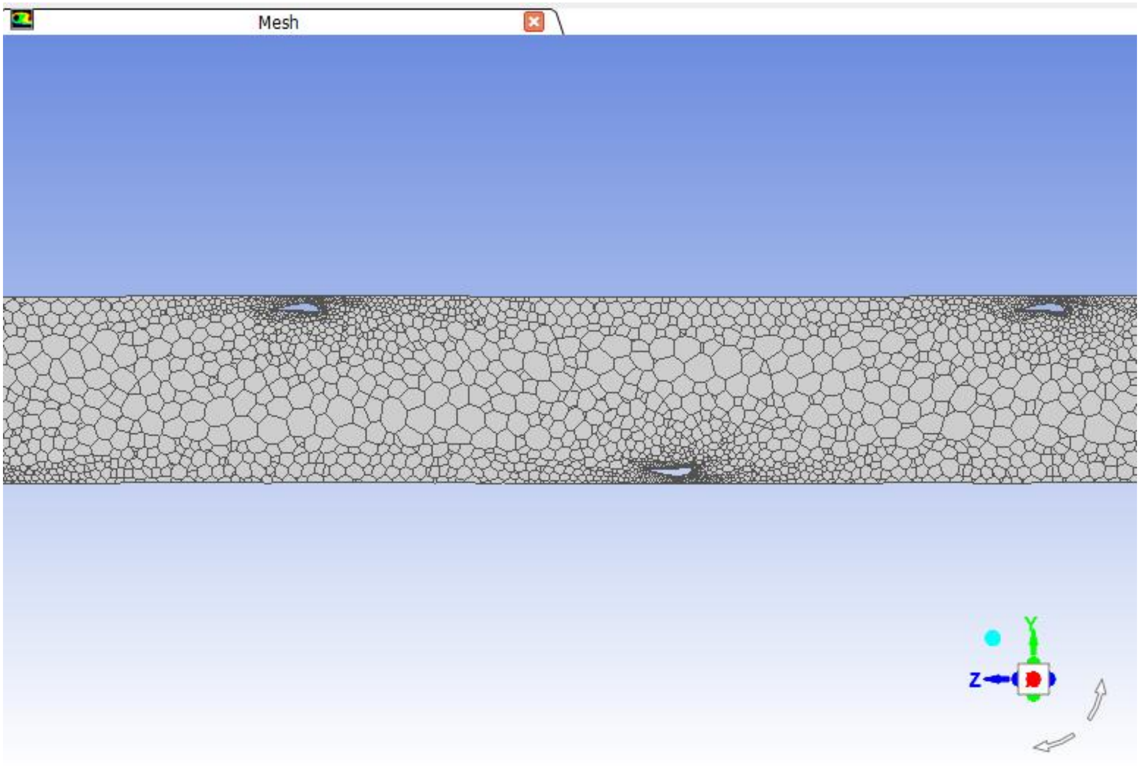

Figure 2.14. A longitudinal section of the tube and helical mesh

2.10. Thermophysical Properties Of Nanofluid

Sharma et al. [67] argue that nano fluids are particle suspension of metals, metal oxides , carbides ,nitrides, carbon nanotubes ,etc., dispersed in a continuous environment such as water, ethylene glycol, refrigerants and engine oil of size smaller than 100 nm. The thermo physical features of nanofluid are observed to be larger than those of the base fluid. When mixing nanoparticle with base fluid (water), the mixture is homogeneous and can be treated as a single substance, not a mixture suggested by Demir et al. [68]. Yet, with different physical properties, these features rely on the volume concentration of nanoparticles in addition to the size and shape of the particles as summarized in Table 3.

The equations to obtain the physical features of nanofuild are presented below: [69]

1- Density (ρ): It is identified as material's mass per unit volume and it have a crucial role in the heat transfer, particularly in natural convection. In this study, Pak and Cho equation was applied.

$$\rho_{nf} = \emptyset * \rho_s + (1 - \emptyset) * \rho_w \qquad (11)$$

2- Specific heat capacity (C_p): It is the measurement of the heat energy needed to raise the temperature of a unit amount of a substance by a specific temperature interval. It's for metal less than liquid. Therefore, the specific heat for Nanofluid is less than pure fluid. In this study, Pak and Cho equation was applied.

$$C_{pnf} = \frac{\phi * (\rho_s * c_{ps}) + (1-\phi) * (\rho_w * c_{pw})}{\rho_{nf}} \qquad (12)$$

3- Thermal conductivity (k): It is a crucial property in the heat transfer as it has ability to conduct the heat. In addition, the thermal conductivity of metals is quite higher than liquid. In this study, Yu and Choi equation was applied.

$$K_{nf} = \left[\frac{k_s + 2k_w + 2 * (k_s - k_w) * (1+\beta)^3 * \phi}{k_s + 2k_w - (k_s - k_w) * (1+\beta)^3 * \phi}\right] * k_w \quad \beta = 0.1 \qquad (13)$$

4- Viscosity (μ): It's the major property that refers to the resistance of fluid against deformation via either extensional stress or shear stress. It is the resistance of liquid to flow. In this study, Einstein equation was applied.

$$\mu_{nf} = \mu_w * (1 + 2.5 * \phi) \qquad (14)$$

Table 2.4. Thermo physical properties of CuO nanoparticles and water at T=15C [83]

	ρ (kg/m3)	K(W/m k)	Cp (J/Kg k)
CuO	6350	69	535.6
Water	999.1	0.589	4185

Table 2.5. Thermo physical properties of Cuo/water nanofluid

ϕ	$\rho\ kg/m^3$	*k w/m.k*	*Cp J/kg .k*	μ *kg/m.s*
0.00015	999.902635	4181.523608	0.589343966	0.001138427
0.00039	1001.186851	4175.972975	0.58989459	0.00113911
0.01	1052.609	3964.845223	0.612227975	0.00116645
0.02	1106.118	3765.990636	0.636074768	0.0011949

CHAPTER 3

RESULT AND DISCUSSIONS

In this chapter, we present all the results that was obtained from CFD program when using nanofluid with different volume concentrations (0.015%, 0.039%, 1%and 2%) and three pitch ratios of helical inserted (p=3d, 4d and 5d) with cross section area airfoil naca 0030. The results are compared with smooth tube/water as a reference result. All the analysis was conducted with Reynolds number between 4000<Re<14000 with regular heat flux 25kw/m^2

