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M.Sc. in Mechanical Engineering

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UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

INVESTIGATION OF HEAT TRANSFER ENHANCEMENT OF A CIRCULAR TUBE FITTED WITH A WIRE COIL AROUND A WIRE COIL

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Supervisor:
Assist. Prof. Dr. Fuat YILMAZ

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This is to certify that we have read this thesis and that in our majority opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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Ali Salah Salman GHRAIRI

ABSTRACT

INVESTIGATION OF HEAT TRANSFER ENHANCEMENT OF A CIRCULAR TUBE FITTED WITH A WIRE COIL AROUND A WIRE COIL

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M.Sc. in Mechanical Engineering
Supervisor: Assist. Prof. Dr. Fuat YILMAZ
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Heat exchangers have overall use in nearly all major industries world enormous. Enhanced heat transfer performance and operational resilience are two very remarkable portions of newfangled heat exchangers. Effective use of heat exchangers in different industries requires exact resoluteness of heat transfer and pressure drop data. The main objective of this thesis work is to report thermo hydraulic performance evaluation of a commercial enhanced tube using numerical simulation techniques in a heat exchanger using ANSYS Fluent v17.A wire coil insert around a wire coil in tube heat exchanger was designed in SOLID WORKS 2014. The heat exchanger was configured. Steady state single phase analyses were performed to determine Nusselt number and friction factor. The enhancement of turbulent convective heat transfer inside pipes by means of wire coil insert around a wire coil as an augmented device is numerically studied. The test section consisted of a smooth tube of 510mm long and 16 mm diameter and length of the double wire coil insert is equal to 500 mm. The outer diameters of the wire coil insert around a wire coil insert are equal to the14.5mm and 14mm. Six different cases of circular, triangular, square of the wire coil insert around a wire coil were investigated. As a first design case, pipe diameter is 16 mm, secondary pitch coil diameter is 1.44 mm, and diameter of insert 14.5mm. As a second design case, pipe diameter is equal 16mm, secondary pitch coil diameter is 2.72 mm, and the insert diameter is 14mm. The range of Reynolds numbers was between 5000 and 25000. A constant heat flux technique was exposed to pipe wall in the test section. Results in the study range of Reynolds number showed that the Nusselt number of TW1 and TW2 were higher than a smooth pipe in the range of 72% to 191.247,and 70% to 175%, respectively For SW1 and SW2, results were in the range of 61.133% to 155.636 and 59.73% to 144%, and for CW1 and CW2, results were in the range of 49% to 124.13% and 46.851% to 107.382%, respectively. So the triangular section wire coil around a triangular section wire coil was given the highest ratio.

Key words: wire coil insert around a wire coil, heat exchanger, ANSYS, heat transfer enhancement efficiency, CFD, wire coil.

ÖZET

BİR SARMAL TEL ETRAFINDA SARMAL TEL İÇEREN BORUNUN ISI TRANSFERİ İYİLEŞTİRMESİNİN İNCELENMESİ

GHRAIRI, Ali Salah Salman
Yüksek Lisans, Makina Mühendisliği
Danışman: Yrd. Doç. Dr.Fuat YILMAZ
Eylül 2017
87 sayfa

Isı değiştiricilerinin hemen hemen tüm büyük sanayilerde yaygın kullanımları vardır. Geliştirilmiş ısı transferi performansı ve operasyonel esneklik, ısı eşanjörleri alanında çok dikkat çeken iki bölümdür. Isı eşanjörlerinin farklı endüstrilerde etkin bir şekilde kullanılması, ısı transferi ve basınç düşüşü verilerinin kesin kararlığını gerektirir. Bu tez çalışmasının temel amacı, ticari bir geliştirilmiş tüp içi geçişimli elemanın termo hidrolik performanslarının ANSYS Fluent v17 kullanarak sayısal simülasyon teknikleri yardımıyla değerlendirmesini yapmaktır. SOLID WORKS 2014'de tüp eşanjöründeki tel bobin etrafında bir tel bobinin geometrik tasarımı yapılmıştır. Nusselt sayısı ve sürtünme faktörü belirlemek için kararlı durum akışında tek fazlı bir analiz yapıldı. Bir sarmal tel etrafında sarmal tel içeren boru içerisindeki türbülanslı konveksiyonlu ısı transferinin iyileştirmesi sayısal olarak incelenmiştir. Test bölgesi 510 mm uzunluğunda ve 16 mm çaplı pürüzsüz borudan oluşmuştur ve çift telli bobin insertinin uzunluğu 500 mm dir. Tel bobin elemanların dış çapları 14.5 mm ve 14 mm'ye eşittir. Tel bobin etrafında tel bobin elemanının dairesel, üçgen, kare kesitlerden oluşan altı tipi incelendi. Birinci tasarımda, boru çapı 16 mm, ikincil bobinin tel çapı 1,44 mm ve insert çapı 14,5 mm. İkinci tasarımda ise, boru çapı 16mm, ikincil bobinin tel çapı 2.72 mm ve insert çapı 14mm'dir. Reynolds sayı aralığı 5000 ile 25000 arasında uygulanmıştır. Test bölümünde boru duvarına sabit bir ısı akış miktarı çalışılmıştır. Reynolds sayısının çalışma aralığındaki sonuçlar göstermiştirki TW1 ve TW2'nin Nusselt sayılarısırasıyla % 72-191.247 ve % 70-175 aralığında düz borudan daha yüksektir. SW1 ve SW2 için sonuçlar % 61.133 ila % 155.636 ve % 59.73 ila % 144 aralığında ve CW1 ve CW2 için sonuçlar sırasıyla % 49 ila % 124.13 ve % 46.851 ila % 107.382 aralığında bulunmuştur. Anlaşıldığı üzere, üçgen kesitli tel bobin etrafındaki üçgen kesitli tel tasarımı en yüksek Nusselt sayısı oranını vermiştir.

Anahtar kelime: tel bobin etrafında tel bobin olan geçişimli eleman, ısı değiştirici, ANSYS, ısı transferi arttırma verimliliği, CFD, tel bobin.

To My

Father and mother, which they spend their lives for me and give the support to reach this level from the knowledge

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LIST OF SYMBOLS / ABBREVIATIONS

A	Area (m^2)
Cp	Fluid specific heat $(J.kg^{-1}.°C^{-1})$
D	Diameter of pipe
Dh	Hydraulic diameter
D	Diameter of wire coil
Dp	Diameter of primary wire coil
Ds	Diameter of secondary wire coil
e_p	thickness of primary wire coil (m)
e_s	thickness of secondary wire coil (m)
L	Length of tube
L	Length of coil
Nu	Nusselt Number
Nu_a	Nusselt Number of insertion tube
Nu_o	Nusselt Number of smooth tube
F	Friction factor
f_a	Friction of insertion tube
f_o	Friction of smooth tube
P	Density
P	Pitch (m)
P_p	Pitch of primary wire coil (m)
p/D	Pitch ratio
R3	Bergles criterion

K	Fluid thermal conductivity $(W.m^{-1}.K^{-1})$
$\dot{V}$	Volume flow rate
ΔP	Pressure drop (pa)
FN	Fixed number of tubes
FG	Fixed geometry
T_o	Outside temperature (K)
T_i	Inlet temperature (K)
T_b	Bulk temperature (K)
T_w	Wall temperature (K)
VG	Variable geometry
η	Heat transfer efficiency ,PEC
Pr	Prandtl Number
Tw1	Triangular wire coil insert around triangular wire coil type one
Tw2	Triangular wire coil insert around triangular wire coil type two
CW1	Circular wire coil insert around circular wire coil type one
CW2	Circular wire coil insert around circular wire coil type two
SW1	Square wire coil insert around Square wire coil type one
SW2	Square wire coil insert around Square wire coil type two

CHAPTER 1
INTRODUCTION

1.1 Introduction

The conversion, utilization, and recovery of energy in every industrial, commercial, and domestic application involve a heat exchange process. Some combined examples are steam generation in power plants; feasible heating and cooling of viscosity in thermal processing of chemical, pharmaceutical, and agricultural products; refrigerant evaporation and condensation in air conditioning and refrigeration; gas flow heating in manufacturing and waste heat recovery; air and liquid cooling of engine and turbo machinery systems; and cooling of electrical machines and electronic devices. Improving of the heat exchange can be significantly better for the thermal efficiency in such applications as well as the economics of their design and operation. Enhancement techniques predominantly reduce the thermal resistance in a conventional heat exchanger and consolidate higher convective heat transfer coefficient with or without surface area augmentation. As a result, the size of a heat exchanger can be miniature or the heat duty of a present exchanger can be increased, or the pumping power additional requirements can be reduced, or it utilizes into heat exchangers and benefits of these techniques improve the heat transfer enhancement of heat exchangers and reduce the design cost of heat exchangers. Exchanger operating access temperature difference can be decreased [1]. These techniques can be classified as

- Active techniques
- Passive techniques
- Compound techniques [3]

1.2 Mechanism of Heat Transfer Enhancement

1.2.1 Active Technique

These techniques are more complex than passive technique in terms of their application and design. They require some outside power contribution to impact the coveted stream alteration and warmth exchange change. In this way, their use is constrained in contrast with passive techniques. These techniques have not demonstrated much potential, and it is hard to give an outer power contribution to many cases. For the development of the enhancement process for this type of technology, it requires the presence of an influential external force [2] resulting of:

I. Surface and fluid vibrations.
II. Fluid injection to or suction from boundary layer.
III. Jet impingement.
IV. Application of electrostatic fields and electro hydrodynamic.

The difficulties and complexities in the manufacturing and requiring additional power of these types of technologies limit the applicability of this technology for specific applications.

1.2.2 Passive Technique

These techniques do not demand any direct input of extrinsic power. They use surface or geometric adjustments to the channel of flow by incorporating an insert, material, or an additional device. Exclude for extended surfaces, which increase the effective heat transfer surface area, these passive methods promote higher heat transfer coefficients by annoying or convert the existing flow attitude. These techniques are accompanied by a development in the pressure drop. Reported applications used on the internal convective flow in order to enhance the heat transfer by us the passive techniques are given below [2]

I. Treated surface (coating).
II. Extended surfaces used with liquids and gases.
III. Displaced insert devices.
IV. Swirl flow devices (unmovable).
V. Surface tension devices.

VI. Additives.

The essential principle of these techniques is the improvement of heat transfer by the following principles [2]:

1) Reduction of the thermal boundary layer thickness.
2) Increasing interruptions in the flow of fluids.
3) Increasing the velocity gradients near the wall.

The effectiveness of giving augmentation techniques depends largely on the mode of heat transfer or the type, both heat exchanger and the properties of the fluids, as well as the pressure drop over the given device that creates the enhancement and then the additional power required to cover the increase of pressure drop. The passive technique encompasses a problem of industrialization cost as in finned tube or ribbed tube, or cost of adding material as in wire coil insert.

1.2.3 Compound Techniques

Two or more of passive and active strategies are utilized at the same time to obtain a greater improvement in heat transfer than that created by one technique applied individually. Much more improvement can be achieved then individual techniques [2]. This technique requires complex design and therefore, it has limited applications. For instance:

I. Fins and electric domains.

II. Radially grooved rotating disk.

1.3 Nomenclature used in Heat Transfer Enhancement

1.3.1 Performance Evaluation Criteria (PEC)

It is impossible to establish an absolute applicable selection criterion for enhancement techniques, because numerous factors influence the designer's decision. In addition to the relative thermal-hydraulic performance improvements brought about by the enhancement devices, there are many factors that must be considered. They include economic (capital, installation, maintenance, etc.), manufacturability (machining, forming, etc.), reliability material compatibility, long-time performance, and finally safety. Combined thermal-hydraulic goals include constriction the size of a heat exchanger required for a specified heat duty, increasing the heat obligation of an existing heat exchanger, reducing the approach temperature difference for the process streams, or reducing the pumping power. The presence of system and design constraints leads to a number of performance evaluation criteria. The geometric variables for pipe-side flow in a shell-and-pipe heat exchanger are tube diameter and pipe length. There are lots of approximations [6, 7, 8]. According to [6], PEC shows below characteristic behavior. PEC increases the heat transfer. PEC can reduce the pumping power. PEC can reduce the size of heat exchangers and in this way, pressure drop can be reduced. PEC of Webb [8] can be classified some criteria related the geometrical constraints such as

1- The name of first criterion is FG (fixed geometry) which is related to the cross sectional envelope area and the constant tube length.

2- The name of second criterion is FN (fixed number of tubes). In contrast with FG criteria, the length of the heat exchange is variable. Thanks to this criterion, it can decrease the surface area of the flow and the required pump power for constant heat capacity.

3- The name of third criterion is VG (variable geometry) which maintains constant exchanger flow rate.

The criterion of Bergles is R3 which is explained by:

$$\mathrm{R3} = \frac{\mathrm{Nu_a}}{\mathrm{Nu_o}} \tag{1}$$

Nu_a is the Nusselt number of tube with wire coil insert around wire for equal pumping power, and Nu_o is the Nusselt number of smooth tube for equal pumping power. In the case of tube with wire coil around wire coil, heat transfer area is equal to smooth tube heat transfer area (A_a=A_o). To satisfy the constraint

Reynolds number Re_o, which matches [9] for a constant pumping power,

$$\left(V\dot{\Delta}P\right)_0 = \left(V\dot{\Delta}P\right)_a$$

The equations of the Reynolds number and friction are:

$$\mathrm{Re} = \frac{\rho .\, \mathrm{U_{mean}} .\, \mathrm{D_{hydraulic}}}{\mu} \tag{2}$$

$$\mathrm{f} = \frac{2 .\, \Delta\mathrm{P} .\, \mathrm{D}}{\rho .\, \mathrm{U^2}_{\mathrm{mean}} .\, \mathrm{L}} \tag{3}$$

$$(fRe^3)_0 = (fRe^3)_0 \Rightarrow Re_0 = Re_0 = \left(\frac{f_a}{f_0}\right)^{\frac{1}{3}} \tag{4}$$

and summation of Equation 1, 2, and 3 is equal to:

PEC (ɳ), is the ratio of the Nu_a to Nu_o for a constant pumping power, PEC can be written as:

$$ɳ = \left.\frac{ha}{ho}\right|_{pp} = \left.\frac{Nu_a}{Nu_o}\right|_{pp} = \left(\frac{Nu_a}{Nu_o}\right)\left(\frac{f_a}{f_o}\right)^{-1/3} \tag{5}$$

1.3.2 Nusselt Number

It is the proportion of the convective heat transfer circulating at the surface and is defined as Nusselt number. Here h is the convective heat transfer coefficient, d hydraulic diameter of the tube, and k is the thermal conductivity.

$$Nu = \frac{h.D_{hydraulic}}{k} \tag{6}$$

1.3.3 Prandt Number

It is defined as the ratio of the molecular diffusivity of momentum to the molecular diffusivity of heat [5].

1.3.4 Pitch of Wire Coil

Pitch is defined as the distance between two adjacent top point of wire coil that are same plane and parallel planes [5].

1.4 Aim of This Study

The main objective of this study is to investigate the performance of a wire coil insert around a wire coil in a tube for different cross sections on the flow behavior and turbulent convective heat transfer and pressure drop. These are circular, square, and triangular. The following parameters were scrutinized.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

In this chapter, reviews of heat transfer augmentation and flow properties using wire coil inserts as swirl flow devices and other improvement mechanism as a part of passive and compound improvement techniques are presented. The review magnitude on works dealing with wire coil inserts is related with economic heat transfer augmentation techniques. Several examples can be given such as that heat recovery processes, air conditioning, cooling systems, chemical reactors, food, and dairy processes [3]. The review of heat transfer improvement is classified into two sections: Heat transfer improvement using wire coil inserts, and heat transfer enhancement compound with wire coil inserts.

2.2 Heat Transfer Enhancement

Here, a brief review for the most recent works through in the field of heat transfer improvement on the single-phase flow is included the concentration on turbulence caused by devices or inserts combined with the flow duct which may be referred to as “turbulence promoters”. Some studies stated that the relation in the improvement of heat transfer is swirl vortices generated by these insert devices.

2.2.1 Heat Transfer Enhancement using Wire Coil Inserts

Wire coil inserts as vortex flow devices are actually used in applications as oil cooling devices, preheated or fired boilers. They show diverse properties in relation to other enhancement techniques:

(a) Low expense.
(b) Easy installation and removal.
(c) Preservation of the original plain tube mechanical intensity.
(d) Possibility of investiture in an existing plain tube heat exchanger.

Figure 2.1 shows a design of a wire coil inserted in close impinge with the interior tube wall, where p is the pitch for helical wire coil insert, e is the wire-diameter, and d is the tube interior diameter. These parameters can be proportionate to define the wire geometry in non-dimensional forms: pitch ratio p/d, wire-diameter to pipe diameter ratio e/d, and pitch to the wire-diameter ratio p/e. The pipe side flow paradigm is modified by the existence of a helically coiled wire as follows:

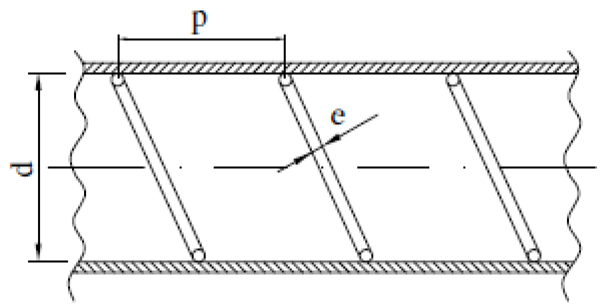


Figure 2.1Sketch of a helical wire coil fitted inside a smooth tube

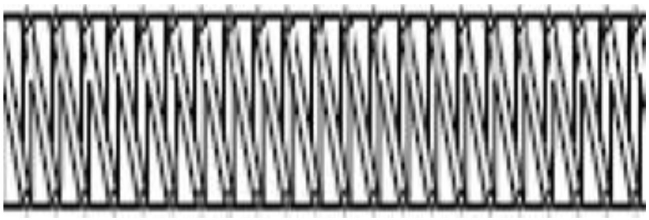
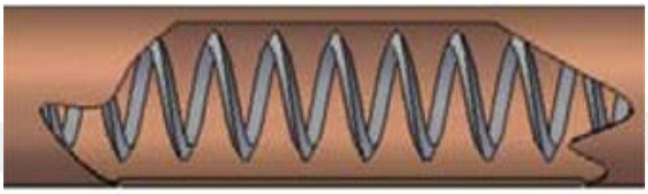
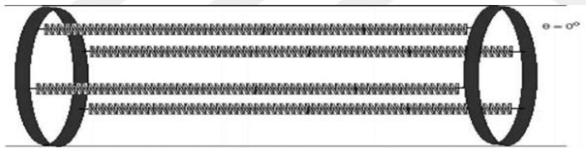
If the wire coil insert over flowing as a swirl flow generator, a helical wire coil flow at the periphery is created .This rotary flow is given across the axially adaptability central flow and causes centrifugal forces In most of the liquids, density decreases with temperature, and centrifugal forces produce a movement of the heated fluid from the boundary layer across the tube axis .Besides, whenever wire coils are in contact with the tube wall, they act as roughness elements and immediately impede the laminar sub layer.

Several researchers have been studied different configurations of wire coil inserts as swirl flow devices as shown in Table 2.1. The enhancement of energy enhancement has been observed clearly in the case of the mixed fluid .Extreme practical and productive wire coil inserts are in among the mechanisms that stimulate secondary flows to enhance the heat transfer. Helical shape of the wire causes a great time of residence and the longest path of the fluid through the tube. The secondary circulation is generated as a result of geometric field.

Garcia et al. [10] have been investigated the effect of wire coil inserts on heat transfer improvement in pipes and double pipe heat exchangers in order to understand their thermal and hydraulic behavior in laminar, transition, and turbulent flow. By utilizing water and water-propylene glycol mixtures at various temperatures, a wide range of flow regimes has been scrutinized over the Reynolds number range between 80 to 90,000 and Prandt number range of 2.8 to 150. Six wire coils were used within a geometrical range of a pitch ratio between 1.17 and 2.68 and wire diameter to pipe diameter ratio of $0.07 < e/d < 0.10$.Results showed that the Reynolds number was lower than 500, Nusselt number values closed to the Nusselt number of smooth tubes. When the Reynolds number was between 500 and 3000, Nusselt number dependence on Prandtl number and Reynolds number was observed. When the Reynolds number was greater than 3000, the heat transfer effect was negligible. Wire coil with a lowest pitch ratio showed the highest heat transfer improvement. The highest heat transfer rate according to R3 criterion was observed in the transition region which R3 reached 200 %. In this study, the negative effect was observed on the pressure drop because the pressure drop was raised nine times approximately in compare with smooth pipe. Heat transfer was increased four times compared with smooth tube. At low Reynolds numbers, wire coil was not any difference from the smooth tube. However, the critical Reynolds number was nearly 700 for the pipe with wire coil.