3.1. Smooth Tube (water)

3.1.1. Heat Transfer

The quantitative results obtained in the case of using smooth tube with water flow only indicated agreement in the equation of the Nusselt with the Dittus-boelter equation(15) [59] where the error rate varied from $\pm$6-9 as illustrated in Figure (1)

$$Nu = 0{,}023 Re^{0{,}8} Pr^{0{,}4} \tag{15}$$

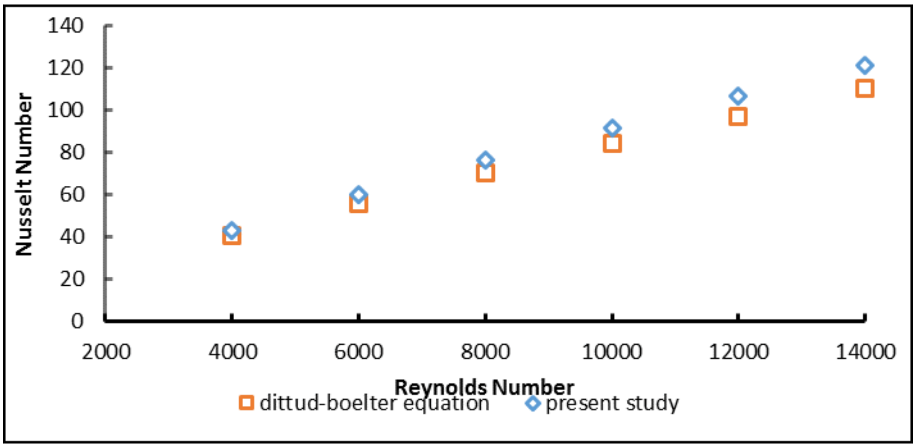

Figure 3.1. The quantitative Nusselt number and the prediction *Dittus-boelter* correlation for water versus Reynolds number

3.1.2 Friction Factor

The quantitative results obtained in the case of using smooth tube with water current only indicated agreement with the equation of friction factor with the *Blasius* equation (16) [59] where the error rate varied between $\pm$1-9 as illustrated in Figure 2.

$$f = 0.316 * Re^{-0.25} \quad (16)$$

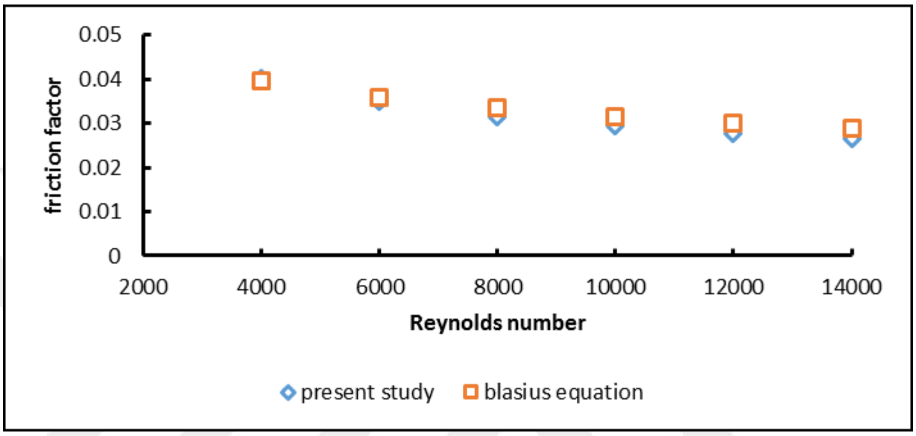

Figure 3.2. The quantitative friction factor and the prediction *Blasius* correlation for water versus Reynolds number

3.2. Smooth Tube (Nanofluid)

3.2.1. Heat Transfer

The Nusselt Number obtained quantitatively was compared with three Nusselt correlations that were obtained experimentally (Velagapudi Equation (17) [71], Xuan And Li Equation (18) [72] and Vajjha (19) [21]). Figure) outlines that in case of using smooth tube with CuO nanoparticles/water, there was a match in the *Nesselt* equation with the *Velagapudi* equation (17) with an error rate ranging from$\pm 7 - \pm 10$

$$Nu = 0.027 * Re^{0.8} * Pr^{0.4} \quad (17)$$

$$Nu = 0.0059(1 + 7.686\emptyset^{0.6886} Pe^{0.001})Re^{0.9238} Pr^{0.4} \quad (18)$$

$$Nu = 0.065(Re^{0.65} - 60.22)(1 + 0.0169\emptyset^{0.15})Pr^{0.542} \quad (19)$$

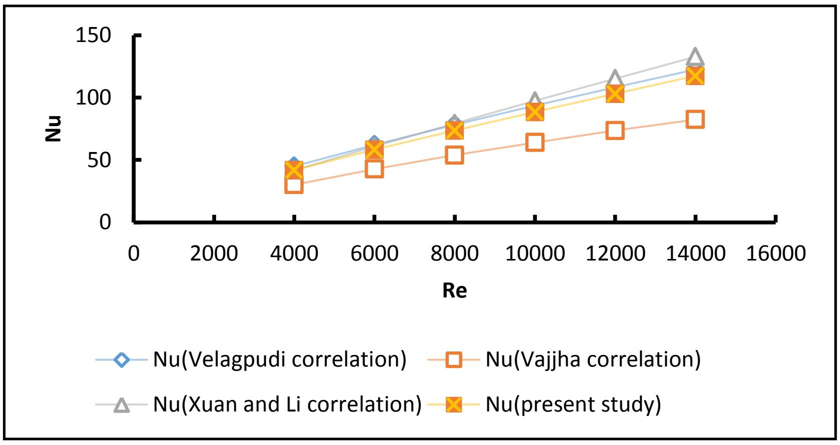

Figure 3.3. The quantitative Nusselt number and the prediction correlation for CuO nano fluid with base fluid water

3.2.2. Friction Factor

As Figure 4 outlines, the friction factor obtained quantitatively via using CuO nanofluid with different volume concentrations in smooth tube provide almost the same value of friction factor in water.