Yakut and Sahin [11] experimentally scrutinized the effect of various pitches of wire coil inserts of 4 mm diameter and 1240 mm length. The test fluid was air. Three different pitches (10, 20 and 30 mm) were utilized in the Reynolds number range of 5000-38000. Their observations explained that the vortex properties of the turbulators should be adopted as a selecting criterion for the heat transfer and friction factor to obtain heat transfer improvement in the heat exchanger.

Table 2.1 Configuration Sketches of SeriousWire Coils

Insert configuration	**Description**
	Coiled square wire
	Triangle cross sectioned coiled wire
	Helical spring Wire
	Circular cross sectioned Wire coiled

Naphon [12] studied the heat transfer and the pressure drop characteristics of the horizontal double tube with wire coil insert. The outer and inner diameters were 9.52 and 8.92 mm, respectively. The thickness of wire coil was one mm and insert diameter of wire coil was 7.80 mm. Water was used as a working fluid in the heat exchanger. The inlet temperature region for cold water was from 15 to 20 c and hot water temperature region was between 40 and 45 c. The effects of the coil pitch and related parameters on heat transfer and pressure drop properties were tested. Results showed that wire coil insert had an important effect on the improvement of heat transfer, in particular, on laminar flow.

Garcia et al. [13] the effects of three-wire coils having various pitch inserted in a smooth pipe on laminar and transitional flow heat transfer were investigated. The experiments have been conducted for Reynolds number range of 10–2500 and Prandtl number range of 200–700. The results showed that the wire coils did not improve the heat transfer at Reynolds numbers up to 200, and the wire coil appreciably improved the heat transfer for Reynolds number domain between 200 and 1000. For instance, the heat transfer coefficient of wire coil in the pipe was increased up to eight times higher than the smooth pipe at Reynolds number of around 1000. The wire coil higher heat transfer enhancement in the low Reynolds number range which changed from 700 to 2500. Pipe with a wire coil had a better performance if it compared with twisted tape at Reynolds number range between 700 to 2500.

Promvonge [14] experimentally tested the effects of wire coil inserts having square cross sections. They found that the Nusselt number for both circular and square wire coils increases with increasing Reynolds number and the lowering of pitch. The best performance factors for wire coil inserts having square cross section were obtained for low Reynolds numbers between 1.2-1.3. When the wire coils compared with smooth pipe at a constant pumping power, an augment in heat transfer rate is obtained, especially for low Reynolds numbers. Even though obviously large differences have been noted among coil wires, their performance evaluations are similar at condition of Re = 5000 with enhancement efficiency of heat transfer 1.2-1.3 and 1.1-1.15 at Re = 25,000. Subsequently, the wire coil insert of square cross section ought to be exercised to obtain higher thermo hydraulic performance. Consequently, it will lead to more built-in heat exchanger.

Behabadi et al. [15] have experimental study on heat transfer enhancement and pressure drop properties of forced convective evaporation in a pipe in the existence of wire coil insert utilizing of R-134a as a test fluid. The experimental analysis was conducted for wire coils with varied wire diameters of 0.5, 0.7, 1.0 and 1.5 mm and several coil pitches of 5, 8, 10 and 13 mm. When the results obtained were compared to the straight tube flow, it was understood that the coiled wire inserts caused an increase in the heat transfer and the pressure drop.

Behabadi et al. [16] have also experimentally studied the thermo hydraulic behavior of wire coil inserts during heating of engine oil inside a horizontal pipe of a double pipe heat exchanger. The experimental analysis has been conducted at low Reynolds numbers ranging from 10 to 1500 for the oil-side using seven coiled wires having pitches of 12–69 mm and wire coil diameters of 2.0 mm and 3.5 mm. The results showed that particularly at low Reynolds numbers coil inserts with a minimize wire coil diameter, and a lower coil pitch offered better performance.

Eren et al. [17] have experimentally inspected the heat transfer behavior of circular coil spring turbulators in the Reynolds number range of $2500 < Re < 12000$. The results were parameterized by the four different outer diameters of the spring tabulators (7.2 mm, 9.5 mm, 12mm, and 13 mm), the three descend angles of the springs (0 deg, 7 deg, and 10 deg),and numbers of the springs (4, 5, 6). They concluded that increasing spring number, spring diameter, and incline angle resulted in remarkable enhancement on heat transfer, comparatively 1.5-2.5 times of the results of a smooth empty pipe. Friction factor increases 40-80 times of the results of a smooth tube. For the smallest incline angle of the springs 0 deg heat transfer and friction factor have the lowest values, while for 10 deg the heat transfer and friction factor have the highest values. If consider the design parameter, the angle of inclination has the dominant effect on heat transfer and friction factor, on the contrary, spring number effect is very small.

Esparza and Rojas [18] have conducted three-dimensional numerical simulations for in compressible laminar flow into smooth round pipes fitted with wire coils having different thickness and helical pitches by Open FOAM software package. The numerical results were validated to experiments. CFD approach was found a good tool for optimization and design purposes of enhanced heat exchanger systems.

Eiamsa-ard et al. [19] investigated the heat transfer properties of tandem wire coil in a square duct in the Reynolds number range of 4000 to 25000. The element wire coil inserted in the channel is used to generate a spiral that helps to wash up the flow trapped in the corners of the flow channel. Then, this was supplied the development the heat transfer rate of the channel. Air was used as working fluid. The thorough length wire coil provided the higher heat transfer and friction factor than the tandem wire coil insert under the same working conditions.

Gunes et al. [20] experimentally studied the thermo-hydraulic behavior of wire coil insert in a horizontal pipe. A coil with an equilateral triangular cross section is separated from the pipe wall. This study was performed with three different pitch ratios (1, 2, and 3). The distance between the wall and wire coil was equal to 1mm. Experiments were carried out in the range of Reynolds number from 3500 to 27000. Air was utilized as a working fluid and uniform heat flux was implemented to the external surface of the pipe. Results were compared with smooth tube. Results showed that maximum PEC was obtained 36.5% for a/D=0.0892 and p/D=1 at Reynolds number of around 3858.

Nasr et al. [21] presented an implementation of artificial neural networks to explore the effects of four types of helical coiled wire inserts on heat transfer evolution and pressure drop in transition and turbulent flow regimes with the Reynolds numbers range of 4200 to 49,000. The wire coil pitch ratio of 0.156 to 0.354, and wire diameter to the hydraulic diameter ratio of 0.027 to 0.094 were used. Experimental study was done to validate the approach using Nusselt numbers and friction factors of pipes with wire coil inserts. The validation results showed that the mean relative errors between the experimental data and the obtained results were found to be less than 3.27 % for the friction factor and lower than1.79 % for Nusselt numbers.

Biswas and Salam [22] experimentally investigated the pipe-side heat transfer coefficient, friction factor, heat transfer augmentation efficiency of air flow in a circular pipe fitted with wire coil insert under turbulent condition. A stainless-steel coil with a wire thickness 2.8 mm and coil diameter 24 mm were used. The results showed that the Nusselt number and friction factor for tube with wire coil insert were enhanced in the range of 1.5 to 2.3 times and in the range of 3 to 3.5 times than that of the smooth pipe. Heat transfer increase efficiencies were found in the range of 1.3 to 2.6 at constant pumping power and decreased with the increase of Reynolds number.

Ali et al. [23] experimentally investigated the uniform heat flux pipe with wire coil insert in the turbulent flow regime within the Reynolds number region of 14400 to 42900. They found that the augmentation efficiency and performance criterion range were of 46.9-82.6% and 100.1-128%, respectively.

Garcia et al. [24] experimentally scrutinized the flow technique of wire coil inserts in a pipe using PIV measurement techniques and hydrogen bubble visualization. At Reynolds number of less than 400, wire coil insert in a pipe showed similar flow characteristics with smooth pipes. A swirl flow was appeared for wire coil with a short pitch at Reynolds numbers region between 500 and 700. The insertion of wire coil in a round pipe highly speeded up to the transition to turbulence. This phenomenon was occurred at Reynolds numbers between 700 and 1000 depending on the pitch of wire.

Garcia et al. [25] experimentally studied the thermal-hydraulic properties of three types of passive technique based on artificial roughness: wire coil insert, dimpled and corrugated tubes. The shapes of the wire coil, corrugated pipes, and dimpled tubes strongly affect the transition to turbulence. The experimental results were taken in laminar, transition, and turbulent region. When compared to heat transfer effect of artificial roughness shape, the shape has a greater effect on the pressure drop. Results showed that when the Reynolds number was lower than 200, any technique not affect positively, therefore, smooth tubes should be used. In the range of Reynolds number between 200 and 2000, wire coil insert was better than the others. However, when Reynolds number higher than 2000, corrugated or dimpled tubes were favored because they had a lower pressure drop.

Collins et al. [26] experimentally investigated the effect of wire coil on heat transfer improvement for high-heat-load applications. Heat transfer at reasonably low flow rates was significantly increased by the presence of wire coil. Results showed that by utilizing a new heat-transfer augmentation technique, higher levels of heat transfer can be applied with considerably less pressure loss than already used heat transfer augmentation techniques.

Pahlavanzadeh et al. [27] experimentally tested the effect of two various pipe inserts (wire coil and wire mesh) on the heat transfer, pressure drop, and mineral salts fouling alleviation in a pipe of a heat exchanger. A 3/4-in. pipe is heated by squad heaters to simulate a tube of heat exchanger. Working fluid is water with certain quality. The heat transfer rate was averagely enhanced by 22–28% for wire coil with p/d=0.125 and e/d=0.00375, and 163–174% for medium density through a plain tube value. However, the pressure drop penalty was also gone up by 46% for wire coil and 500% for wire mesh.

Gunes et al. [28] experimentally examined the thermo-hydraulic behavior of equilateral triangle cross sectioned wire coil. The length of pipe was 3.1 m and each length of equilateral triangle was 6 mm. wire coil was separated from the wall and the distance between wall and wire coil are 1 mm and 2 mm. Three pitch ratios (1, 2, and 3) was examined. The inner diameter of the pipe was 56 mm. The Reynolds number range between 4105 and 26400. Testing fluid was air. Table 2.1 show the equilateral triangle cross sectioned wire coil and equilateral triangle cross sectioned wire coils inserted in a horizontal pipe.

Vahidifar and Kahrom [29] have investigated the effects of a wire coil and ring inserts in a horizontal double tube heat exchanger on heat transfer and the pressure drop characteristics using the air as a test fluid in the Reynolds number range between 5000 and 25000 with a Prandtl number of 0.7. A geometrical range of a pitch ratio 1, 2, and 4 and wire diameter to pipe diameter ratio of 0.05, 0.07, and 0.11 were used. The results showed that the wire coils display a superior performance than rings, and the overall improvement efficiency of 128% was obtained with wire coil insert with d/D=0.11, P/D =1 at Reynolds number of around 10000.

Table 2.2 Summary of investigations of wire coil inserts

Author s	Fluid	Configuration of wire coil	Type of investigation	Observations
Garcia et al. [10]	Water propylene glycol mixturs	Helical-wire-coils with helical pitch 1.17 < p/d < 2.68 and wire diameter 0.07 < e/d < 0.10	Experimental studyin circular tube	In laminar flow, results show that wire coils behave mainly as a smooth pipe. In turbulent flow, wire coils reason a high pressure drop increase which depends mainly on pitch to wire-diameter ratio p/e.
Yakut and sahin et al.[11]	Air	coiled wires with three arrangements (10, 20 and 30 mm pitches)	Experiment in circular tube	Vortex properties of the turbulators should be considered as a selection criteria with heat transfer and friction characteristics in heat transfer improvement applications.
Paisarn Naphon et al.[12]	water	Iron coiled wire	Experiment in horizontal double pipe	The coil insert has a significant effect on the heat transfer improvement in particular the laminar flow region. The non-isothermal evidencing of the heat transfer coefficient and the friction coefficient is proposed. The proposed data are reasonably consistent with the forecast.
Alberto Garcia et al.[13]	water	The study on three wire coil of different pitch inserted a smooth pipe.	Experiment in circular tube	The friction in the fully layered area increases between 5% and 40%. The transition from laminar to turbulent is continuous. The friction in the fully layered area increases between 5% and 40%. The transition from laminar to turbulent is continuous.
Promvong et al. [14]	water	The study on three wire coil of different pitch inserted a smooth pipe.	Experiment in circular tube	Re = 5000–25,000 and Pr = 0.7. The utilize of coiled square wire insert reason a high pressure drop raise, which depends fundamentally on spring pitches and wire thickness, and also provides significant heat transfer enhancement, R3 = 1.8–2.6.
Behabadi et al. [15]	R-134a	Four coiled wires having pitches of 5–13 mm and wire diameters of 0.5-1.5 mm	Experiment in a horizontal evaporator	Effect of wire coils on heat transfer coefficients tends to improved with the rise of wire diameter and decreasing of coil pitch decrease with a higher penalty due to the increasing of pressure drop as , compared to the plain flow.

Behabadi et al. [16]	engine oil	seven coiled wires having pitches of 12–69 mm and wire diameters of 2.0 mm and 3.5	Experiment in double pipe counter-flow heat	Two experimental correlations have been sophisticated to predict amended heat transfer coefficients in the error band ±20%
Eren et al. [17]	Air	of circular coil spring having different diameters, number of turns and incline angles	Experiment in circular tube	spring diameter, and decline angle result in considerable improvement on heat transfer, relatively 1.5–2.5 times of the results of a smooth empty pipe. By the way, friction factor increases 40–80 times of the results found for a smooth pipe.
Esparza and Rojas[18]	Incompres sible fluid	Four coiled wires having different wire pitches and wire thickness	CFD simulation in circular tube	The effect of the pitch on the friction factor has been addressed by performing a parametrical study with a pitch-periodic computational domain for wire coils within the dimensionless pitch range, 1.50 ⩽ p/d ⩽ 4.50, and dimensionless wire diameter, e/d = 0.074, showing that the rise of the non dimensional pitch, p/d, decreases the friction factor.
Eiamsa-ard et al. [19]	Air	tandem wire coil elements	Experiment in circular tube	Under the same operating conditions, the full-length coil provides a higher heat transfer and coefficient of friction than the series coil element.
Gunes et al. [20]	Air	Equilateral triangle cross sectioned coiled wire	Experiment in circular tube	Effect of wire coil insert pitches and wire thickness on heat transfer coefficients and friction are calculated and the better operating regime of all coiled wire inserts is detected at low Reynolds number.
Nasr et al. [21]	water	Helical-wire-coils with different helical pitch wire thickness	artificial neural networks (ANNs) in circular tube	The mean proportional errors between the expected results and experimental data were found lower than 1.79% for Nusselt numbers and lower than 3.27% for friction factor

Biswas and Salam [22]	Air	A stainless-steel coil with thickness (e) was 2.8 mm and coil diameter (d) 24 mm	Experiment in circular tube	Effect of wire coils on pipe friction and heat transfer juncture illustrate under distinct values of flow velocity, wire coil diameter, pitch and length.
Ali et al. [23]	Air	helical coils inserts	Experiment in circular tube	Flow pattern, slug rise velocity and void fraction are higher for wire coil insert than smooth pipe
Garcia et al. [24]	Hydrogen bubble	wire coil inserts in a pipe	Experiment in smooth tube	A swirl flow was appeared for wire coil with a short pitch at Reynolds numbers between 500 and 700. The insertion of wire coil in a round pipe considerably accelerated transition to turbulence.
Garcia et al. [25]	Hydrogen bubble	wire coil insert	Experiment in smooth pipe	The experimental results were taken in all flow regime (laminar, transition, and turbulent). Artificial roughness showed better pressure drop properties than the others.
Collins et al. [26]	Water	wire coil insert	Experiment in circular tube	realization a new heat-transfer improvement mechanism being estimated at the APS include the use of wire-coil inserts confirm to be excellent to already utilized techniques.
Pahlavan zadeh et al. [27]	water and mineral salts foulig	wire coil and wire mesh	Experiment in circular tube	pressure drop augmentation essentially by 46% for wire coil and 500% for wire mesh. Wire coil insert with vibration lighten mineral salts fouling about 34%.
Gunes et al. [28]	Air	Wire coil insert	Experiment in circular tube	As a result and the experimental results detect that utilize these coiled wire are thermodynamically useful at all Reynolds numbers.
Vahidifar and Kahrom. [29]	Air	wire coils with a pitch of (P/D=1, 2, 4) and wire diameter of (d/D=0.05, 0.07, 0.11) combined	Experiment in double pipe heat exchanger	wire coil with d/D=0.11, P/D =1 and Reynolds number of 10000, gives overall increase efficiency amounted to 128%.

2.2.2 Heat Transfer Enhancement using Wire Coil Inserts in Compound Techniques

This section describes the properties of heat transfer and fluid flow generated by compound techniques using wire coil swirl generators with constant and variable wire pitch, accompanied by other increment techniques ,such as snail admittance, twisted tape inserts and vacillating baffled reactors as shown Table 2.3. summary of important implementing of twisted tape in compound techniques is approaching in Table 2.4.

Wang and Sunden [30] compared the performance on heat transfer improvement of twisted tape and wire coil. The flow regimes of investigation were laminar and turbulent. Both of twisted tape and wire coil inserts offered better performance in the laminar region if it compared with the turbulent region. In the laminar region, the maximum PEC was around 16. However, in the turbulent region, it was around 2 When the pressure drop is of no concern, twisted tape inserts could be suggested in both laminar and turbulent regions. Because of twisted tape inserts had a higher R3 than wire coil inserts. When the pressure drop was a constraint, wire coil inserts might become more impressive because of the less pressure drop penalty. The performance was well related with the fluid property. Pipe insert technology was more impressive for fluids with high viscosity (high Prandtl number) especially in the laminar region. Indeed, many high viscous liquids work in laminar region and have the considerably low heat transfer coefficients.

Promvonge et al. [31] examined the effects of circular and square wire coils in integration with a spiral type swirl generator fitted at the access of heat fluxed pipe. Test fluid was air. The range of Reynolds number was between 5000 and 25000. The results showed that both circular and square wire coils with spiral entry led to a noticeable increase in friction factor and heat transfer than the smooth pipe under the same conditions. Heat transfer enhancement tended to decrease with the rise of Reynolds number. Square wire coil showed the best PEC. The average PECs of the square and circular wire coil were about 1.3 and 1.25, respectively. The square wire coil provided higher heat transfer and performance than the circular one around 10-15%.The lowest PEC was found for circular wire coil with snail entry.

Promvonge et al. [32] implemented an experimental test to understand the effect of wire coils insert combined with twisted tape with constant and different wire coil pitch ratios. Three different wire coil pitch ratios (4, 6 and 8) and two different twist ratios (4 and 6) were used in the range of Reynolds number from 3000 to 18,000. The best operating condition for combined turbulators was found at low Reynolds number with the lowest values of wire coil pitch and twist ratio. With the increase in Reynolds number, the Nusselt number increased. In the case of low Reynolds number, the heat transfer performance is doubled by a smooth pipe by a combination of constant pumping power.

Eiamsa-ard et al. [33] also demonstrated the combined device effects of the twisted tape with a constant or periodically change pitch ratio of the wire coil inserton heat transfer, friction factor and thermal performance behaviors. Two different twist ratios and various pitch ratio configuration of wire coil insert were used. One of them was called the D-coil (decreasing coil pitch ratio arrangement) and the other was called the DI-coil (decreasing/increasing coil pitch ratio configuration).) and the other was called the DI-coil (decreasing/increasing coil pitch ratio arrangement). The effect of each device was compared with combined types. In this, study, air was selected as a working fluid. The Reynolds numbers range was between 4600 and 20,000. Table 2.3 shows the geometrical shapes and parameters about the combined non uniform devices and relevant parameters can be seen from Table 2.4. Their results reveal that the arrangement of twist tape with a ratio of 3 and the decreasing or increasing coil pitch ratio at low Reynolds number produced the highest thermal performance factor of around 1.25 as compared with the wire coil alone, the twist tape alone, the twist tape with uniform coiled wire, and the twist tape with decreasing coil pitch ratio.