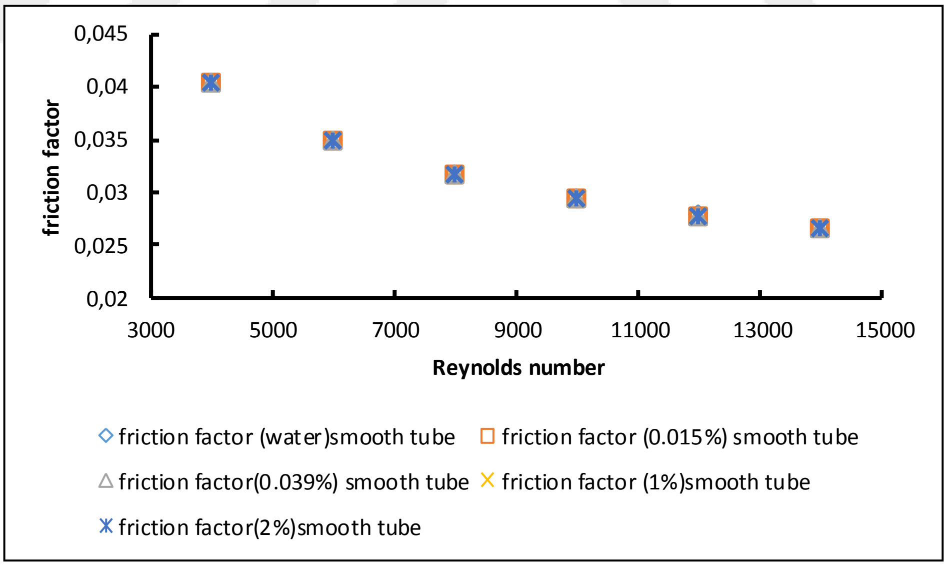

Figure 3.4. Friction factor of water and different volume concentrations of CuO/water nanofluid in smooth tube

3.2.3. Performance Enhancement Coefficient

The performance enhancement coefficient of the tube with nanofluid was calculated by using Equation 7. The results suggest that using nanofluid with different volume concentrations raised the heat transfer coefficient and this resulted in a rise in the performance enhancement coefficient. Figure 5 points out that the performance enhancement coefficient rose with the increase in the volumedensity. This increment was stemmed from the change in the base fluid features, especially by raising the thermal conductivity.

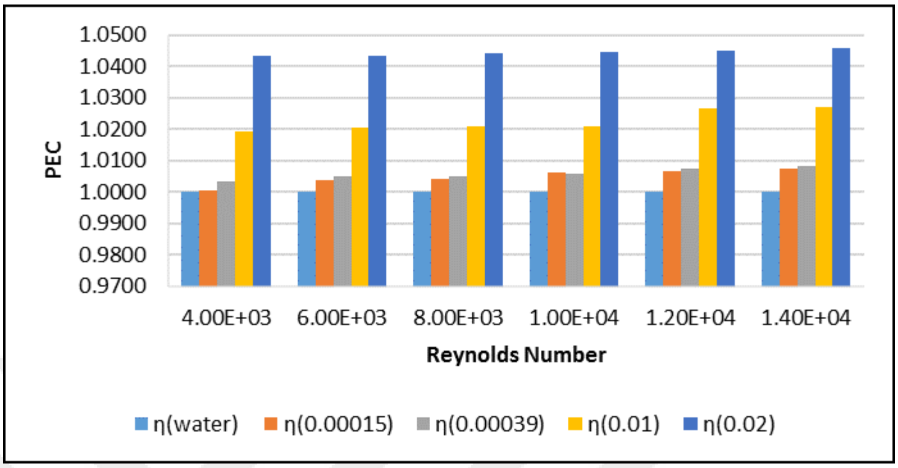

Figure 3.5. The performance enhancement coefficient for nanofluid in smooth tube

3.3. Tube with Helical Inserted (Water)

3.3.1. Heat Transfer

Figure 6 depicts the impact of using the helical when utilized with the tube, which points out the rise in the coefficient of heat transfer by raising the value of the Reynolds number and also the reduction of the value of pitch ratio compared with the results of heat transfer in the tube smooth. This increment was stemmed from the turbulence density and flow.

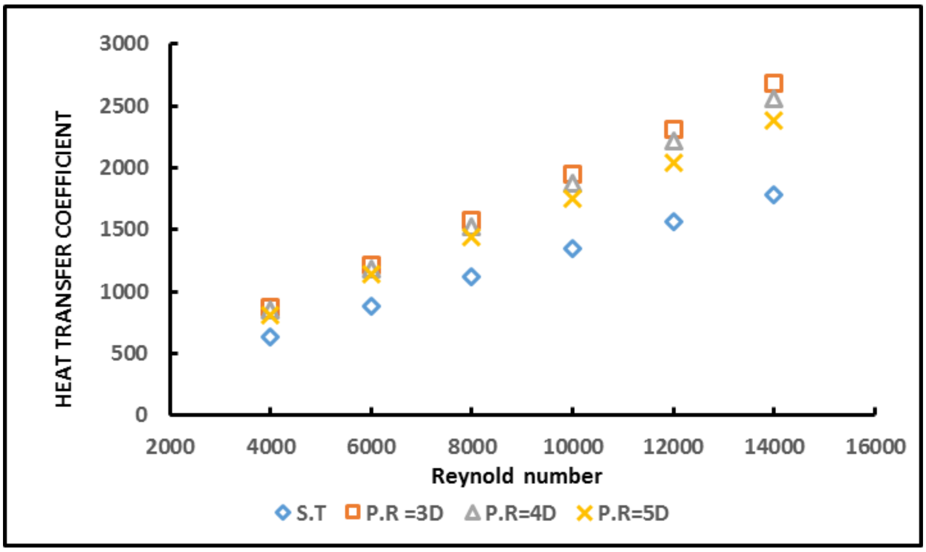

Figure 3.6. The heat transfer coefficient of water in different pitch ratio

3.3.2 Friction Factor

Pitch ratio refers to the number of helical coil. When this ratio lowers, this means that the helical coiled number rises and it's the major motive for the pressure drop. Figure 7 illustrates the relation between the Reynolds number and the friction factor for smooth tube and tube with helical. The figure also indicates a drop in the friction factor with the rise in the value of the Reynolds number and it rises by decreasing the pitch ratio of the helical.

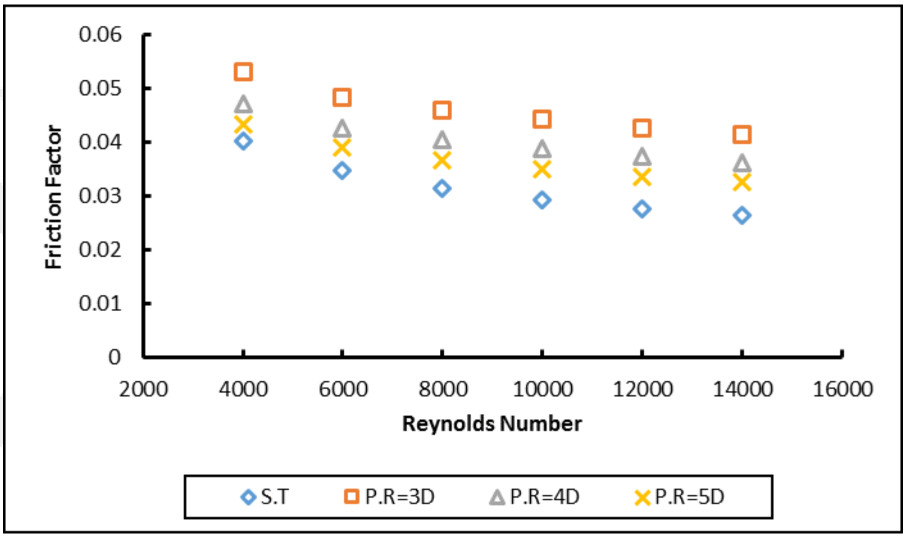

Figure 3.7. The friction factor of water in different pitch ratio

3.3.3 Performance Enhancement Coefficient

The results suggested that using helical with different pitch ratios raised the heat transfer coefficient and that led to a rise in the performance enhancement coefficient. The performance enhancement coefficient versus Reynolds number is outlined clearly in Figure 8, which points out that the performance enhancement coefficient rose with the decrease in the pitch ratio.

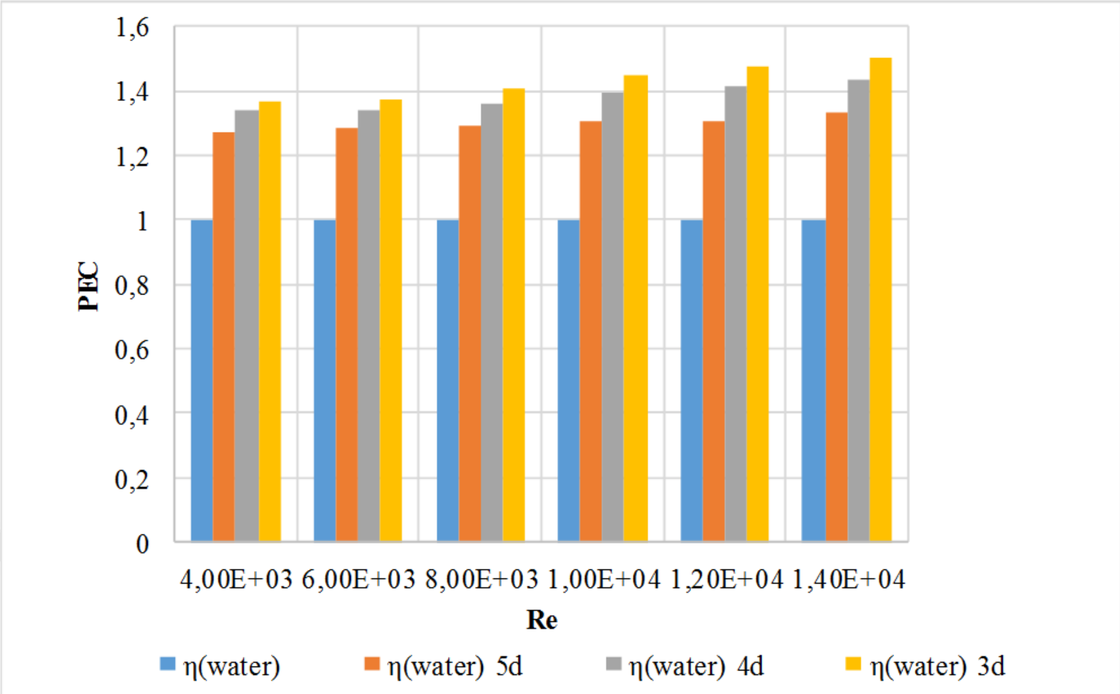

Figure 3.8. The performance enhancement coefficient for water in smooth tube and helical inserted

3.4. Tube With Helical Inserted (Nanofluid)

3.4.1. Heat Transfer

As a result of using nanoparticles with base fluid, the thermal features of the base fluid shifted. The thermal conductivity for nanofluid rose. These increments resulted in a rise in the heat transfer coefficient. Hence, using the helical inserted with different pitch ratio (p/d=3, 4 and 5) caused a rise in the coefficient of heat transfer as well. Also, this increment rose by the decrease in the pitch ratio. Reynolds Number was another coefficient which caused a rise in the heat transfer coefficient value by raising the Reynolds number at the same volume concentrationas illustrated in Figures 9, 10, 11 and 12 below.