Solano et al. [34] have implemented CFD simulation to study the compound effect of oscillatory motion and helical wire coil inserts on heat transfer improvement in oscillatory baffled reactors under periodic and laminar flow conditions. The results uncover that the heat transfer for the helical wire coil in the tested range of oscillation conditions could be increased by a factor of four compared to a smooth tube. coil insert with d/D=0.11, P/D =1 at Reynolds number of around 10000.

Desale and Ghuge [35] performed an experimental work on heat transfer, pressure drop characteristics, and thermal performance in a constant heat fluxed tube using wire coils with three different wire diameters of 1, 2, and 3 in conjunction with Teflon ribs in three configurations along a chord of coil circle using air as test fluid. They concluded that the compound devices of wire coil with Teflon ribs provide the highest thermal performance.

Table 2.3 Configuration sketches of various Compound Techniques

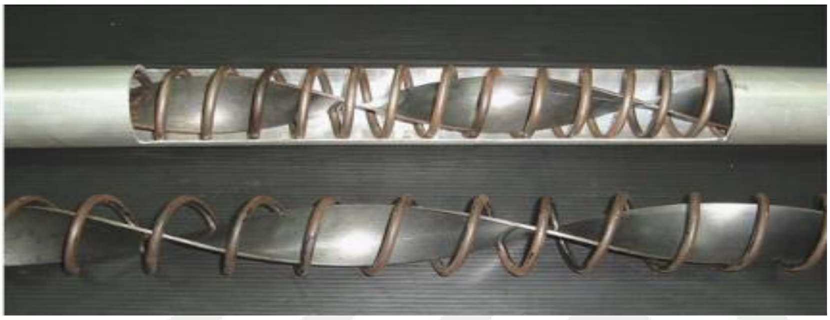
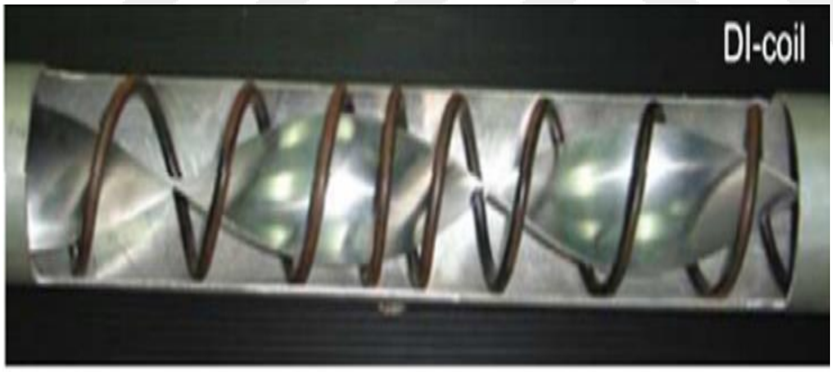
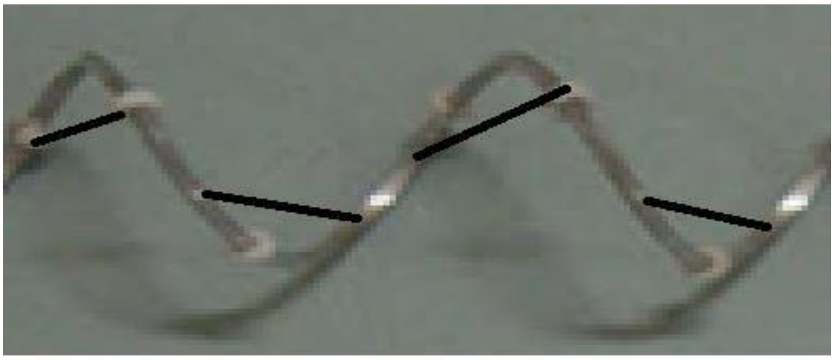
Insert configuration	Description
	Test pipe with wire coil and twisted tape inserts
	Test suction fitted with wire coil and twisted tape
	Coiled wire inserts with chord Rib

Table 2.4 Summary of implementation of twisted tape in compound techniques

Authors	Fluid	Configuration of wire coil	Type of investigation	Observations
wang and Sunden [30]	Water and ethylene glycol	Wire coil insert And Twisted Tape Insert	Experiment in circular pipe	pipe technology was more impressive. for fluids with high viscosity (high Prandtl number) in the laminar region. Indeed, many high viscous liquids in laminar region had considerably low heat transfer coefficient.
Promvonge et al. [31]	Air	circular and square wire coils in conjunction with a snail type swirl generator	Experiment in circular tube	Effect for both circular and square wire coils with snail entry on heat transfer. Denomination resort to consolidate with the height of Reynolds number as compared with coiled wire/snail entry alone .
Promvonge et al. [32]	Air	wire coils in conjunction with twisted tapes	Experiment in circular tube	Effect of wire coils in conjunction with twisted tapes on heat transfer coefficients resort to consolidate with the elevation of Reynolds number as compared with wire coil/twisted tape alone.
Eiamsa-ard et al. [33]	Air	twisted tape (TT) and constant/periodically varying wire coil pitch ratio.	Experiment in horizontal double pipe.	Effect of combined twisted tape (TT) with wire coils on heat transfer coefficients tends to enhanced with the rise of Reynolds number as with twisted tape / wire coil alone.
Solano et al. [34]	Incomp-ressible fluid	coiled wire inserts	CFD simulation Oscillatory baffled reactors (OBRs)	laminar eddies increase downstream of the wire and spread over the next wire coil pitch, consolidate radial mixing.

Desale and Ghuge et al. [35]	Air	wire coil with different diameters, 1, 2 and 3 in with Teflon ribs with chord three configurations (Cl/D = 0.5, 0.6 and 0.7)	Experiment in circular tube	wire coil with Teflon ribs provide the highest thermal performance.

2.3 Scope of The Thesis

The previous studies showed that the presence of coil wire inserts had improved the heat transfer coefficient due to the vortex (swirl flow) generated around the insert. Therefore, these review has motivated the present study to combine the effect of wire coil insert around a wire coil as novel configuration of passive techniques for increasing the heat transfer. The main aim of the thesis is to develop the heat transfer enhancement by using a novel insert design. It was analyzed by ANSYS FLUENT 17 modules.

CHAPTER 3
NUMERICAL VALIDATION

3.1 Introduction

In order to analyses flow and thermal fields in a pipe under the heat flux, including a wire coil insert, a solution of the standard k-ε models are used to model turbulent flow in pipe model with the energy equation is required. Because of the complexity of wire coil insert configurations, it is impossible to obtain an analytical solution of the governing equations for practical configuration. Numerical simulations allow the analysis of the complex geometry of the flow scope. Therefore, finite volume numerical techniques by ANSYS Fluent code v17 have been used to solve the equations.

3.2 Numerical Validation

An initial validation of the wire coil -and-tube was used for the Numerical results validation and the results compared with the experimental data of Nasr et al. [21] .for the same pitch. The experimental results were wire coil separated from the wall. en wire coil touch the wall, the inflation type mesh is difficult and layer is the most important parameters to get good results Nasr et al. [21] was used for numerical validation. Nasr experimentally examined the thermo-hydraulic behavior of wire coil inserted in a horizontal pipe and these wire coils are used as a tabulators. The shape of geometry of pipe was circular and the length e was 500 mm. However , the insertion length of wire coil was 500 mm and diameter of pipe 16mm diameter of each wire coil was 1.2 mm. this coil separated from the wall 1.1 mm, approximately. The pitch of wire coil was 4.5mm and pitch ratio was equal to p/D-0.28125. The wire coil diameter to pipe diameter ratio (e/D) was equal to 0.075.Figure 3.1 and 3.2 show the geometry of pipe. Table 3.1 explains the geometrical parameters of experimental study. In this study, water was used as the working fluid and the characteristic of water were assumed to be constant. This assumption is valid for water within the operating temperature range inlet of fluid was 303 k and the temperature of wall changing from 353.688 w/m^2 to 1432.394 w/m^2 kThe range of Reynolds numberfor Nasr et al. [22]was between 4294.01 and 39838.81That the Reynolds number range of numerical case for to calculate Nusselt number .and Reynolds number between 3149 and 31487 to calculate friction factor Table 3.2 shows the boundary conditions of the experimental and numerical studies.

Table 3.1 Geometrical parameters of Mr.Jafari Nasr et al. [21]

Geometrical parameters	
D pipe	16 mm
dwire coil	1.2 mm
Length of pipe	500 mm
Length of wire coil	500mm
pitch of wire coil	4.5mm
diameter insert	13.8mm
p/D	0.2815
e/D	0.075

Table 3.2 Boundarycondition of geometry

Boundary condition	
Reynolds number range for Nusselt numbers	4294.01-39838.31
Reynolds number range for fraction factor	3149-31487
Working fluid	Water
Temperature of wall	353.688 w/m^2 - 1432.394 w/m^2
Temperature inlet	303k

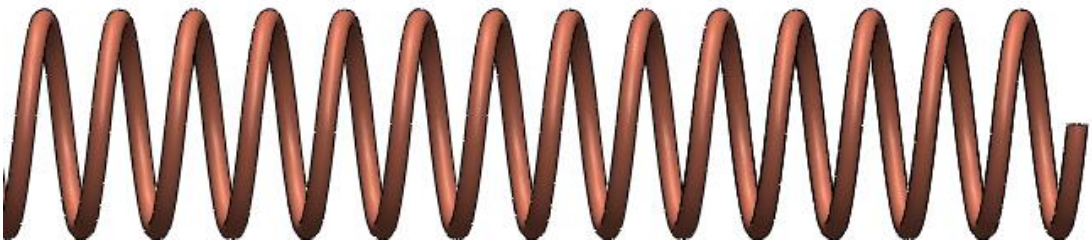


Figure 3.1 Wire coil insert

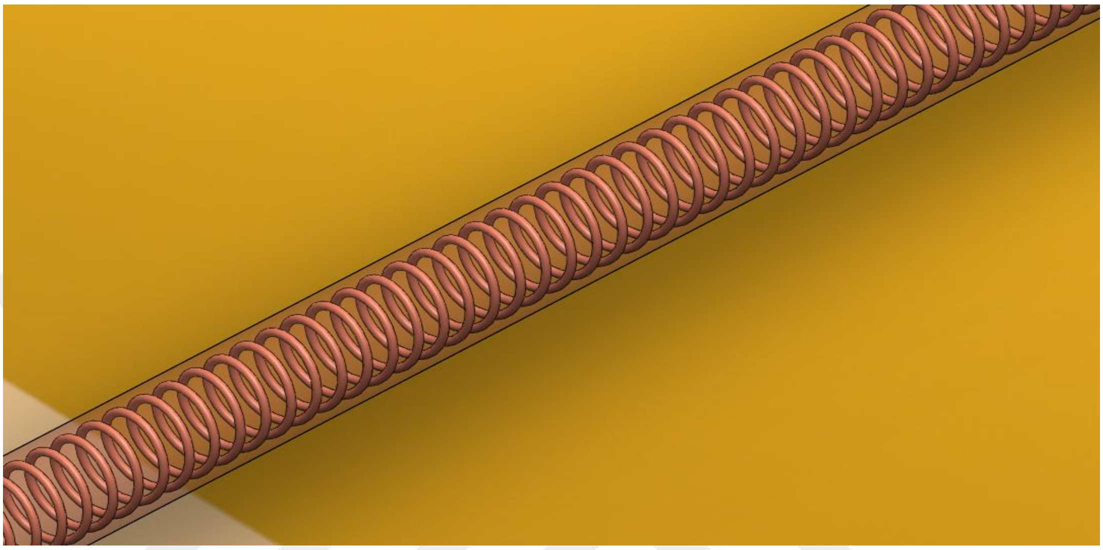


Figure 3.2 Cross section of pipe with wire coil insert

3.2.1 Mesh Independency of the Validation Case

Geometry of the pipe with wire coil is modeled in ansys fluent software v 17.Mesh was done by using Ansys Fluent Meshing . All meshing procedure was taken from Ansys Users Guide.the mesh independency.As mentioned above the first step in divide the domain into a number of control volumes, this usually called mesh generation in CFD world. The quality of themesh will reckon the degree of thoroughness of the results obtained from Fluent. However, there is always a trade-off between the thoroughness and the costs. As the mesh getting finer and finer, the computational cost and the time cost are alsoincreased. So prior to investigating different simulation cases, the mesh independent , there are two different mesh sizes used to conduct mesh independence study. For all two cases, the outlet temperatures of water are measured. Based on the simulation results, the difference between b and c is 0.23% in Nusselt number and in friction factor . To reduce time and computational cost using the median mesh size.the inflation layers are generated around wall and coil side of both water domains to achieve better accuracy and capture the flow physics, the Skewness of the model was0.84979 and orthogonal qualityactual to 0.122.

Table 3.3A Mesh independency of validation for Nusselt Number

NUMBEROF MESHELEMENTS	REYNOLDS NUMBER	NUSSELT NUMBER
11494441	4294.01	79.2311
10342314	4294.01	79.30448

Table 3.3B Mesh independency of validation for Friction

NUMBEROF MESHELEMENTS	REYNOLDS NUMBER	FRICTION
11494441	3149	0.12153
10342314	3149	0.11035

Meshing was done to the geometry example by program planned and sizing was done to get the in demand element size, nodes and smoothing. After obtain the required size and inflation layer around tube and coil insert.

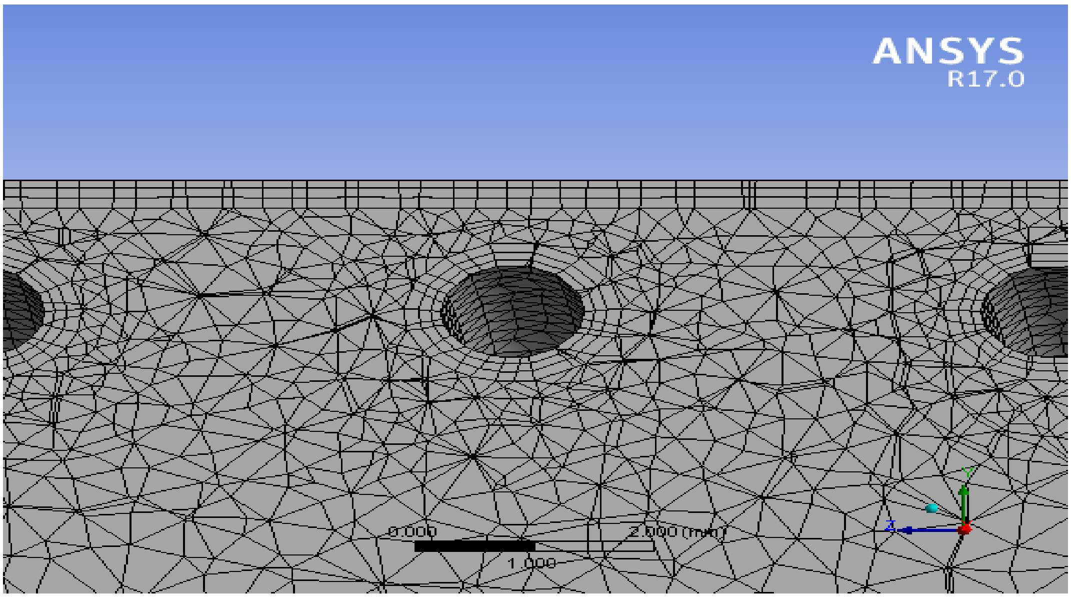


Figure 3.3 The longitudinal mesh of tube with wire coil insert and inflation layers around tube and wire coil

3.2.2 Numerical Setup of Validation

In the study of Nasr et al. [21], the working regime was turbulent. In Ansys Fluent v17$k-\varepsilon$turbulence model types are used for turbulent regime. The present work includes thermal analyses therefore energy equation must be solved. In the literature, $k-\varepsilon$model is generally used for the study related the heat transfer enhancements of a pipe with wire coil. The $k-\varepsilon$turbulence model and enhanced wall heat treatment were chosen in this study. Momentum, energy, continuity, and $k-\varepsilon$ equations were solved.The order of convergence criteria for continuity and $k-\varepsilon$was 10^{-4}. However, convergence criteria for energy equation was 10^{-6}. The pressure-velocity coupling was solved by SIMPLE algorithm. Momentum and energy equations were solved by second order upwind. The summary of numerical setup is listed in Table 3.4.

Table 3.4 Numerical setup outline for validation

Setup and solution methods	Type second , order , and solution degree
material	Water
Model	$\mathrm{k}-\varepsilon$ turbulence model
Solution method	SIMPLE algorithm
Convergence criteria	Energy= 10^{-6},Momentum, continuity and $\mathrm{k}-\varepsilon=10^{-4}$
Equation solver	second order up wind for momentum and Energy equation

3.2.3 Boundary Conditions of Validation

In the study Nasr et al. [21], the working regime was turbulent. Reynolds number was in the range of 4294.01 to 39838.31. However, the Reynolds number was in the To calculated Nusselt numbers .Inlet temperature of the fluid was 303K and wall temperature was changing heat flux from 353.688$\mathrm{w/m^2}$ to 1432.394 $\mathrm{w/m^2}$ similar with the study of Nasr et al. [21] and the Reynolds number was in the To calculated fraction factor of the range 3149 to 31487 and Inlet temperature water 303k and temperature of wall zero similar with the study of Nasr et al. [21] The using

Reynolds number, turbulence intensity, and velocities for validation are listed in Table 3.5A and Table 3.5B.

Table 3. 5A Velocity ,Reynolds number and turbulent intensity for validation

Reynolds number	velocity	turbulent intensity
4294.01	0.33947	0.056236
13192.03	1.042916	0.048874
20272.54	1.602677	0.046319
27320.71	2.159881	0.044623
39838.31	3.149479	0.042568

Table 3. 5B Velocity ,Reynolds number and turbulent intensity for validation

Reynolds number	velocity	turbulent intensity
3149	0.248949	0.058459
6747	0.533394	0.053147
17933	1.422464	0.047015
21366	1.689122	0.046016
31487	2.489253	0.043838

According to inlet velocity, Reynolds number and turbulent intensity were calculated. When Reynolds number was calculating, hydraulic diameter of the pipe was used by using equation 8.

$$Re = \frac{\rho . u . D\ hyraulic}{\mu} \qquad (7)$$

$$Dhydraulic = \frac{4 . Area}{perimeter} = 12.71mm \qquad (8)$$

$$Turbulent\ intensity\ = I = 0.16\ Re^{-\frac{1}{8}} \qquad (9)$$

3.2.4 Numerical Validation Results

The figures (3.5,3.6) show the numerical validation result of Nasr et al. [21] These figures show the Nusselt number against Reynolds number. When these data were calculated ,mean temperature of the flow was used and mean velocity of flow was also used. Nusselt number and friction were calculated below equation 11, 14.

$$Re = \frac{\rho . u . D\ hyraulic}{\mu} \tag{10}$$

$$Nu = \frac{h . D\ hydraulic}{k} \tag{11}$$

$$h = \frac{m . Cp . (To - Ti)}{A(Tw - Tb)} \tag{12}$$

$$Tb = \frac{Tin + Tout}{2} \tag{13}$$

$$F = \frac{\Delta P}{L}\frac{D}{2\rho U^2} \tag{14}$$

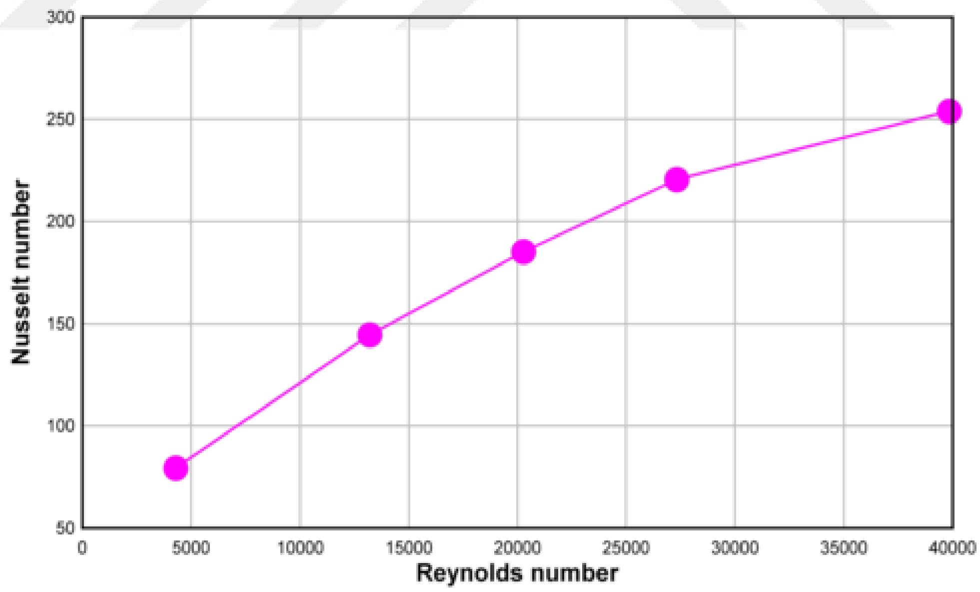


Figure 3.4 Reynolds number versus Nusselt number

As understanding from Figure3.4, the Nusselt number deviation between numerical result and the data of Nasr et al. [21] was obtained from 1.346 % When Reynolds number was increased, Nusselt number and ddeviation also increased.