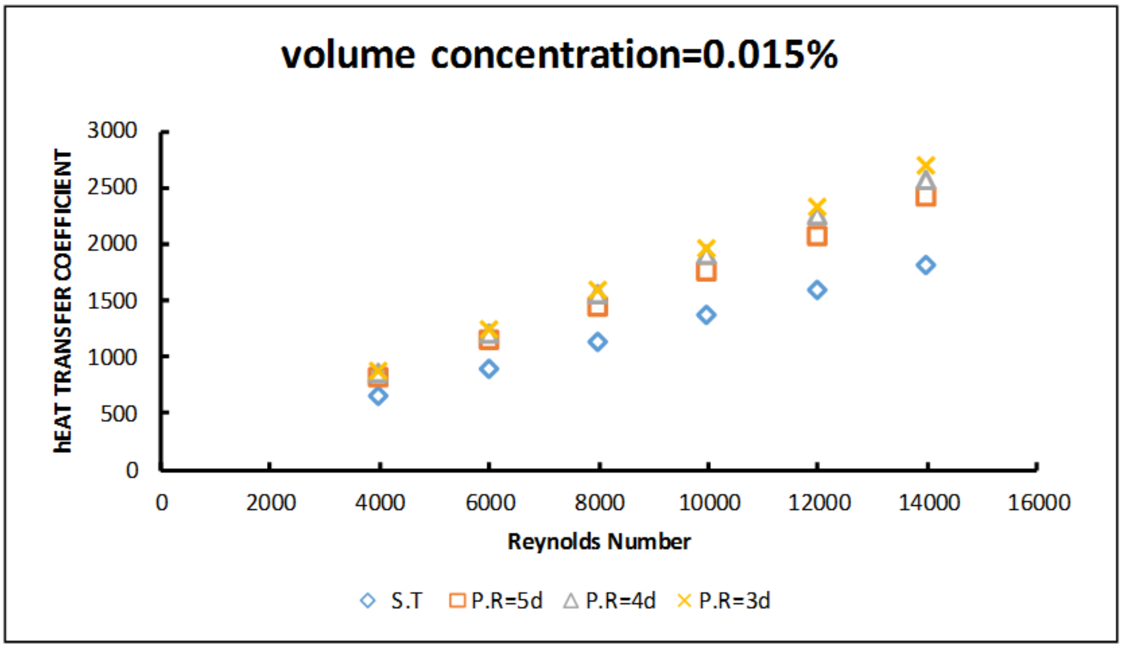

Figure 3.9. The relation between Reynolds number and heat transfer coefficient for nanofluid with volume concentration of 0.015% in smooth tube and helical inserted with different pitch ratios

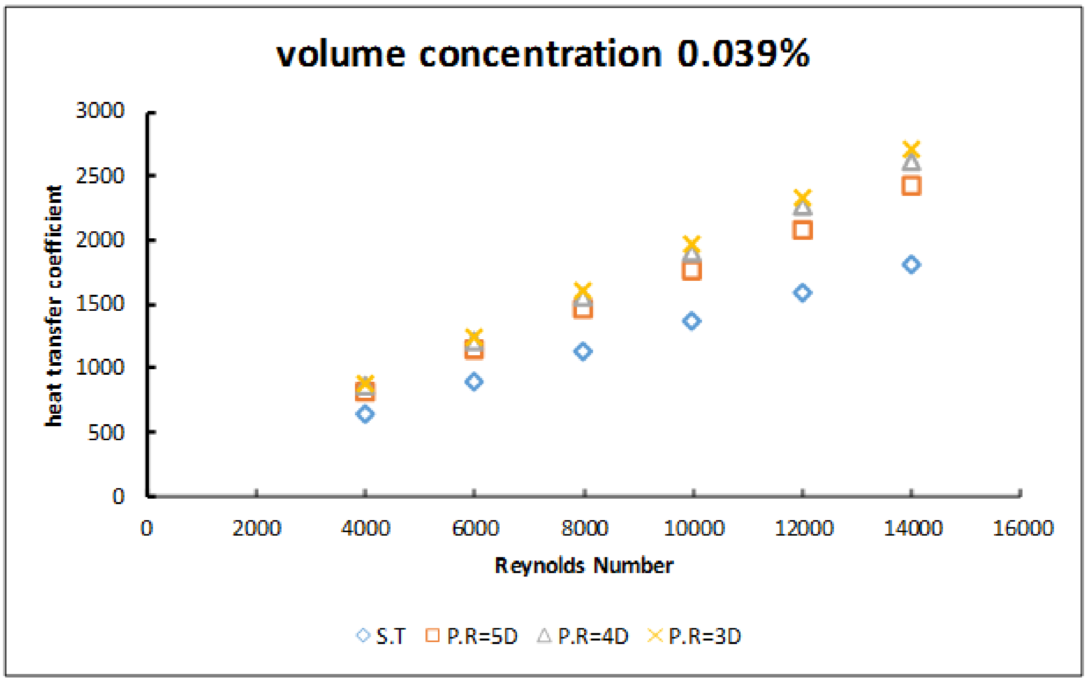

Figure 3.10. The relation between Reynolds number and heat transfer coefficient for nanofluid with volume concentration of 0.039% in smooth tune and helical inserted with different pitch ratios

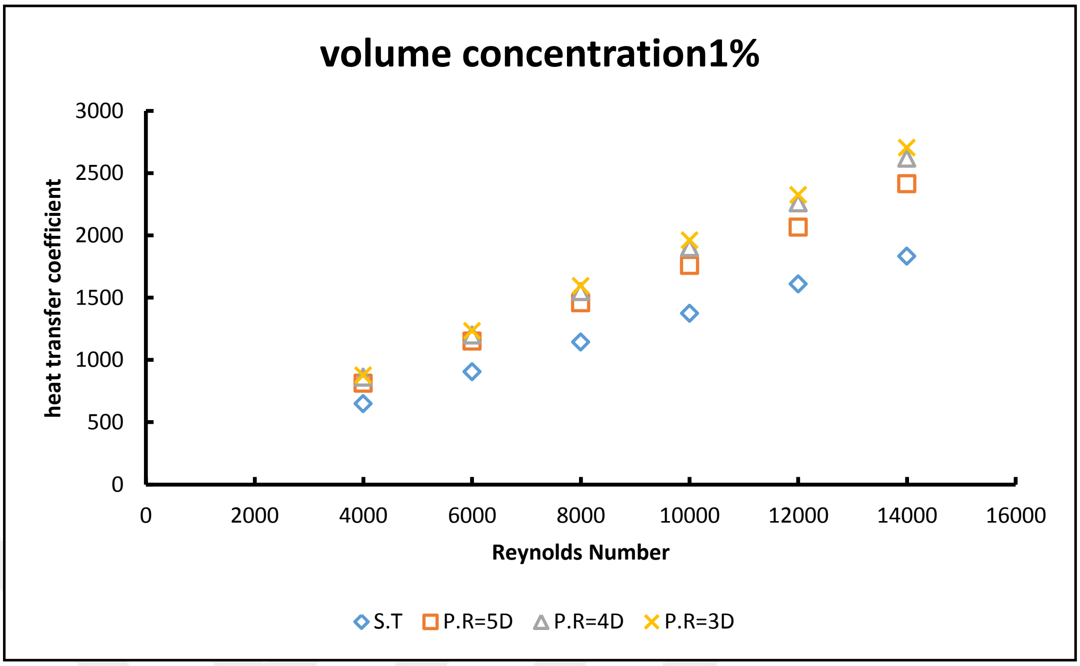

Figure 3.11. The relation between Reynolds number and heat transfer coefficient for nanofluid with volume concentration of 1% in smooth tune and helical inserted with different pitch ratios