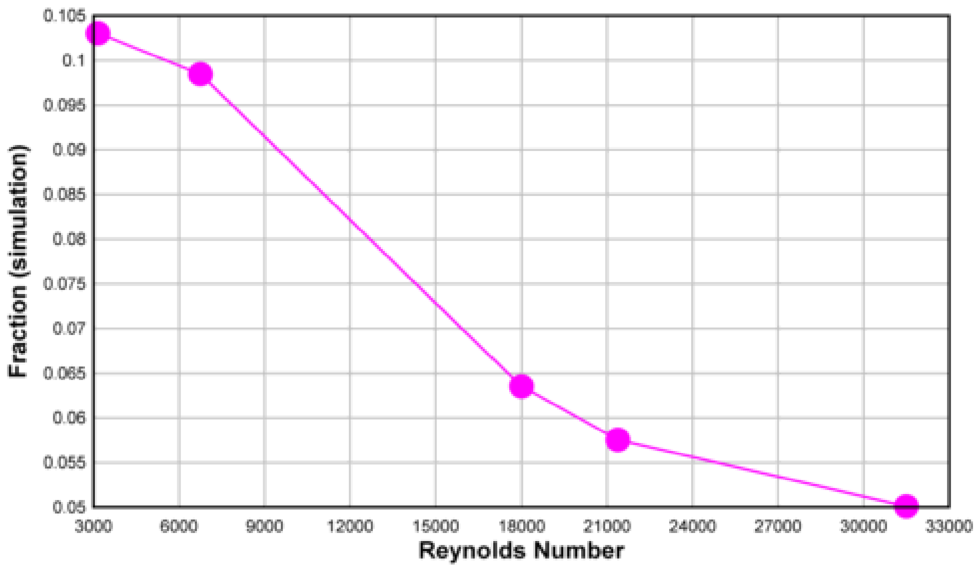


Figure 3.5 Reynolds number versus Friction

understanding from Figure 3.5 , the friction deviation between numerical result and the data of Nasr et al. [21] was calculated in the range of 6.82%.

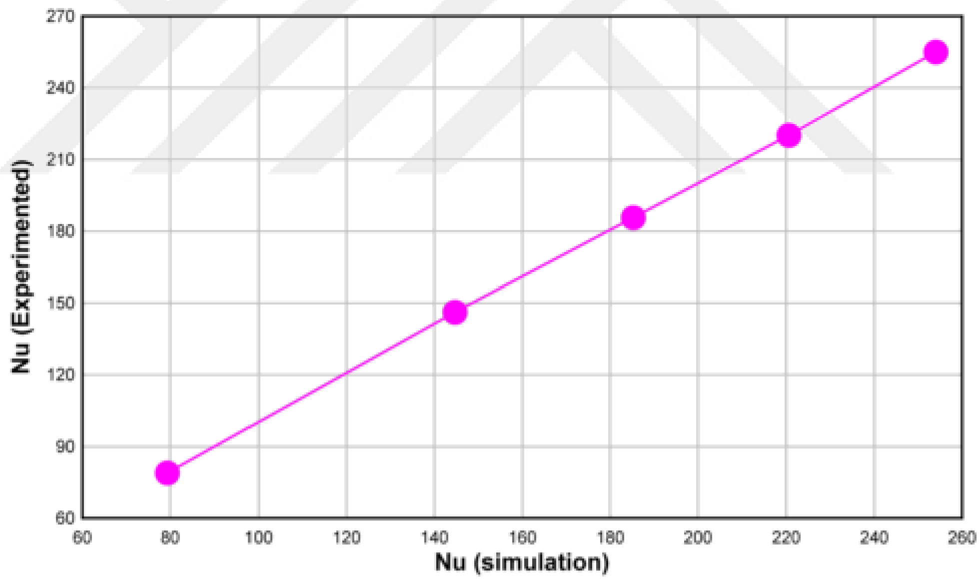


Figure 3.5 Nusselt Number(simulation) versus Nusselt Number (Experimental)

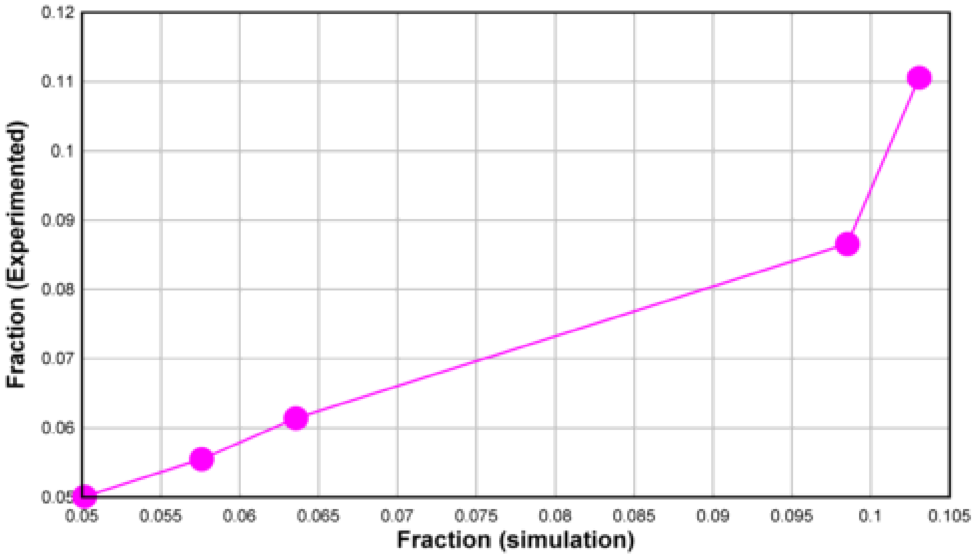


Figure 3.6 Friction (simulation) versus Friction (Experimental)

3.3 Numerical Validation of Smooth Pipe

The diameter of the pipe 16mm with Nusselt number of smooth pipe depends on the pipe length. The pipe length was equal to 510 mm to insure the thermal entry length.

$$Re = \frac{\rho . u . D \text{ hyraulic}}{\mu} \tag{15}$$

Nusselt number can be calculated from the equation below:

$$Nu = \frac{h . D}{K} \tag{16}$$

The friction factor can be illustrate on the grounds of an equipollent shear force in the flow direction per unit of heat transfer (or friction area) Whether this equivalent shear force is a true viscous shear or a primarily a pressure force. For the surface considered the pressure drop across the pipe is due to the viscous shear. It can be calculated by measuring the pressure inlet and down flow of the tested pipe and according to the equation:

$$F = \frac{2 . \Delta P . D}{\rho . U^2 \text{ mean } L} \tag{17}$$

3.3.1 Mesh of Smooth Pipe

The mesh difference between pitch for 4.5mm and smooth pipe was number of mesh elements. Because the gap between wire coil and wall of pipe was too small. However, there was no any mesh limitation coming from the wire coil in the smooth pipe. This is the advantage of smooth pipe in decreasing the numbers of mesh element. When the numbers of mesh element are decreased, the solution time is also decreased. Table 3.6 shows the mesh independency smooth pipe. andFigures 3.8-10 show the inlet mesh,wall surface mesh of smooth pipe, andmesh of longitudinal section of the pipe.

Table 3.6 Shows the mesh independency smooth pipe

NUMBEROF MESHELEMENTS	REYNOLDS NUMBER	NUSSELT NUMBER	FRICTION
2781153	5000	25.94328	0.09821
1006577	5000	26.8287	0.0999

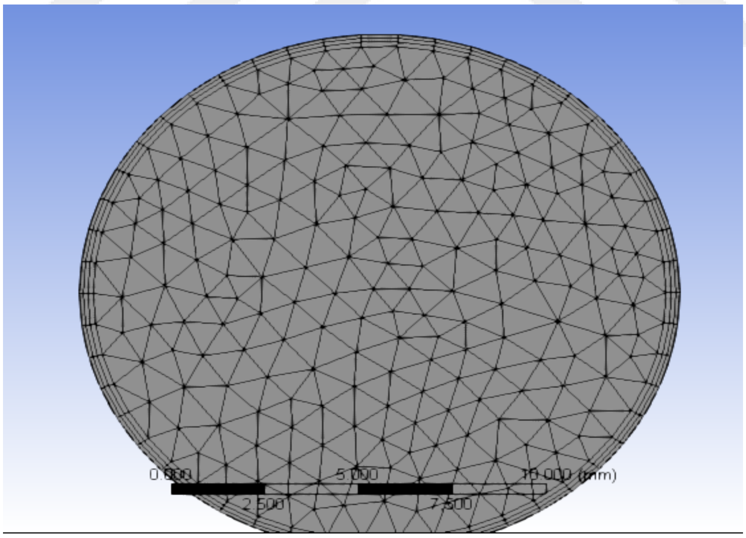


Figure 3.7 Inlet mesh of smooth pipe

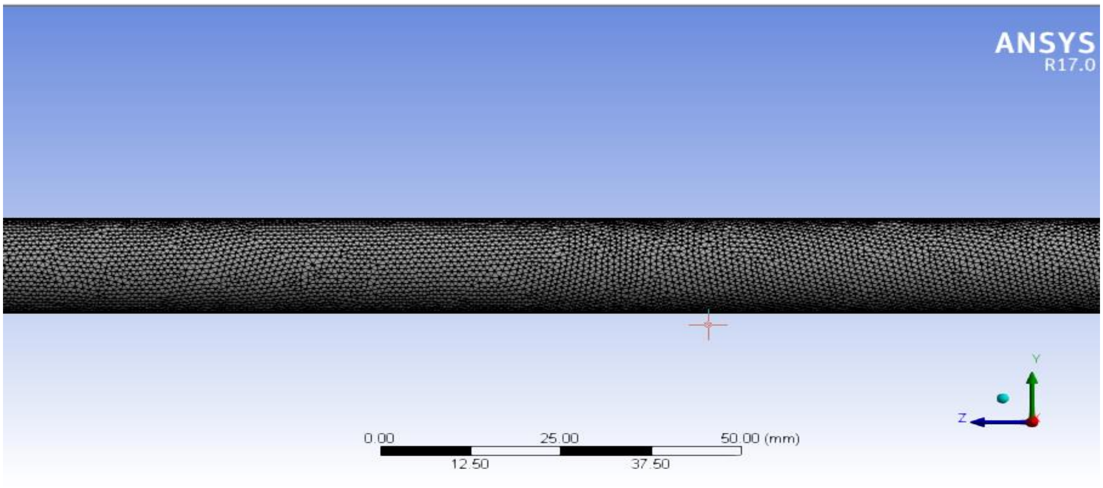


Figure 3.8 The wall surface mesh smooth pipe

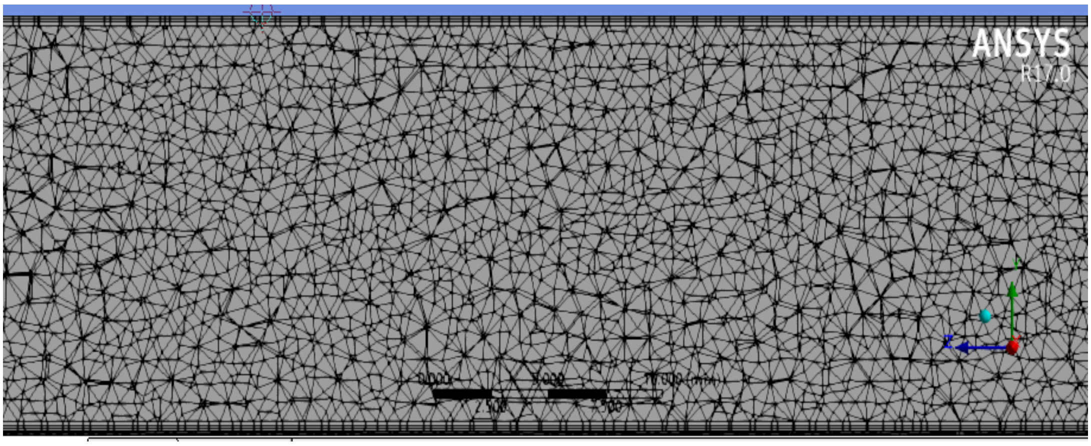


Figure 3.9 The mesh of longitudinal section smooth pipe

3.3.2 Numerical Setup of Smooth pipe

The standard$k-\varepsilon$ models are used to model turbulent flow in pipe based on the Reynolds number each viscous turbulent flow respectively. The choice of the example is confirmed on the Reynolds number from 5000-25000. viscous turbulent model is used . the order of convergence criteria for continuity and $k-\varepsilon$ was 10^{3-}However convergence criteria for energy equation was 10^{6-}. The pressure- velocity coupling was solved by SIMPLE algorithm. Momentum and energy equations were solved by second order up wind.

Table 3.7 Numerical setup of smooth pipe

Setup and solution methods	Type second order , and solution degree
Material	Air
Model	$k-\varepsilon$ turbulence model
Solution method	SIMPLE algorithm
Convergence criteria	Energy= 10^{-6},Momentum, continuity and $k-\varepsilon=10^{-3}$
Equation solver	second order up wind for momentum and Energy equation

In this design, air was used as a working fluid therefore physical properties of air based on the temperature in the range of working temperature must be insert into Ansys Fluent v17. Thermo physical properties (density, dynamic viscosity, thermal conductivity, and specific heat) of air are obtained by a fitting procedure using the data by Assist. Prof. Dr. Fuat YILMAZ, and given by the below equation:

$$\rho(T)=5.2743141-0.032058887*T+0.00010144429*T^2-1.7632128*10^{-7}*T^3+1.5972391*10^{-10}*T^4-5.8969555*10^{-14}*T^5 \quad (18)$$

$$\mu(T)=-1.8863695*10^{-6}+1.0488067*10^{-7}*T-1.9202761*10^{-10}*T^2+3.0654976*10^{-13}*T^3-2.7810282*10^{-16}*T^4+1.0495643*10^{-19}*T^5 \quad (19)$$

$$k(T)=0.011221616-2.4090078*10^{-5}*T+4.6890125*10^{-7}*T^2-1.0489067*10^{-9}*T^3+1.0882259*10^{-12}*T^4-4.4011087*10^{-16}*T^5(20) \quad (20)$$

$$C_p(T)=567.13174+5.4217196*T-0.025812614*T^2+5.875834*10^{-5}*T^3-6.3573659*10^{-8}*T^4+2.6621072*10^{-11}*T^5 \quad (20)$$

$$Pr(T)=0.53988791+0.0031265297*T-1.6264787*10^{-5}*T^2+3.6645885*10^{-8}*T^3-3.8582455*10^{-11}*T^4+1.5660501*10^{-14}*T^5 \quad (21)$$

3.3.3 Numerical Results of Smooth pipe

beforehand to the Numerical using the swirl pipe combined with the wire coil insert around wire coil , the Nusselt number and the friction factor in a plain pipe were calculated. The CFD data were, and then compared with the results given by the well known correlations under a similar state, in order to suppose the validity of the plain pipe.

$$Nu = \frac{h.D}{k} \tag{23}$$

$$F = \frac{2.\Delta P.D}{\rho.U^2 \text{ mean } L} \tag{24}$$

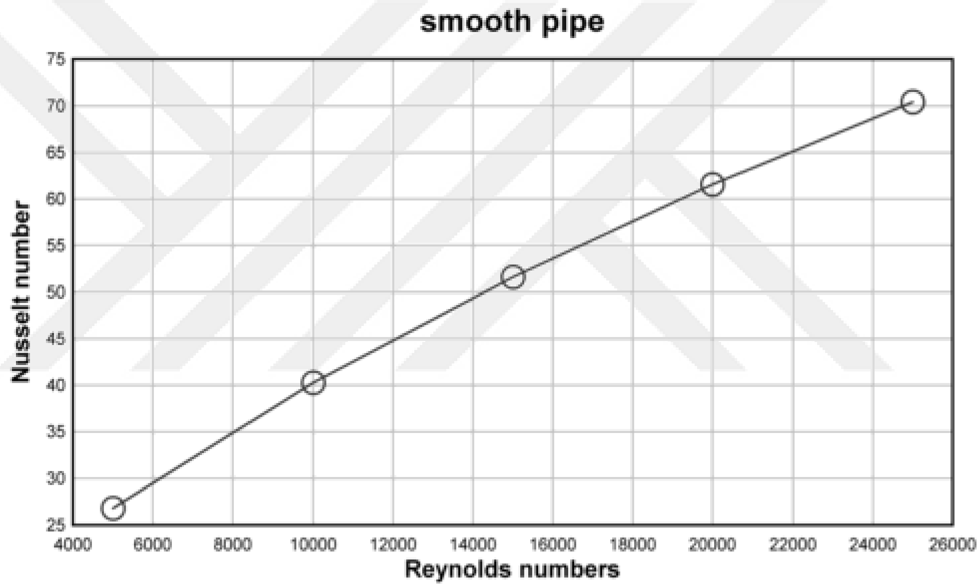


Figure 3.10 Reynolds number versus Nusselt Number of numerical smooth pipe

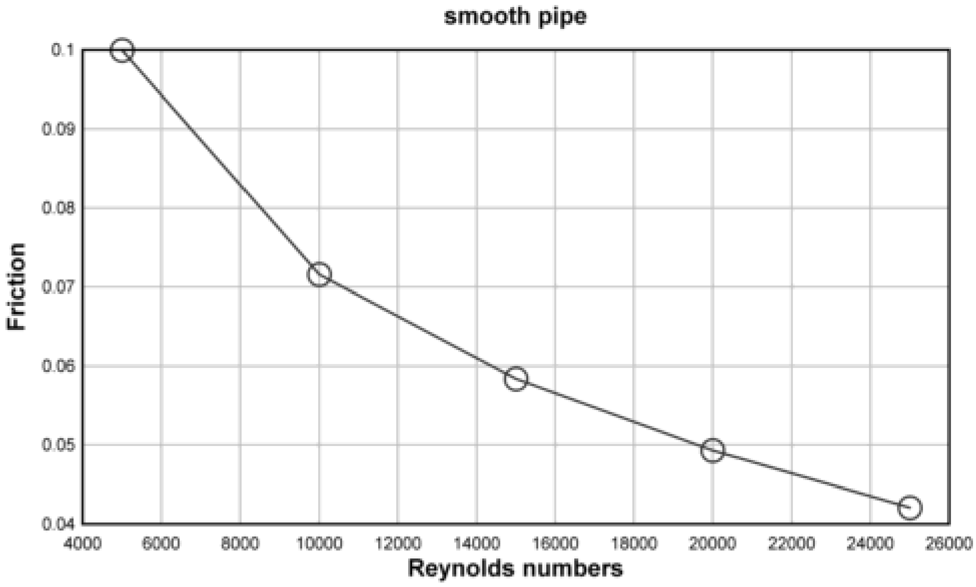


Figure 3.11 Reynolds number versus Friction of numerical smooth pipe

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Introduction

The objective of this thesis is an numerical study for the enhancement of heat transfer on the air in the heat exchangers by using wire insert around wire coil with different diameters, and different pitches. and in three different types ,circular ,Square ,triangular. All geometries generated using Solid Works 2014and export to Ansys fluent v17 with .Comparison of the results from both experiments (smooth pipe and the wire coil insert around wire coil with pipe) is clearly revealing better enhancement of thermal performance with wire coil insert around wire coil .

4.2.1 Numerical Solution for Circular Wire Coil Insert Around Circular Wire Coil Type One

Heat exchanger is modeled using solid works software and export to Ansys fluent v 17 . It is an assembly of all the parts. pipe with circular wire coil insert around circular wire coil , heatexchanger is modeled according to the dimensions of virtually available heat exchanger. and Table 4.1 geometrical parameters.