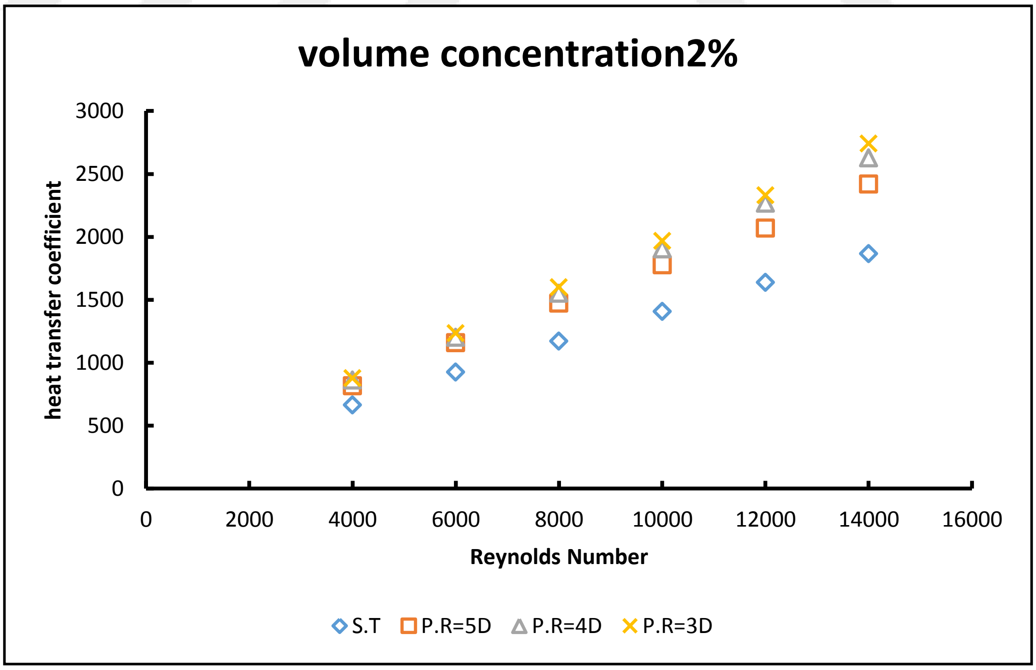

Figure 3.12. The relation between Reynolds number and heat transfer coefficient for Nano fluid with volume concentration of 2% in smooth tune and helical inserted with different pitch ratios

3.4.2. Friction factor

Nano fluid had no impact on the friction factor, but the helical inserted raised the friction factor. Also, the value of friction factor rose when the pitch ratio diminished. The Reynolds Number had considerable impact on the friction factor. Figures 13, 14 and 15 illustrated the relation between the Reynolds number and the friction factor for different volumedensities. The figures indicated a drop in the friction factor with the rise in the values of the Reynolds number.

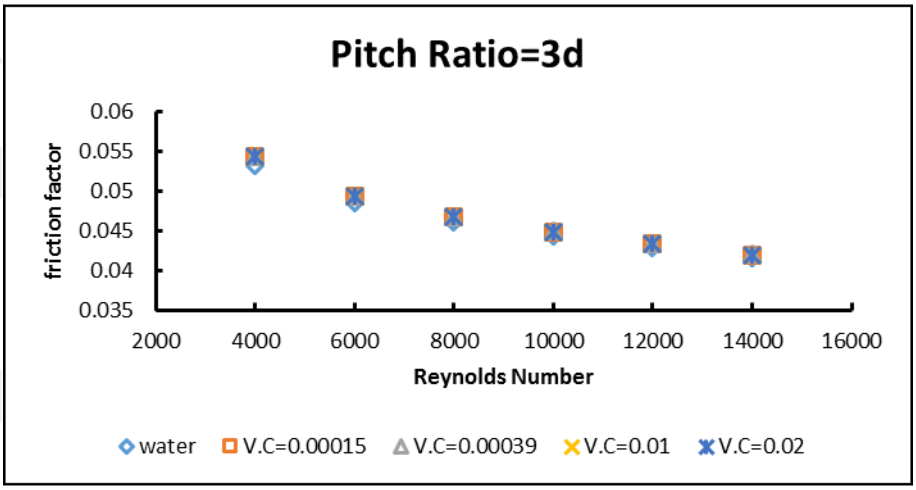

Figure 3.13. The friction factor of water and different volume concentration of CuO/water nanofluid in pitch ratio =3d

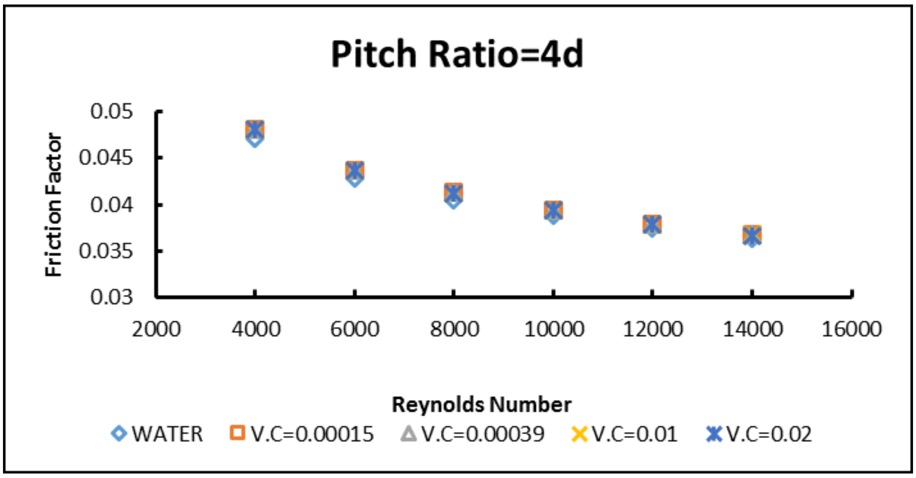

Figure 3.14. The friction factor of water and different volume concentration of CuO/water nanofluid in pitch ratio =4d

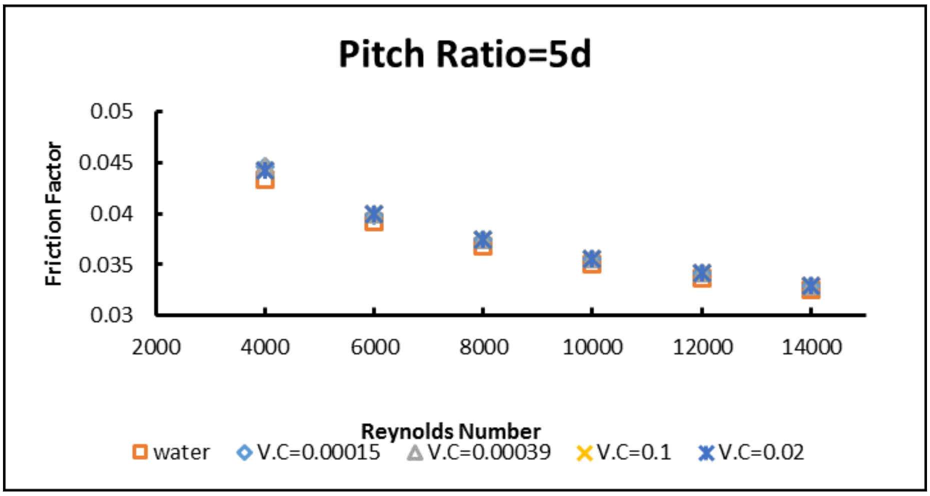

Figure 3.15. The friction factor of water and different volume concentration of CuO/water nanofluid in pitch ratio =5d

3.4.3 Performance Enhancement Coefficient

In this study, the impact of Reynolds number, nanofluid and the helical inserted in heat transfer enhancement was investigated, The figures 16, 17, 18 and 19 clearly indicated us the impact of employing two passive techniques, helical inserted (with different pitch ratios) and nanofluid (with different volume concentrations) on the performance enhancement coefficient. When the Reynolds number rose, the volume concentration also increased and decreased the pitch ratio, all of which resulted in a rise in the performance enhancement coefficient.

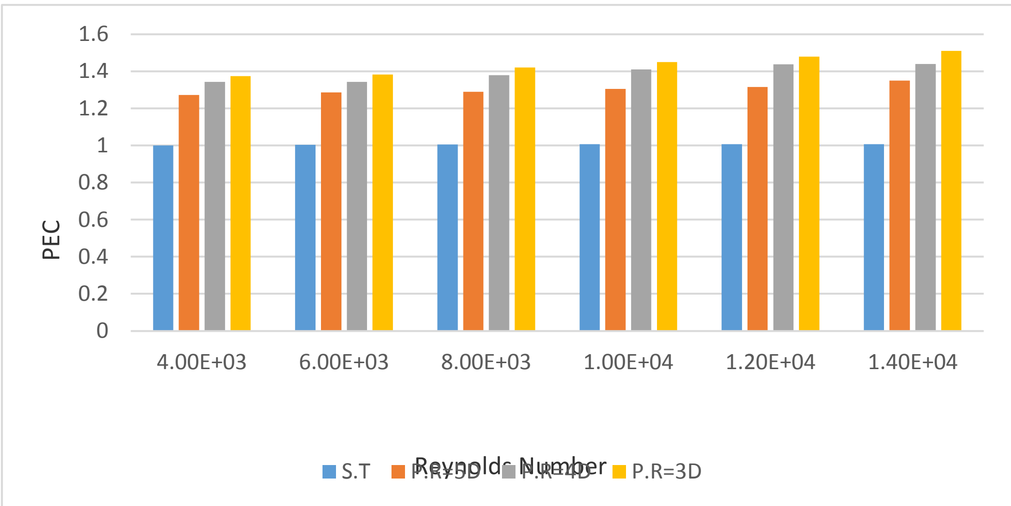

Figure 3.16. Performance enhancement coefficient for nanofluid with volume concentration of 0.015% in smooth tube and helical inserted

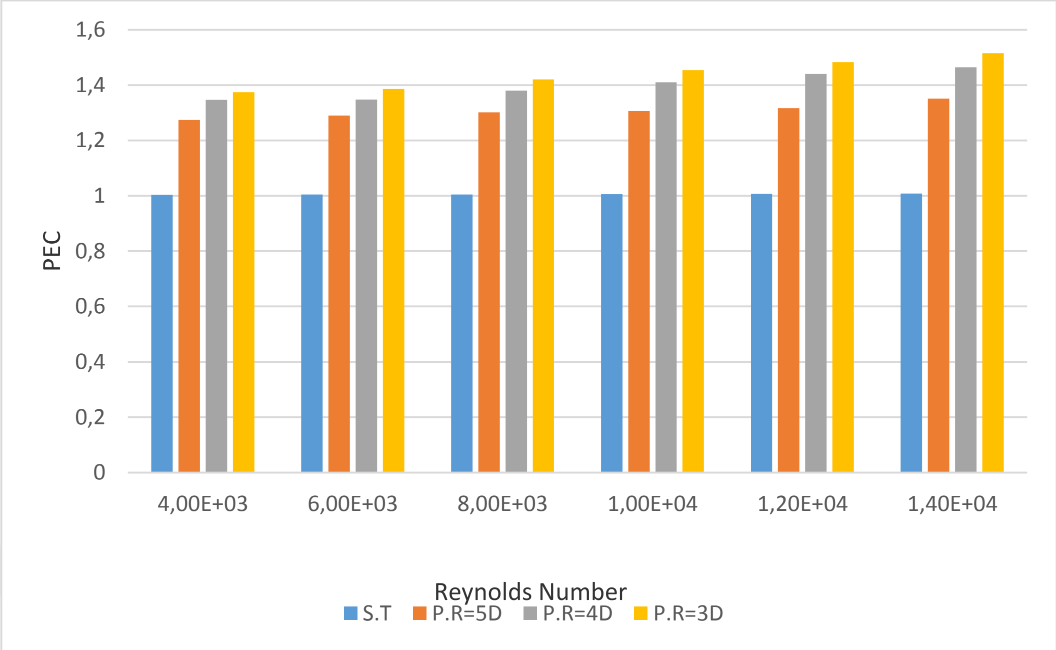

Figure 3.17. Performance enhancement coefficient for nanofluid with volume concentration of 0.039% in smooth tube and helical inserted