Table 4.1 Shows the geometrical parameterscircular wire coil insert around circular wire coil type one

Geometrical parameters	
D pipe	16 mm
d insert	14.5mm
Length of pip , L	510mm
Length of coil, l	500mm
pitch primary coil	16mm
pitch secondary coil	1.44mm
Pp/D	1 mm
Ps/D	0.09 mm
ep /D, es/D	0.075 mm, 0.0625 mm
dp wire coil,ds wire coil	1.2 mm, 1 mm

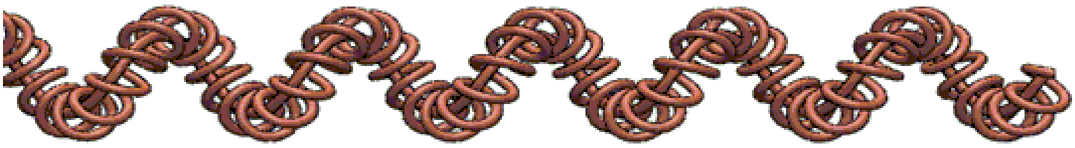


Figure 4.1 Circular wire coil insert around circular wire coil type one

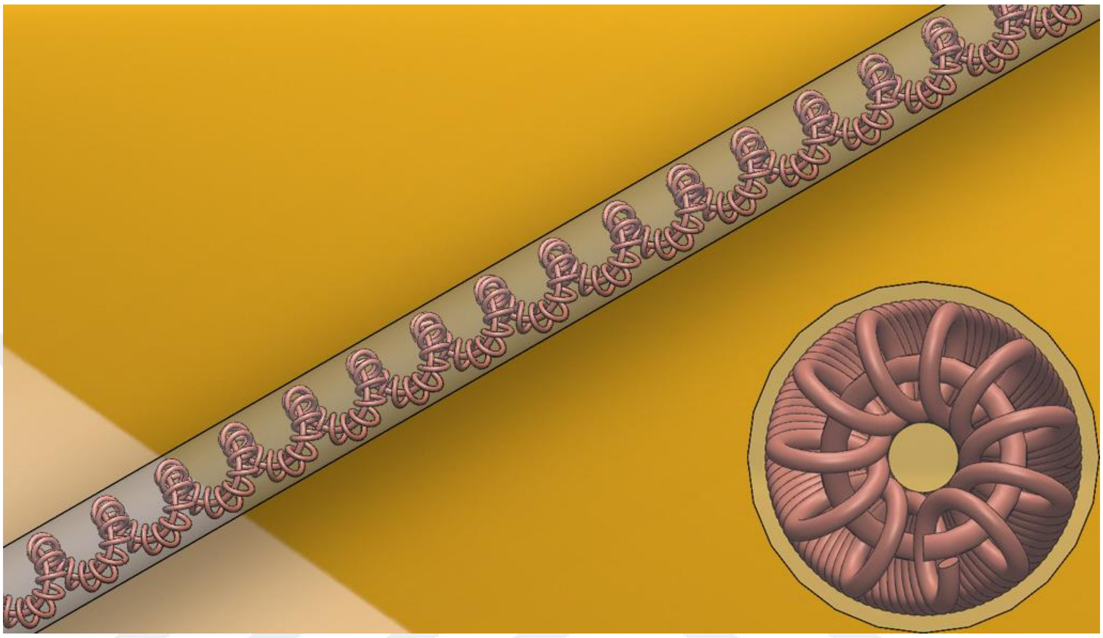


Figure 4.2 Geometry of the circular wire coil insert around circular wire coil in tube fitted type one

4.2.2 Mesh for Circular Wire Coil Insert Around Circular Wire Coil Type One

two different meshes, with 3498971, 5698971, cells, are considered initially. A mesh independent study was performed to verify the results. The results of heat transfer rate and outlet temperatures are compared and the discrepancies between the results are less than 0.5% table(4.2). The intermediate mesh level is chosen for all the simulations, which decrease simulation time by 41.76% and gives comparable results (0.5% deviation) to the very fine mesh.

Table 4.2 Shows the mesh independency of the circular wire coil insert around circular wire coil type one

NUMBEROF MESHELEMENTS	REYNOLDS NUMBER	NUSSELT NUMBER	FRICTION
3498971	5000	55.5321	1.067574
5698971	5000	55.2012	1.02389

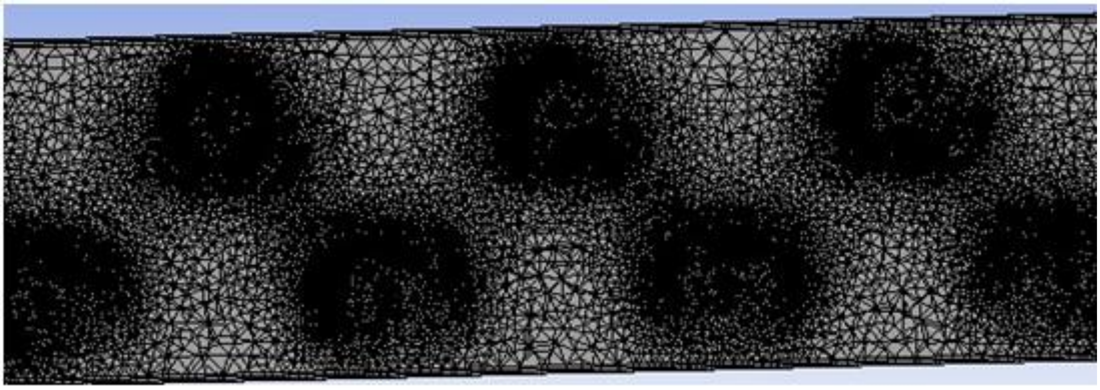


Figure 4.3 The longitudinal mesh of pipe with circular wire coil insert around circular wire coil type one

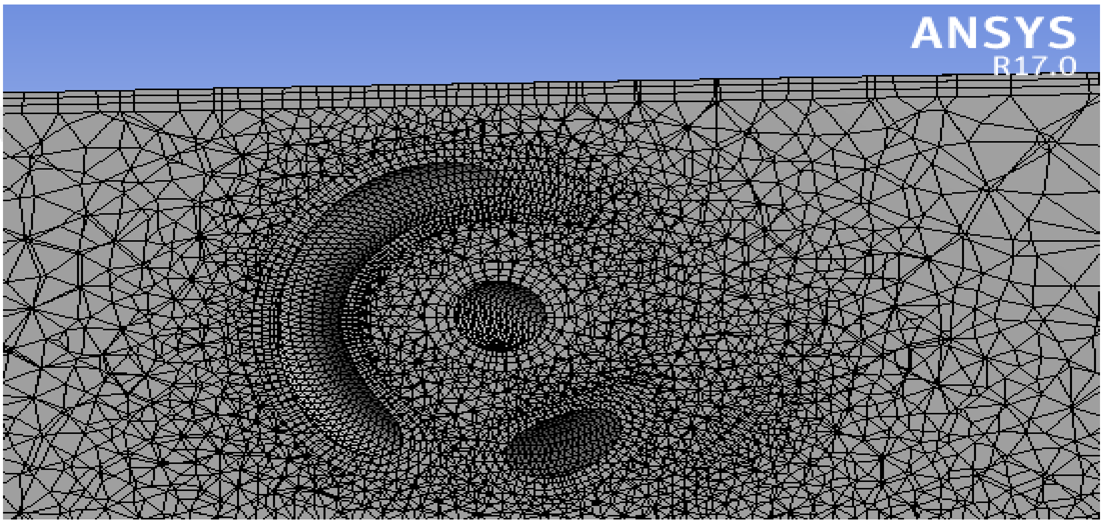


Figure 4.4 Inflation layers mesh around two circular wire coil insert type one

4.2.3 Numerical Setup of Circular Wire Coil Insert Around Circular Wire Coil Type One

The $k-\varepsilon$. turbulence model was used in this case. The program solved the momentum , energy , continuity , and $k-\varepsilon$ equation. The order of convergence criteria for continuity and $k-\varepsilon$ is 10^{-3}, However convergence criteria of energy equation is 10^{-6}, The pressure velocity coupling is solved by SIMPLE algorithm. Momentum and energy equation are solved by second order upwind. The summary of numerical setup is listed Table 4.3.

Table 4.3 Numerical setup procedure for circular wire coil insert around circular wire coil type one

Setup and solution methods	Type order , and solution degree
Material	Air
Model	$k-\varepsilon$ turbulence model
Solution method	SIMPLE algorithm
Convergence criteria	Energy= 10^{-6},Momentum, continuity and $k-\varepsilon = 10^{-3}$
Equation solver	second order up wind for momentum and Energy equation

4.2.4 Boundary Conditions for Circular Wire Coil Insert Around Circular Wire Coil Type One

The boundary condition of the study is expressed in table 4.4 Boundary conditions of the study were included constant temperature at the inlet, constant wall heat flux, no slip conditions at the wall, and uniform velocity profile at the inlet.

Table 4.4 Boundary conditions of circular wire coil insert around circular wire coil type one

Boundary condition	
Reynolds number range	5000-25000
Working fluid	Air
Temperature inlet	288k
Heat flux	$500\mathrm{w/m^2}$

$$\mathrm{Re} = \frac{\rho.\mathrm{U}.\mathrm{D_{hyraulic}}}{\mu} \quad (25)$$

$$\mathrm{Tb} = \frac{\mathrm{Tin + Tout}}{2} \quad (26)$$

$$F = \frac{2.\Delta P.D}{\rho.U^2{}_{mean}\ .L} \quad (27)$$

$$h = \frac{m.C_{p.}\ (To - Ti)}{A.(Tw - Tb)} \quad (28)$$

$$Dhydraulic = \frac{4.Area}{perimeter} = 13.71mm \quad (29)$$

$$Nu = \frac{h.D_{hyraulic}}{k} \quad (30)$$

$$PEC = \left(\frac{Nu_a}{Nu_o}\right)\left(\frac{F_a}{F_o}\right)^{-1/3} \quad (31)$$

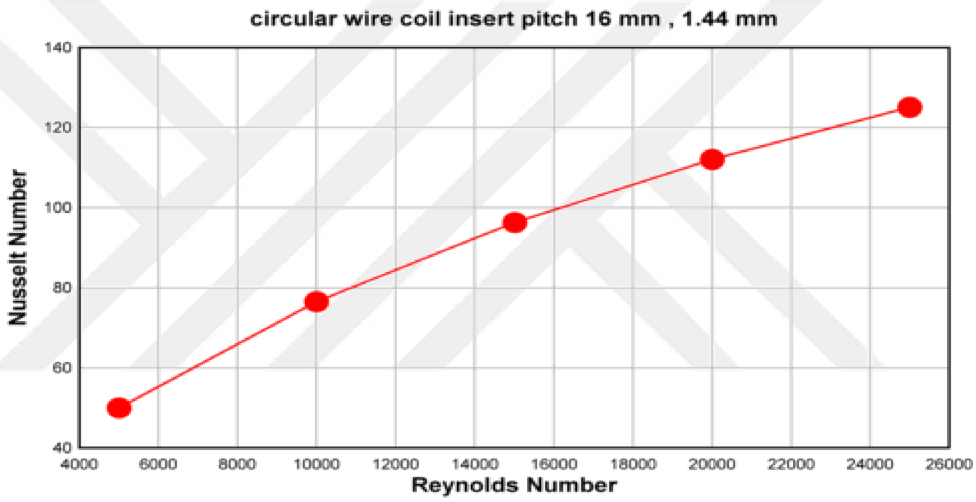


Figure 4.5 Reynolds number versus Nusselt Number of circular wire coil insert around circular wire coil typeone

As understanding from Figure 4.5, Nusselt number increased with increasing Reynolds number. The starting point of Nusselt number was 50 at Reynolds number 5000 and the last point of Nusselt Number reached 125.13 at Reynolds number 25000, approximately.

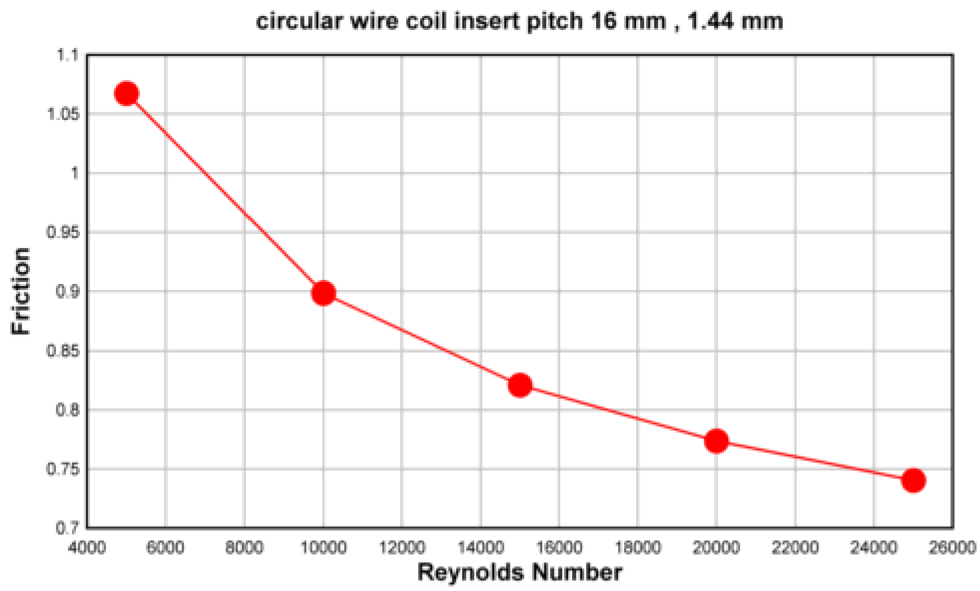


Figure 4.6 Reynolds number versus Friction of circular wire coil insert around circular wire coil type one

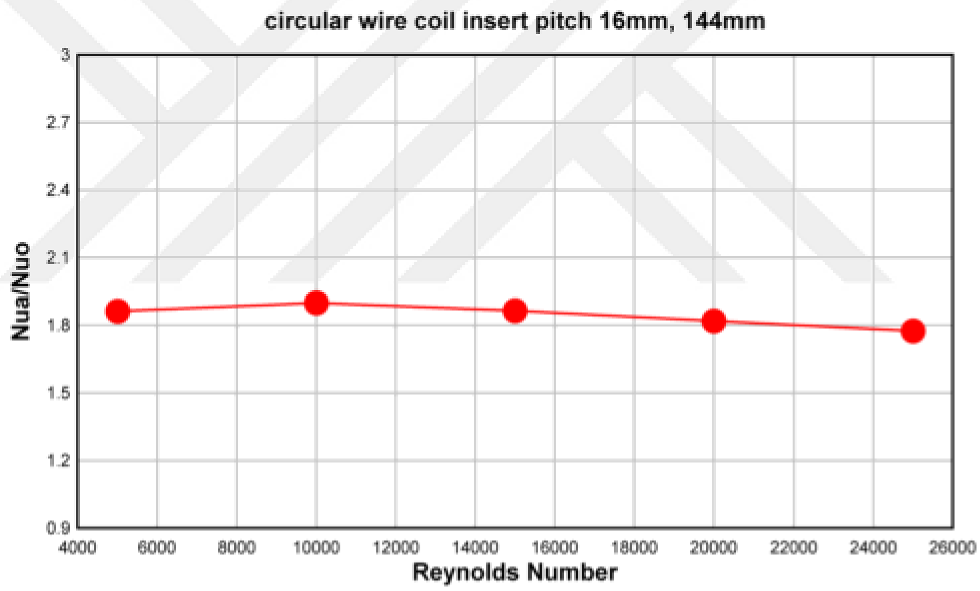


Figure 4.7 Reynolds Number via Nua/Nuo for circular wire coil insert around circular wire coil type one

As understanding from Figure 4.6 Friction decrease with increasing Reynolds number The starting point of 1.067574 at Reynolds number 5000 and the last point of Friction 0.740402 reached at Reynolds number 25000, approximately.

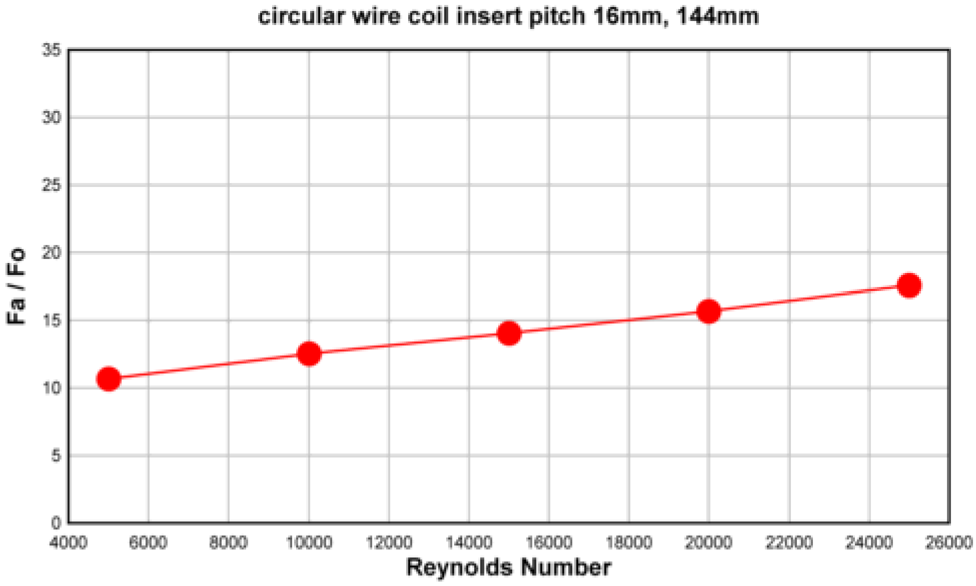


Figure 4.8 Reynolds Number via Fa/Fo for circular wire coil insert around circular wire coil type one

As understanding from Figure 4.7 and Figure 4.8, Nusselt number decreased with increasing Reynolds number. changed from1.8640to 1.77 The highest value of was taken at Reynolds number 5000. The Fa/Fo, changed from 10.680 to 17.592. The highest value of Fa/Fo was taken at Reynolds number 25000.

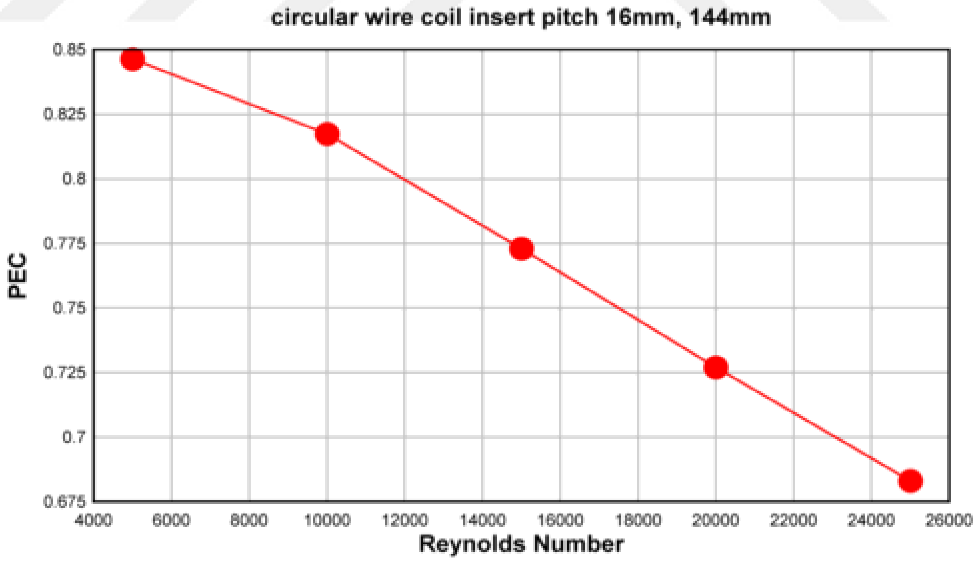


Figure 4.9 Reynolds Number via PEC for circular wire coil insert around circular wire coil typeone

4.2.5 Performance Evaluation Criteria for Circular Wire Coil Insert Around Circular Wire Coil Type One

PEC depends on Nusselt Number and friction and it is calculated by using equation 31. in this equation pp express constant pumping . Nua and fa express the Nusselt Number and friction of the pipe with circular wire coil insert around circular wire coil and Nuo and Fo express the Nusselt Number and friction of smooth pipe . In order to predict the effect of enhancement technique , it is suggested to evaluate the performance on the basis of the enhancement ratio for this study. PEC for circular wire coil insert around circular wire coil type one was calculated with using equation 31 Figure 4. 9 shows the PEC of circular wire coil insert type one versus Reynolds number.

4.2.6 Results and Discussion for Circular Wire Coil Insert Around Circular Wire Coil Type One

In this case, primary pitch coil ratio was equal to 1 and pitch secondary coil ratio was equal to0.09 . As understanding from the literature [10, 15, 22], lower pitch ratio has higher Nusselt number. The using formulas to calculate the results were similar with the other cases. Figure 4. 5 shows the effect of Reynolds number on Nusselt number and Figure 4. 6 shows the effect of Reynolds number on friction.

4.3.1 Numerical Solution for Circular Wire Coil Insert Around Circular Wire Coil Type Two

Table 4.5 Express the geometrical parameters for circular wire coil insert around circular wire coil type two

Geometrical parameters	
D pipe	16 mm
d insert	14mm
Length of pip , L	510mm
Length of coil, l	500mm
pitch primary coil	16mm
pitch secondary coil	2.72 mm
Pp/D	1 mm
Ps/D	0.17 mm
ep /D, es/D	0.075 mm, 0.0625 mm
dp wire coil,ds wire coil	1.2 mm, 1 mm

Figure 4.10 Circular wire coil insert around circular wire coil type two

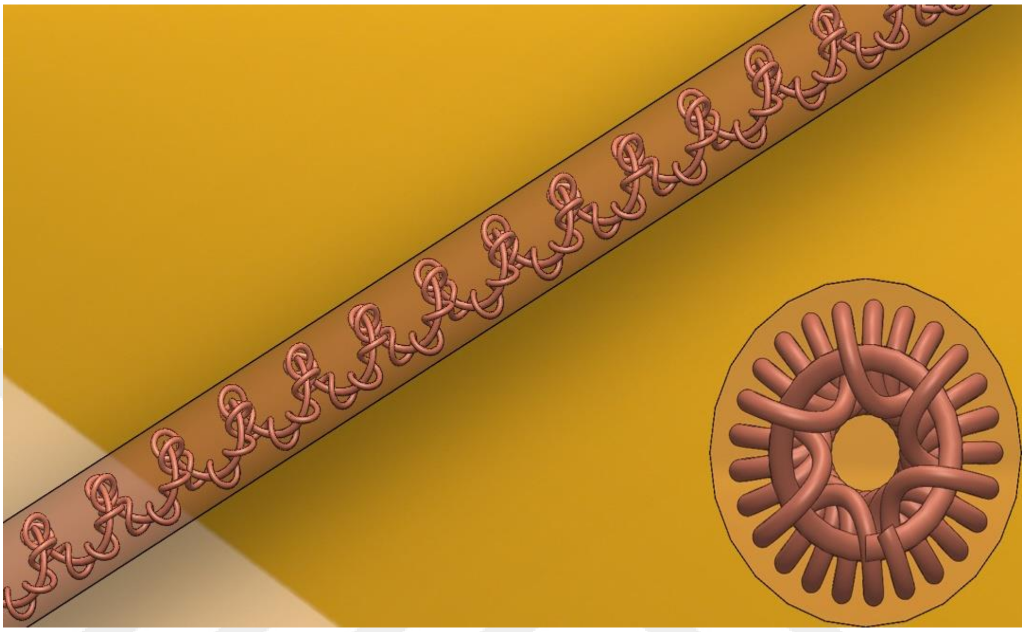


Figure 4.11 Geometry of the circular wire coil insert around circular wire coil in tube fitted type two

4.3.2 mesh for circular wire coil insert around circular wire coil type two

Mesh is generated using Ansys fluent v 17 ,was fine meshed to capture thermal and velocity boundary layer effects ,two different meshes, with 14142266, 15318970, elements were used for analyses. Skewness of the mesh was 0.83893 and orthogonal quality of mesh was 0.22331. According to Users guide of Ansys Meshing, skewness of mesh should be lower than 0.94 and orthogonal quality of mesh should be greater than 0.05.

Table 4.6 Shows the mesh independency of the circular wire coil insert around circular wire coil type two

NUMBEROF MESHELEMENTS	REYNOLDS NUMBER	NUSSELT NUMBER	FRICTION
14142266	5000	47.8520	0.39054778
15318970	5000	47.2922	0.38818825

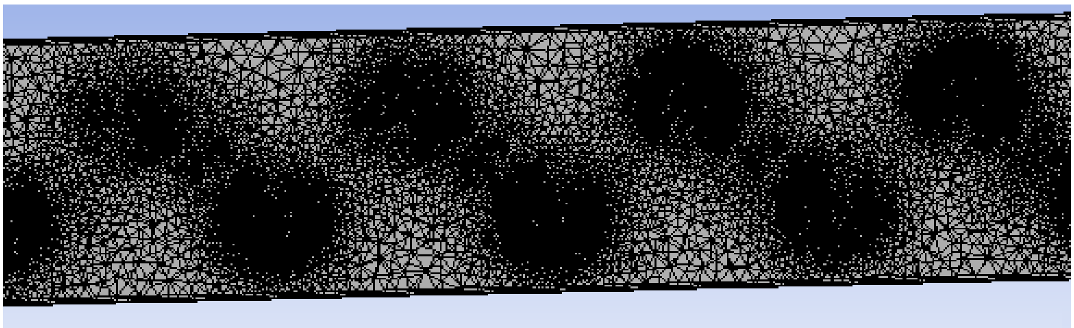


Figure 4.12 The longitudinal mesh of pipe with circular wire coil insert around circular wirecoil type two

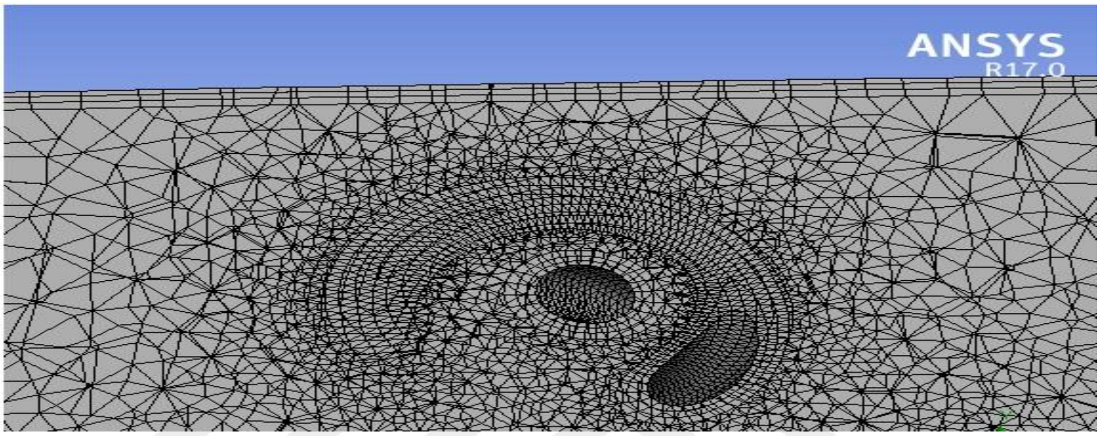


Figure 4.13 Inflation layers mesh around two circular wire coil insert type two

4.3.3 Numerical Setup of Circular Wire Coil Insert Around Circular Wire Coil Type Two

Numerical simulation analyses in Ansys fluent v 17 will be carried out to study thermal hydraulic properties of air flow inside a circular tube with same tube inserts. The flow rate of the tube is considered in field of Reynolds number between 5000 and 25000 The swirling flow devices consisting of . wire coil insert around wire coil with lastly results will be compared to available . The data secured by simulation are favorable with the validation value for a smooth tube with the discrepancy Nusselt number and for the friction factor. Heat flux is more uniform the tube .The following table 4.40 shows Numerical.

Table 4.7 Numerical setup procedure for circular wire coil insert around circular wire coil type two

Setup and solution methods	Type second order , and solution degree
Material	Air
Model	$k - \varepsilon$ turbulence model

Solution method	SIMPLE algorithm
Convergence criteria	Energy= 10^{-6},Momentum, continuity and $k - \varepsilon = 10^{-3}$
Equation solver	second order up wind for momentum and Energy equation

4.3.4 Boundary Conditions for Circular Wire Coil Insert Around Circular Wire Coil Type Two

At the inlet of the heat exchanger and tube, it is assumed that the fluid which is air enters at pipe temperature, Tin 288K. The Reynolds number in the present study is ranging from 5000 – 25000 and the flow is assumed to be flowing at atmospheric pressure. The tube wall of the test section is subjected to uniform constant heat flux, which is equal to $500 w/m^2$and The wall of the tube ispresumed to be quite smooth with zero Roughness , table 4.8 show the boundary conditions .

Table 4.8 Boundary conditions of circular wire coil insert around circular wire coil type two

Boundary condition	
Reynolds number range	5000-25000
Working fluid	Air
Temperature inlet	288k
Heat flux	$500 w/m^2$

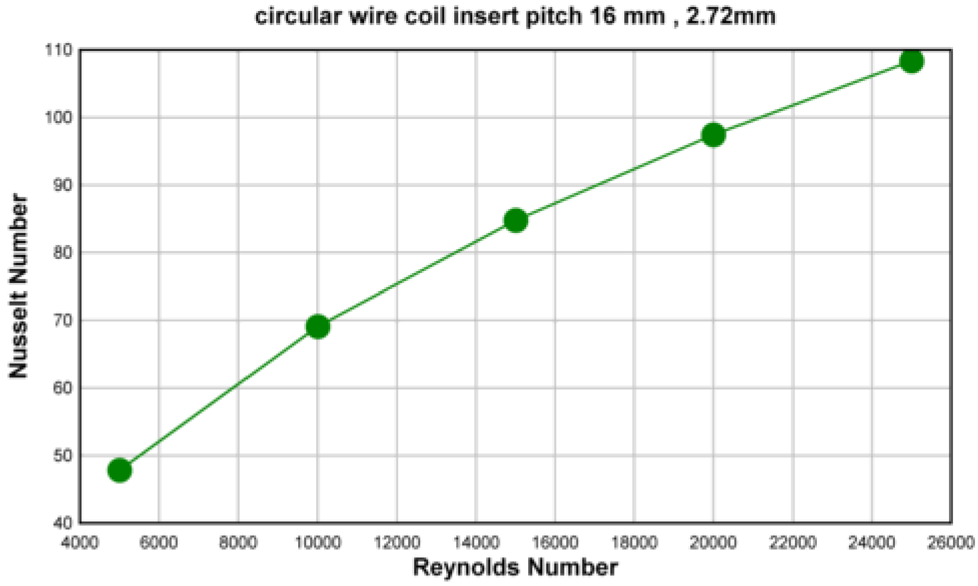


Figure 4.14 Reynolds number versus Nusselt Number of circular wire coil insert around circular wire coil type two

As understanding from Figure 4.14, Nusselt number increased with increasing Reynolds number. The starting point of Nusselt number was 47.85 at Reynolds number 5000 and the last point of Nusselt Number reached 108.83 at Reynolds number 25000, approximately.

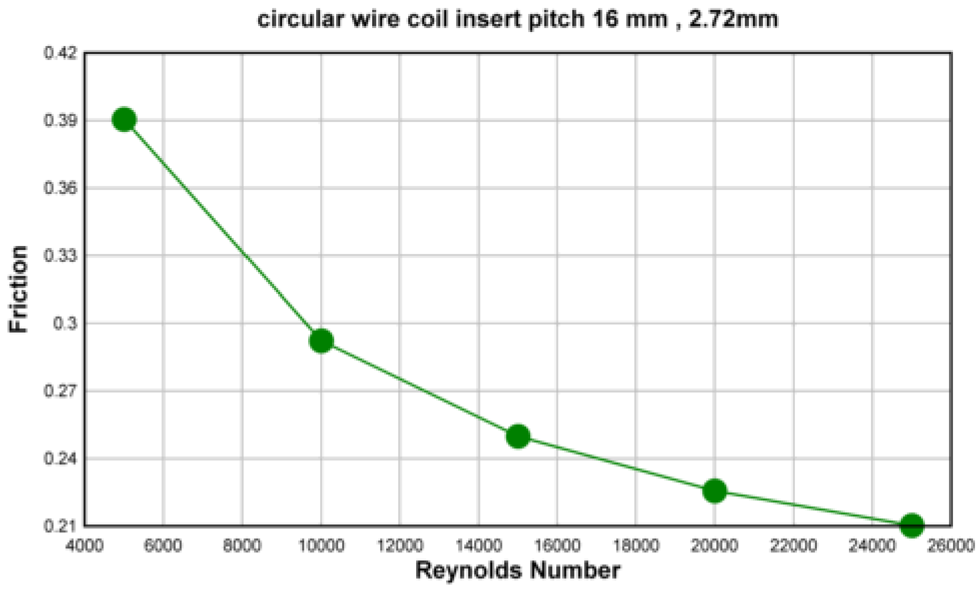


Figure 4.15 Reynolds number versus Friction of circular wire coil insert around circular wire coil type two

As understanding from Figure 4.15 Friction decrease with increasing Reynolds number The starting point of 0.390548 at Reynolds number 5000 and the last point of Friction 0.210379 reached at Reynolds number 25000, approximately.

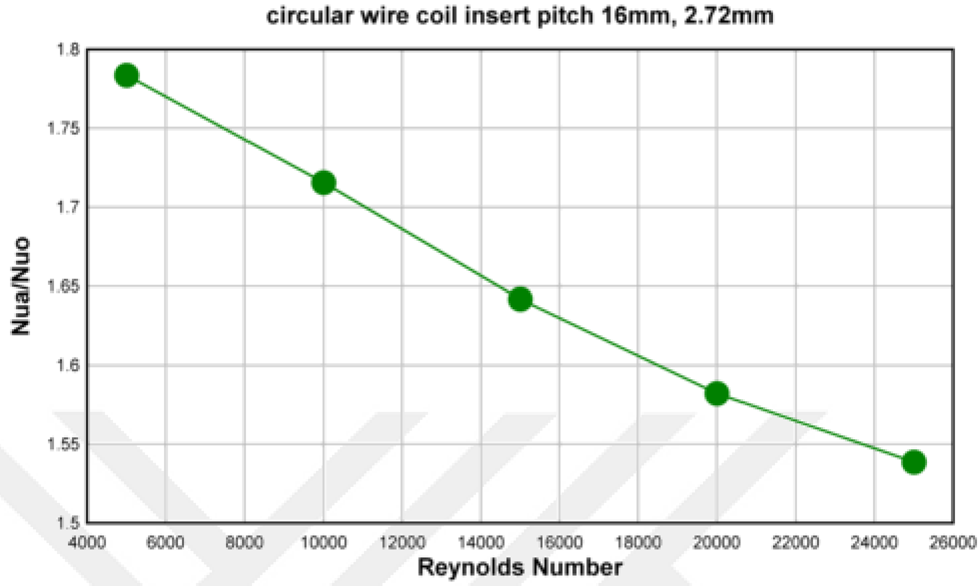


Figure 4.16 Reynolds Number via Nua/Nuo for circular wire coil insert around circular wire coil type two

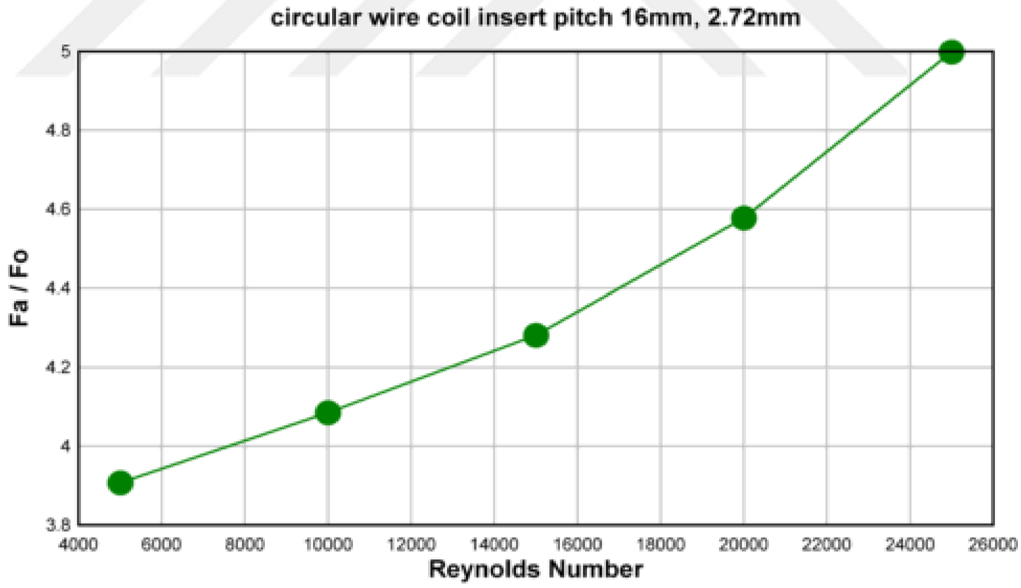


Figure 4.17 Reynolds Number via Fa/Fo for circular wire coil insert around circular wire coil type two

As understanding from Figure 4.16, Nusselt number decreased with increasing Reynolds number. changed from 1.783to 1.538 The highest value of was taken at Reynolds number 5000. The Fa/Fo, changed from 3.907 to 4.998. The highest value of Fa/Fo was taken at Reynolds number 25000.

4.3.5 Performance Evaluation Criteria for Circular Wire Coil Insert Around Circular Wire Coil Type Two

PEC for circular wire coil insert around circular wire coil type two was calculated with using equation 31 Figure 4.18 shows the PEC of square wire coil insert type one versus Reynolds number.

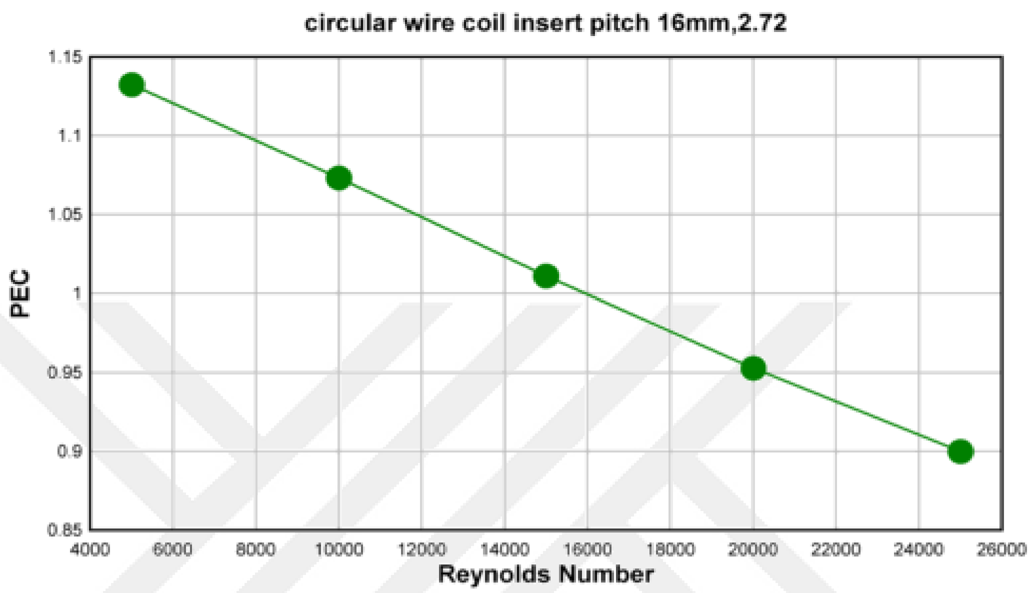


Figure 4.18 Reynolds Number via PEC for circular wire coil insert around circular wire coil type two

As understanding from Figure 4.18, when Reynolds number increased, PEC considerably decreased. PEC was lower than unity because of the friction penalty of the pipe. The friction of smooth pipe is lower than circular wire coil around circular wire coil in pipe. The highest PEC (1.132482) was observed at 5000 Reynolds number, approximately. PEC range was between 0.8999 and 1.1324821in the range of Reynolds number for this study.

4.3.6 Results and Discussion for Circular Wire Coil Insert Around Circular Wire Coil Type Two

In this case, primary pitch coil ratio was equal to 1 and pitch secondary coil ratio was equal to 0. 17 . As understanding from the literature [10, 15, 22], rise pitch ratio has low Nusselt number. The using formulas to calculate the results were similar with the other cases. Figure 4.14 shows the effect of Reynolds number on Nusselt number and Figure 4.15 shows the effect of Reynolds number on friction.