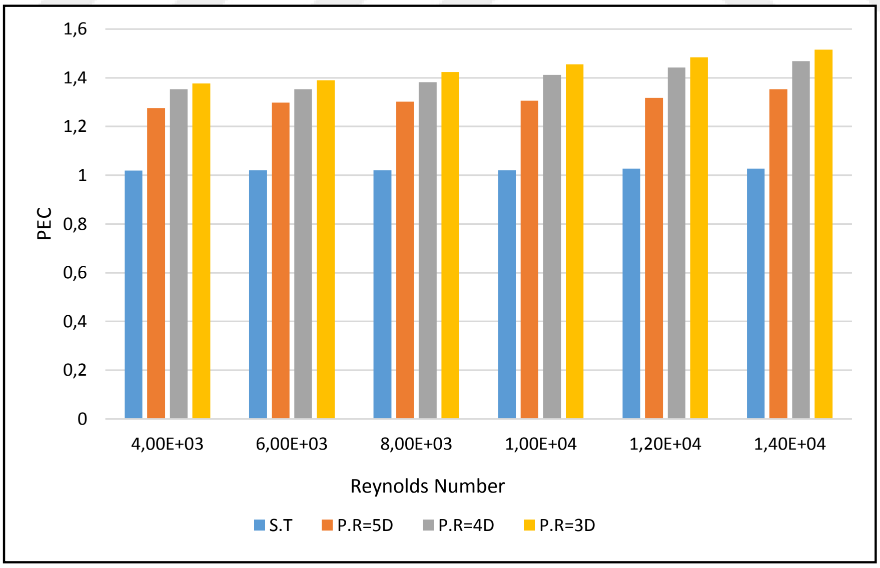

Figure 3.18. Performance enhancement coefficient for nanofluid with volume concentration of 1% in smooth tube and helical inserted

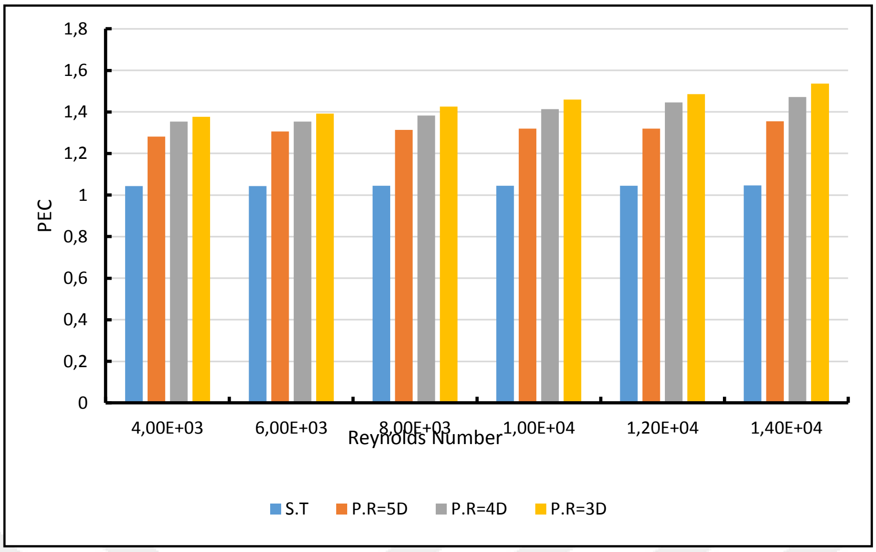

Figure 3.19. Performance enhancement coefficient for nanofluid with volume concentration of 2% in smooth tube and helical inserted

CHAPTER 4

CONCLUSION AND RECOMMENDATION

4.1. Conclusion

Quantitative simulation has been conducted for a horizontal circular tube under turbulent flow regimes exposed to various boundary conditions, Reynolds number, volume concentration, different pitch ratios. The heat transfer rate friction factor and thermal performance rise with the use of nanoparticles in addition to the helical ribs more than without employing these two methods. The heat transfer rate, friction factor and thermal performance also increased when the volume density of nanoparticles rises as well as diminishing the pitch ratio (p/d) of the helical insert. Moreover, increment of Reynolds number raise not only the heat transfer rate but also thermal performance and reduces the fluid friction.

- ✓ The rate of rise in the coefficient of heat transfer when employing the nanofluid ranges from 1.0003 to 1.0073 ,1.0033 to1.0081, 1.0192 to 1.0269 and 1.0433 to 1.0458 for the volume density of 0.015%, 0.039%, 1% and 2% respectively.
- ✓ The rate of rise in the coefficient of heat transfer when implementing the configuration of helical inserts with water ranges between 1.365 to 1.505 , 1.338to1.4351 and 1.268 to 1.335 for the pitch ratio value of p=3d,4d and 5d in turn.
- ✓ The highest heat transfer coefficient is conducted through helical with p/d=3 and nanofluid at volume density of 2% and ranges from 1.3771 to 1.5357
- ✓ There is no significant rise observed in case of using nanofluid for the friction factor and it is almost to the same as the water for smooth tube.

- ✓ The highest increment rate for the friction coefficient of 1.582 is achieved at p/d=3 with the highest volume concentration of 2%.
- ✓ The coefficient of thermal performance rise with the decreasing value of pitch ratio and increment of the volume concentration, as well as rises with the Reynolds number. The highest thermal performance is achieved as 1.5357 with the configuration of p/d=3 and the volume concentration 2% and Reynolds number of 14000.

4.2. Recommendations

The present study indicates the effect of two different passive techniques (helical coil wire with cross section area naca 0030 and Cuo/water nanofluid) on the heat transfer under turbulent current systems. In the upcoming part, we outline some recommendations for further studiesto widen the present study's potential.

- ✓ It is desirable to test new NASA figures as cross section area for helical with a work adjustment for the helical surface.
- ✓ It is suggested to run experimental tests more on fluids in helical coils in order to understand the flow behavior better .
- ✓ It is recommended to use higher concentrations than those applied in this study, taking into account the viscosity values for their direct impact on the pressure drop.
- ✓ Various distances between the helical ribs and tube wall can be tested.
- ✓ In this study, mixture phase flow model and SIMPLEC algorithm is implemented, but further studies can be based on single phase and another algorithm. Despite the drawbacks of the quantitative study, which lacks a significant range of components such as the size and shape of nanoparticles as well as the high cost of its equipment, it can be beneficial to investigate the factors affecting the rise of the heat transfer.
- ✓ The impact of a different size of helical with same Naca number can be also studied.

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