4.4.1 Numerical solution for Square Wire Coil Insert Around Square Wire Coil Type One

The geometries have been drawn in Solid Works 2014 , then exported to the Ansys Fluent v17 and table 4.3 show the geometry.

Table 4.9 Express the geometrical parameters forSquare wire coil insert around Square wire coil type one

Geometrical parameters	
D pipe	16 mm
d insert	14.5mm
Length of pip , L	510mm
Length of coil, l	500mm
pitch primary coil	16mm
pitch secondary coil	1.44mm
Pp/D	1 mm
Ps/D	0.09 mm
ep /D, es/D	0.075 mm, 0.0625 mm
dp wire coil,ds wire coil	1.2 mm, 1 mm

Figure 4.19 Square wire coil insert around Square wire coil type one

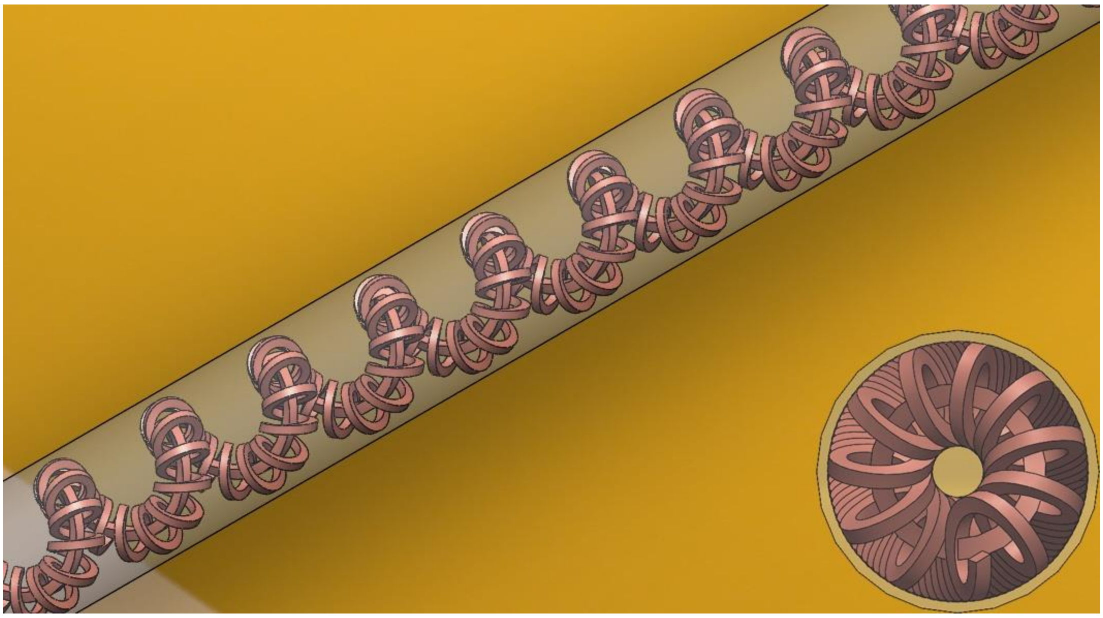


Figure 4.20 Geometry of the Square wire coil insert around Square wire coil in tube fitted type one

4.4.2 Mesh for Square Wire Coil Insert Around Square Wire Coil Type One

In any numerical analysis, mesh independence study is the most considerable step to pavilion reaching whole and dependable results. In this orientation, several models are first created in ANSYS Fluent v17 and were meshed to examine the independency of results from mesh . two different meshes, with 4694527, 4485070, elements were used for analyses Mesh test was also performed to confirm mesh independency of the results.

Table 4.10 Shows the mesh independency of the Square wire coil insert around Square wire coil type one

NUMBEROF MESHELEMENTS	REYNOLDS NUMBER	NUSSELT NUMBER	FRICTION
4694527	5000	62.1330425	1.241428543
4485070	5000	60.81825473	1.200968118

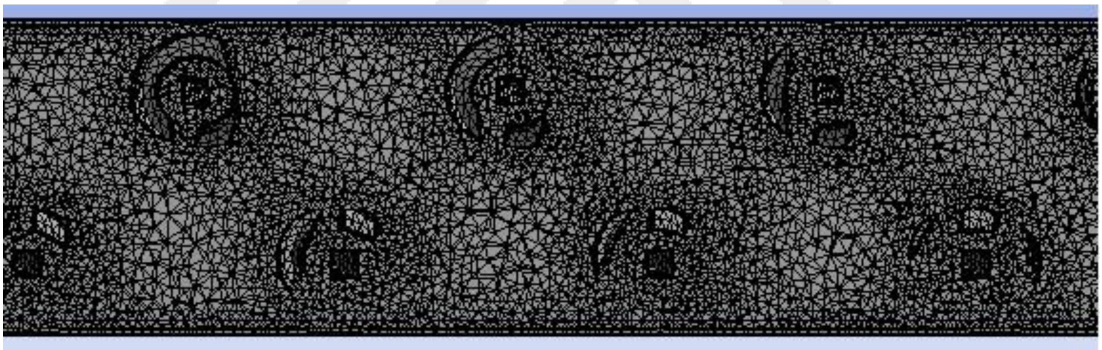


Figure 4.21 The longitudinal mesh of pipe with Square wire coil insert around Square wirecoil type one

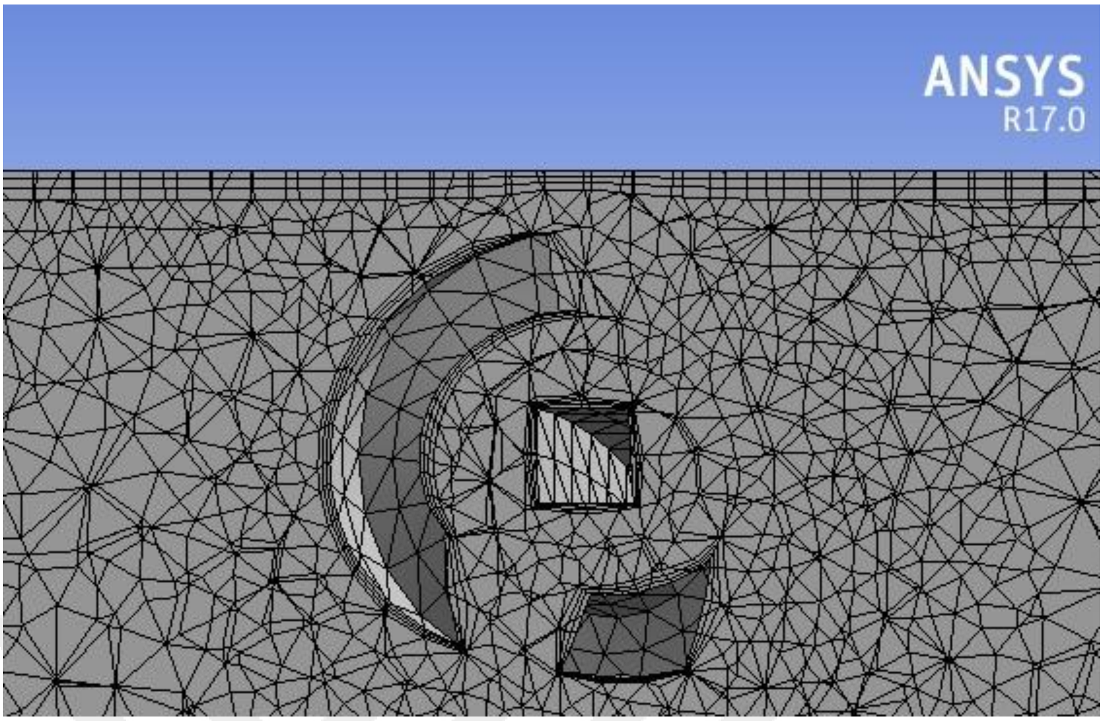


Figure 4.22 Inflation layers mesh around two Square wire coil insert type one

4.4.3 Numerical Setup of Square Wire Coil Insert Around Square Wire Coil Type One

In the present case, the dominant differential equations , momentum, and energy and The k-ε. turbulence model was used in this case were solved numerically by combine Fluent, Ansys 17 package using finite control volume approach based on SIMPLE technique. as well, the second order upwind sketch was used to solve the momentum and energy equations .furthermore, the geometry of the computational domains and the generated mesh were made with Ansys fluent A grid independency of the solution was completed for all the case studies to assert that the obtained results were not contingent to the adopted grid density. The optimum mesh chosen for 4694527elements.

Table 4.11 Numerical setup procedure for Square wire coil insert around Square wire coil type one

Setup and solution methods	Type second order , and solution degree
Material	Air
Model	$k-\varepsilon$ turbulence model
Solution method	SIMPLE algorithm

Convergence criteria	Energy= 10^{-6},Momentum, continuity and $k-\varepsilon=10^{-3}$
Equation solver	second order up wind for momentum and Energy equation

4.4.4 Boundary Condition for Square Wire Coil Insert Around Square Wire Coil Type One

Fully advanced flow and constant temperature boundary conditions were considered at the inlet 288k of the pipe . The turbulence intensity range depend on Reynolds number is between 5000 and 25000 at the inlet. The wall of the tube is presumed to be totally smooth with zero roughness, and the uniform wall temperature of the tube wall is 500 w/m^2.

Table 4.12 Boundary conditions of Square wire coil insert around Square wire coil type one

Boundary condition	
Reynolds number range	5000-25000
working fluid	Air
temperature inlet	288k
heat flux	$500w/m^2$

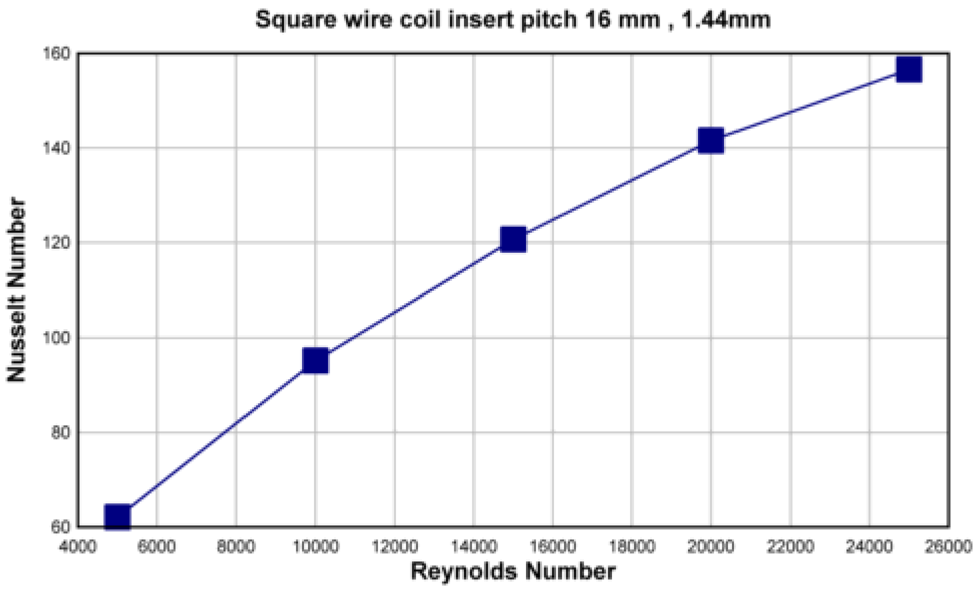


Figure 4.23 Reynolds number versus Nusselt Number of square wire coil insert aroundsquare wire coil type one

As understanding from Figure 4.23, Nusselt number increased with increasing Reynolds number. The starting point of Nusselt number was 62.13304 at Reynolds number 5000 andthe last point of Nusselt Number reached 156.6368 at Reynolds number 25000, approximately. Nusselt number is the measure of the convective heat transfer. Therefore it is important to consider this parameter to evaluate the rate of heat transfer. Figure (4.5), show the variations of heat transfer with Reynolds number at different shape of wire coil insert around wire coil with same diameter insert . These figures also show that the heat transfer for the wire insert around wire coil is highly influence on the Reynolds number than that of the smooth pipe. In each of these figures, it can be noticed the increasing of Nusselt number accompanying with Reynolds number from (5000-25000)

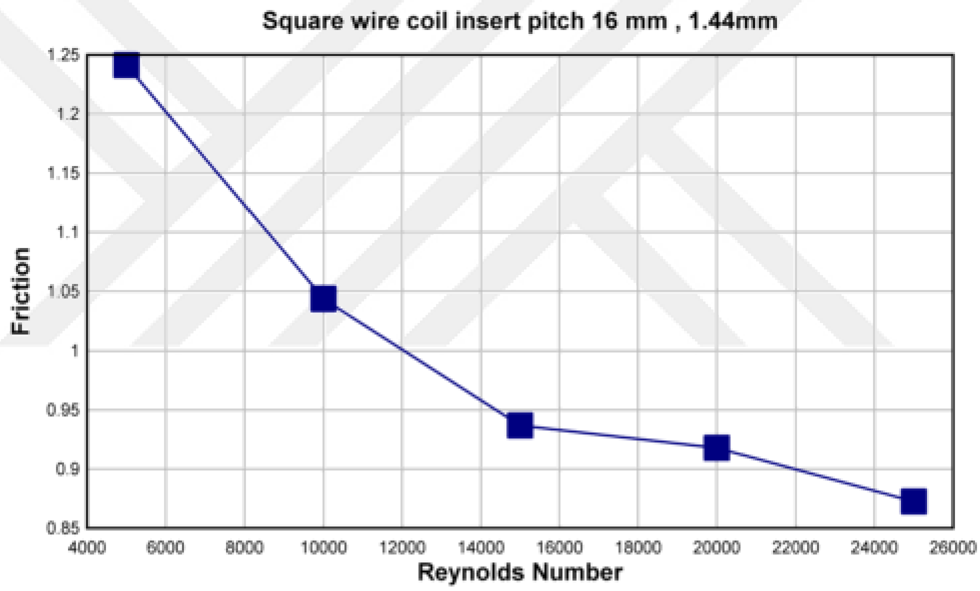


Figure 4.24 Reynolds number versus Friction of square wire coil insert aroundsquare wire coil type one

As understanding from Figure 4.24 Friction decrease with increasing Reynolds number The starting point of 1.241429 at Reynolds number 5000 and the last point of Friction 0.872469 reached at Reynolds number 25000, approximately.

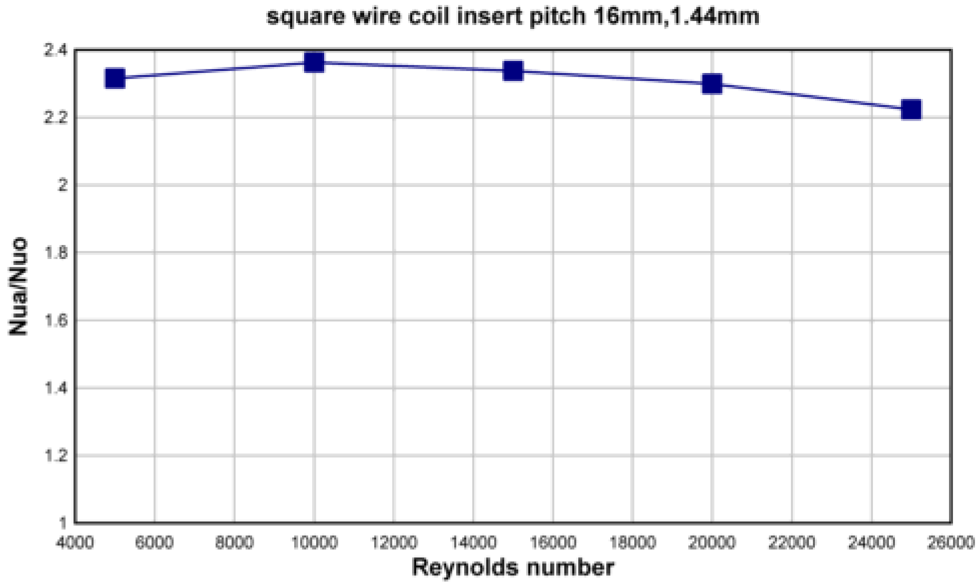


Figure 4.25 Reynolds Number via Nua/Nuo for square wire coil insert aroundsquare wire coil type one

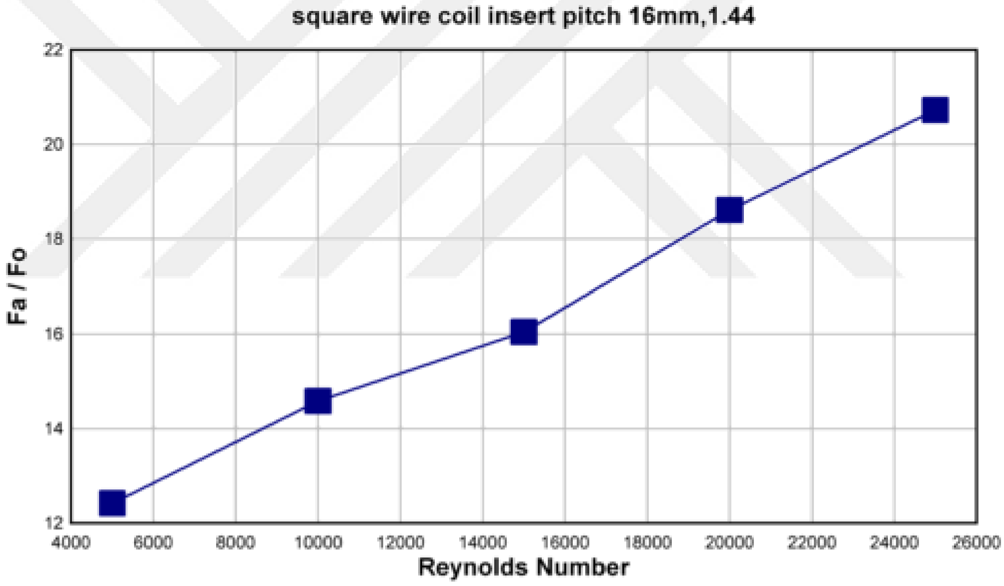


Figure 4.26 Reynolds Number via Fa/Fo for square wire coil insert around square wire coil type one

4.4.5 Performance Evaluation Criteria for Square Wire Coil Insert Around Square Wire Coil Type One

PEC for square wire coil insert around square wire coil type one was calculated with using equation 31 Figure 4.27shows the PEC of square wire coil insert around square wire coil .

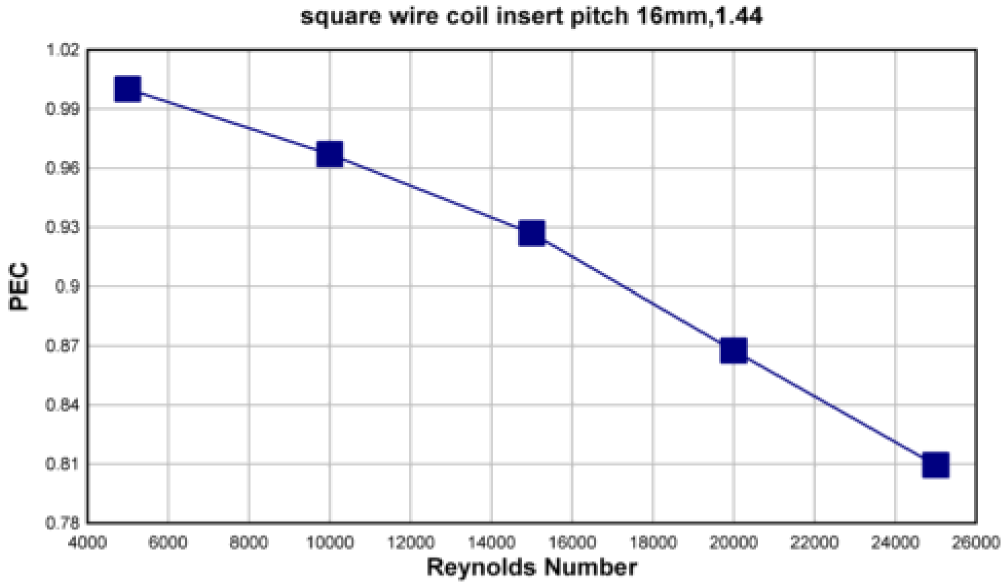


Figure 4.27 Reynolds Number via PEC for square wire coil insert around square wire coil type one

As understanding from Figure 4.27, when Reynolds number increased, PEC considerably decreased. PEC was lower than unity because of the friction penalty of the pipe. The friction of smooth pipe is lower than square wire coil aroundsquare wire coil in pipe. The highest PEC (1) was observed at 5000 Reynolds number, approximately. PEC range was between 0.80 and 1 in the range of Reynolds number for this study.

4.4.6 Results and Discussion for Square Wire Coil Insert Around Square Wire Coil Type One

In this case, primary pitch coil ratio was equal to 1 and pitch secondary coil ratio was equal to0.09 . As understanding from the literature [10, 15, 22], reduce pitch ratio and near wire coil from wall tube has height Nusselt number. The using formulas to calculate the results were similar with the other cases. Figure 4.23 shows the effect of Reynolds number on Nusselt number and Figure 4.24 shows the effect of Reynolds number on friction. If results are compared between circular wire coil around circular wire coil and square wire coil around square wire coil .I seen the improvement in heat transfer in square wire coil more than circular wire coil. The corresponding increase in mean Nusselt numbers in the heat exchanger is about 61.330% to 155.837% with smooth pipe, respectively.

4.5.1 Numerical Solution for Square Wire Coil Insert Around Square Wire Coil Type Two

Test section geometry is created for all the inserts shown in Table 4.13

Table 4.13 Express the geometrical parameters for square wire coil insert around square wire coil type two

Geometrical parameters	
D pipe	16 mm
d insert	14 mm
Length of pip , L	510 mm
Length of coil, l	500 mm
pitch primary coil	16 mm
pitch secondary coil	2.72 mm
Pp/D	1 mm
Ps/D	0.17 mm
ep /D, es/D	0.075 mm, 0.0625 mm
dp wire coil,ds wire coil	1.2 mm, 1 mm

Figure 4.28 Squarewire coil insert around Square wire coil type two

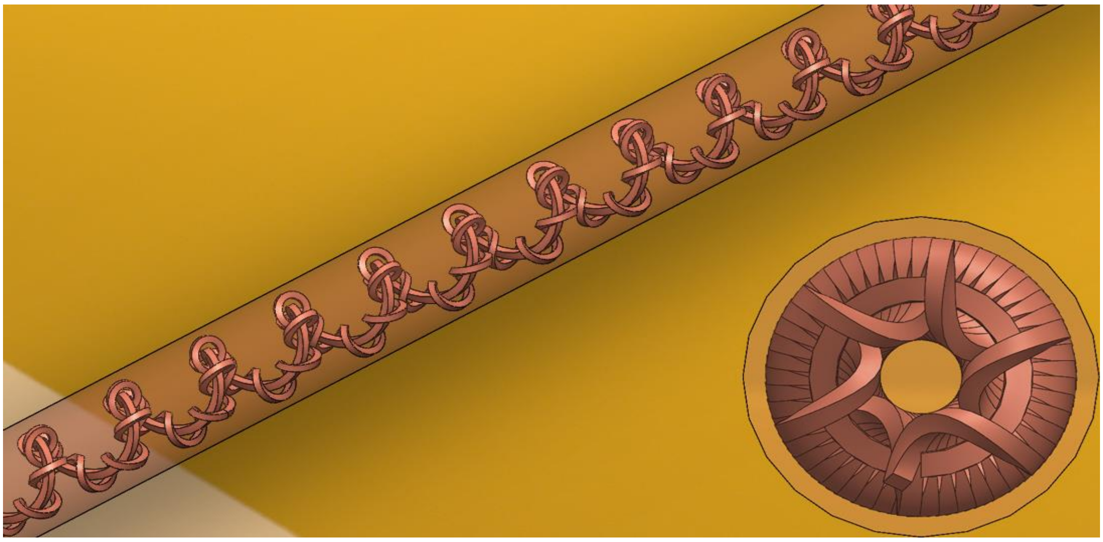


Figure 4.29 Geometry of the Square wire coil insert around Square wire coil in tube fitted type two

4.5.2 Mesh for Square Wire Coil Insert Around Square Wire Coil Type Two

Initially a comparatively fine mesh is created. two meshes were applied on square wire coil insert around square wire coil type two Element numbers of these meshes were 1631070,and 4196661.Table 4.14 Shows the mesh independency of The Nusselt number deviation between 1631070 and 4196661 was 3.72 % and the friction between 1631070 and 4196661 was 1.5758% therefore , the mesh contained 4196661 number of mesh elements were selected.

Table 4.14 Shows the mesh independency of the Square wire coil insert around Square wire coil type two

NUMBEROF MESHELEMENTS	REYNOLDS NUMBER	NUSSELT NUMBER	FRICTION
4196661	5000	60.6889	0.8027350
1631070	5000	58.42830	0.787350

4.5.3 Numerical Setup of Square Wire Coil Insert Around Square Wire Coil Type Two

Numerical Solution The commercial CFD solver Ansys Fluent v17 was used for numerical analysis to solve the dominant equations with a pressure setup solver Semi-implicit pressure linked equation method (SIMPLE) algorithm for pressure velocity coupling and $k-\varepsilon = 10^{-3}$for turbulence model were used. The convergence standard of, for energy and of $= 10^{-6}$for momentum, continuity, and $k-\varepsilon$were applied. The numerical modeling contributory numerical solutions of the protection equations for mass, momentum, and energy.

Table 4.15 Numerical setup procedure for Square wire coil insert around Square wire coil type two

Setup and solution methods	Type second order , and solution degree
Material	Air
Model	$k-\varepsilon$ turbulence model
Solution method	SIMPLE algorithm

Convergence criteria	Energy= 10^{-6},Momentum, continuity and $k-\varepsilon=10^{-3}$
Equation solver	second order up wind for momentum and Energy equation

4.5.4 Boundary Condition for Square Wire Coil Insert Around Square Wire Coil Type Two

Boundary Conditions The direction of the flow is defined to be normal to the boundary, and the fluid inlet temperature is 288k of air . The turbulence intensity range depend on Reynolds number is between 5000 and 25000 at the inlet. The wall of the tube is presupposed to be perfectly smooth with zero roughness,and the uniform wall temperature of the tube wall is 500 w/m^2.

Table 4.16 Boundary conditions of Square wire coil insert around Square wire coil type two

Boundary condition	
Reynolds number range	5000-25000
Working fluid	Air
Temperature inlet	288k
Heat flux	$500w/m^2$

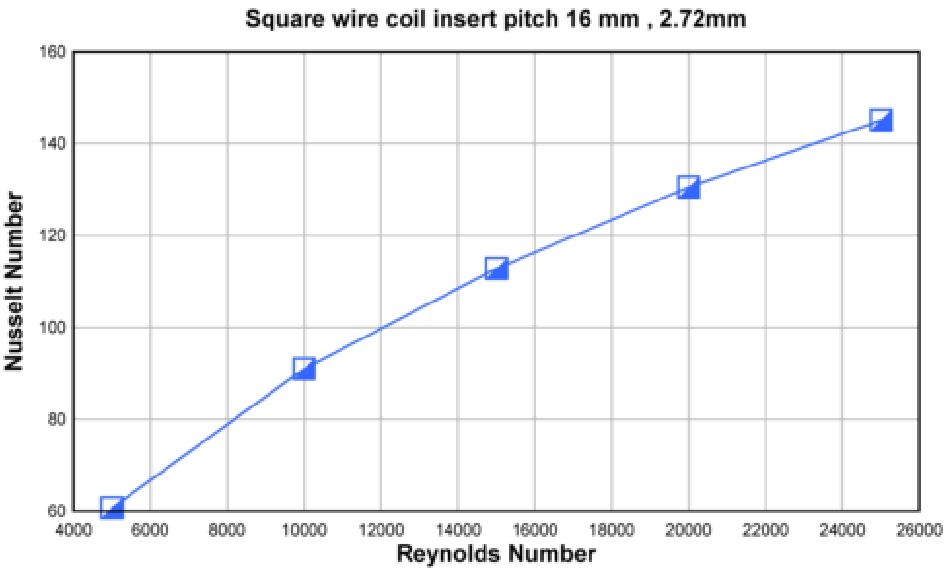


Figure 4.30 Reynolds number versus Nusselt Number of square wire coil insert aroundsquare wire coil type two

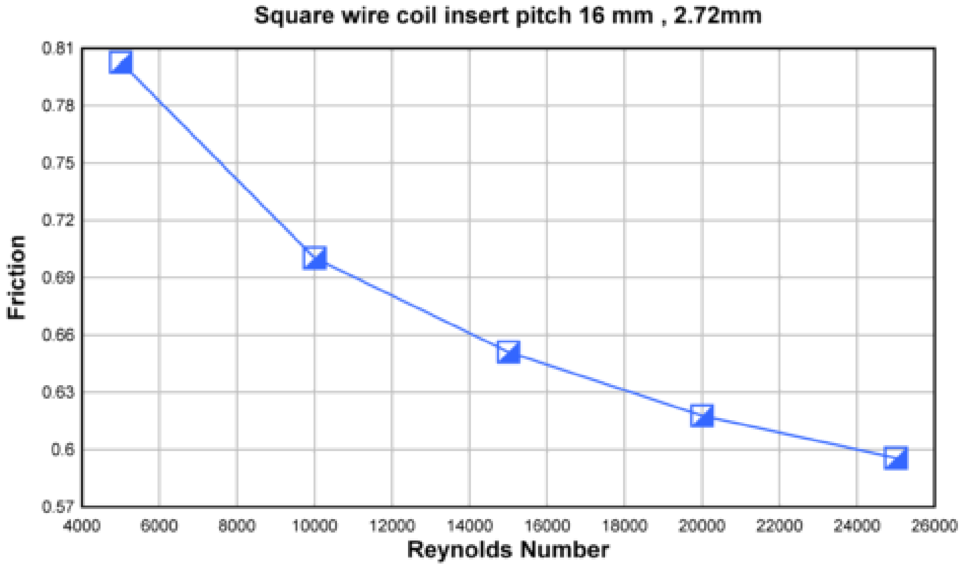


Figure 4.31 Reynolds number versus Friction of square wire coil insert aroundsquare wire coil type two

As understanding from Figure 4.30, Nusselt number decrease with increased pitch and decreasing Reynolds number. The Nusselt number of primary pitch 16mm and secondary pitch 1.44mm is higher than primary pitch 16 and secondary pitch 2.272mm approximately 2.30%, to 7.5% respectively.

Figure 4.31, friction decreased with increasing Reynolds Number, the friction of primary pitch 16mm and secondary pitch 1.44mm is higher than primary pitch 16 and secondary pitch 2.272mm. At lower Reynolds number 0.8 to 0.59 respectively.

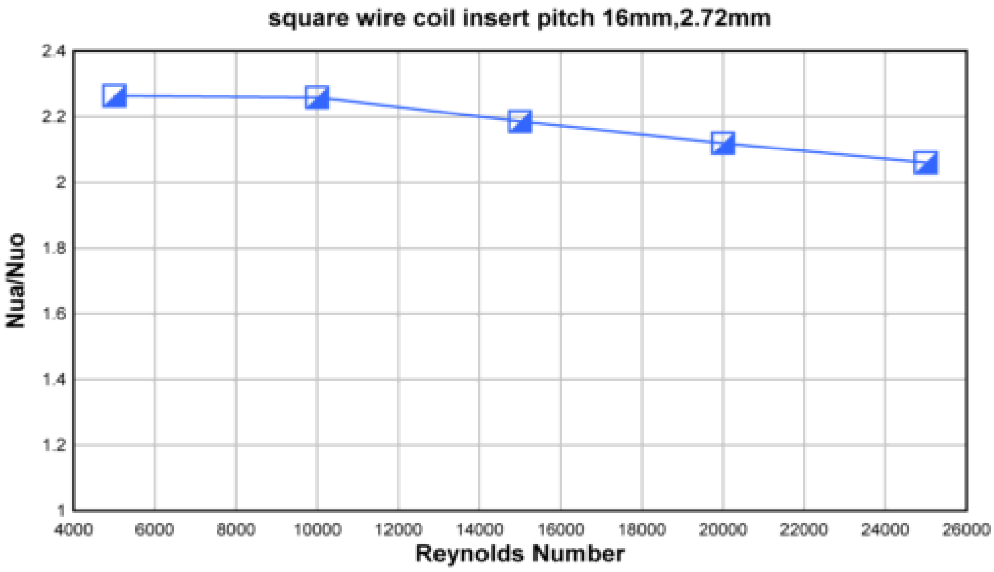


Figure 4.32 Reynolds Number via Nua/Nuo for square wire coil insert around square wire coil type two

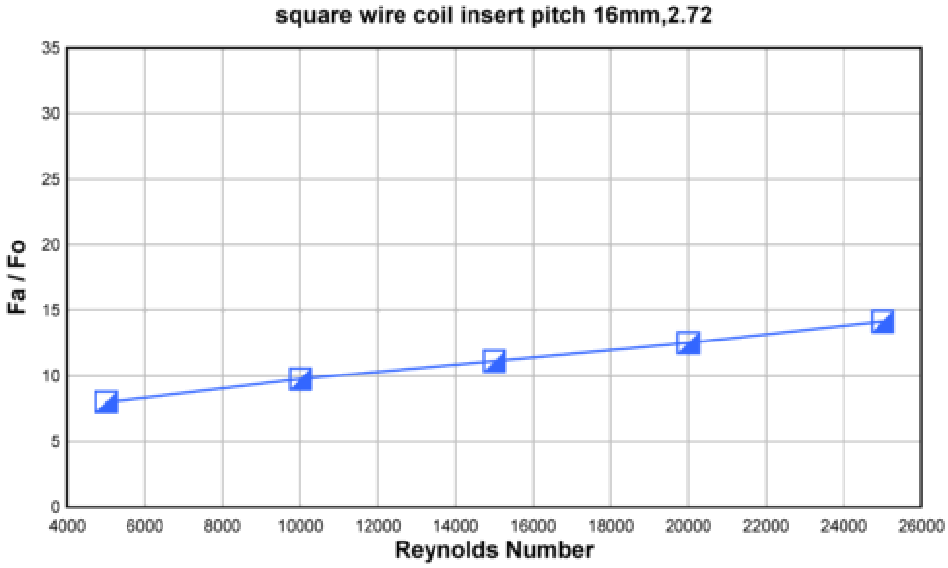


Figure 4.33 Reynolds Number via Fa/Fo for square wire coil insert around square wire coil type two

As understanding from Figure 4.32, Nusselt number decreased with increasing Reynolds number. Nu_a/Nu_o(R3) changed from 2.263 to 2 The highest value of was taken at Reynolds number 5000. and figure 4.33explain The Fa/Fo, changed from 8 to 14. 15313 The highest value of Fa/Fo was taken at Reynolds number 25000. The figures shows that the square wire coil insert around square wire coil type two and smooth tube has the highest heat transfer 59.73% to144% , respectively.

4.5.5 Performance Evaluation Criteria for Square Wire Coil Insert Around Square Wire Coil Type Two

PEC for square wire coil insert around square wire coil type two was calculated with using equation 31.Figure 4.34 show the PEC of square wire coil insert around square wire coil type two versus Reynolds Number.

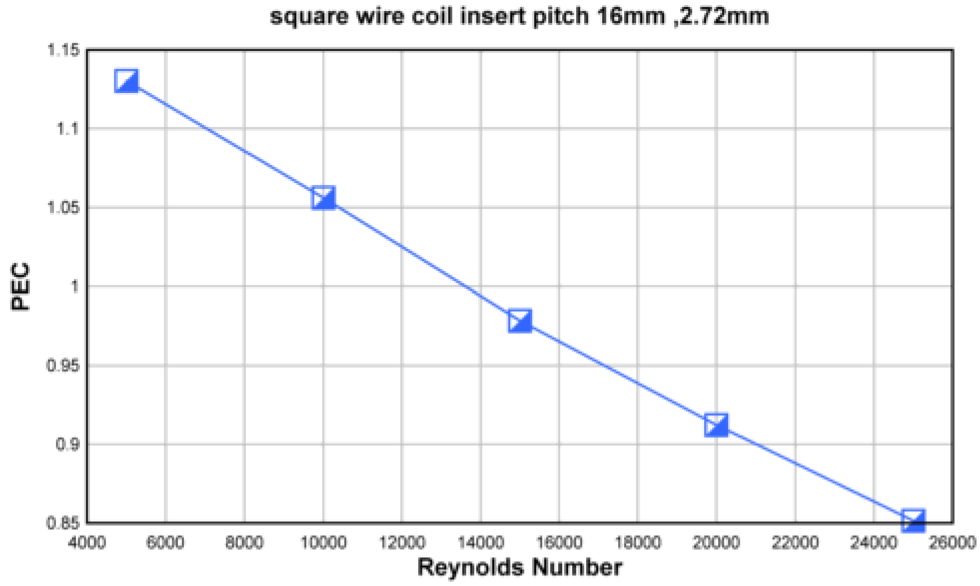


Figure 4.34 Reynolds Number via PEC for square wire coil insert around square wire coil type two

As understanding from Figure 4.34, when Reynolds number increased, PEC considerably decreased. PEC was lower than unity because of the friction penalty of the pipe. The friction of smooth pipe is lower than square wire coil insert aroundsquare wire coil type two in pipe. The highest PEC (1.130433) was observed at 5000 Reynolds number, approximately. PEC range was between 0.85165and 1.130433in the range of Reynolds number for this study. but in square wire coil insert aroundsquare wire coil type one PEC from 1 to 0.8.

4.5.6 Results and Discussion for Square Wire Coil Insert Around Square Wire Coil Type Two

In this case, primary pitch coil ratio was equal to 1 and pitch secondary coil ratio was equal to0.17 . As understanding from the literature [10, 15, 22], reduce pitch ratio and distant wire coil from wall tube has lower Nusselt number. The using formulas to calculate the results were similar with the other cases. Figure 4.30 shows the effect of Reynolds number on Nusselt number and Figure 4.31 shows the effect of Reynolds number on friction. If results are compared between square wire coil insert around square wire coil type one and square wire coil insert around square wire coil type two . I seen the enhancement in heat transfer in square wire coiltype one more than square wire coil type two The corresponding increase in mean Nusselt numbers in the heat exchanger is about 59.73% to 144% with smooth tube , respectively. .

4.6.1 Numerical Solution for Triangular Wire Coil Insert Around Triangular Wire Coil Type One

The geometries have been drawn in SolidWorks 2014 ,Test section geometry is created for all the inserts shown in Table 4.17

Table 4.17 Geometrical parameters for triangular wire coil insert around triangular wire coil type one

Geometrical parameters	
D pipe	16 mm
d insert	14.5mm
Length of pip , L	510mm
Length of coil, l	500mm
pitch primary coil	16mm
pitch secondary coil	1.44mm
Pp/D	1 mm
Ps/D	0.09 mm
ep /D, es/D	0.075 mm, 0.0625 mm
dp wire coil,ds wire coil	1.2 mm, 1 mm

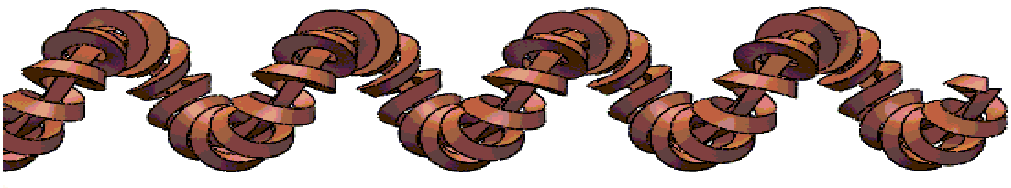


Figure 4.35 Triangular wire coil insert around triangular wire coil type one

Figure 4.36 Geometry of the triangular wire coil insert around triangular wire coil in tube fitted type one

4.6.2 Mesh for Triangular Wire Coil Insert Around Triangular Wire Coil Type One

The mesh quality is very important for the thoroughness and amendment of numerical computation. Mesh was generated by using Ansys Meshing Module v17. two different meshes were used for the mesh independency. The first mesh size was generated with 5543454 mesh elements .and second mesh 2876446.The Nusselt number and friction deviations between 5543454 and 2876446 were than 0.018 percent and the friction deviation between 5543454 and 2876446 was 0.01 percent .respectively. 5543454 elements were used for analysis Mesh test was also performed to confirm mesh independency of the results.

Table 4.18 Shows the mesh independency of the triangular wire coil insert around triangular wire coil type one

NUMBEROF MESHELEMENTS	REYNOLDS NUMBER	NUSSELT NUMBER	FRICTION
5543454	5000	73.8577274	1.589726762
2876446	5000	72.86637998	1.590896526

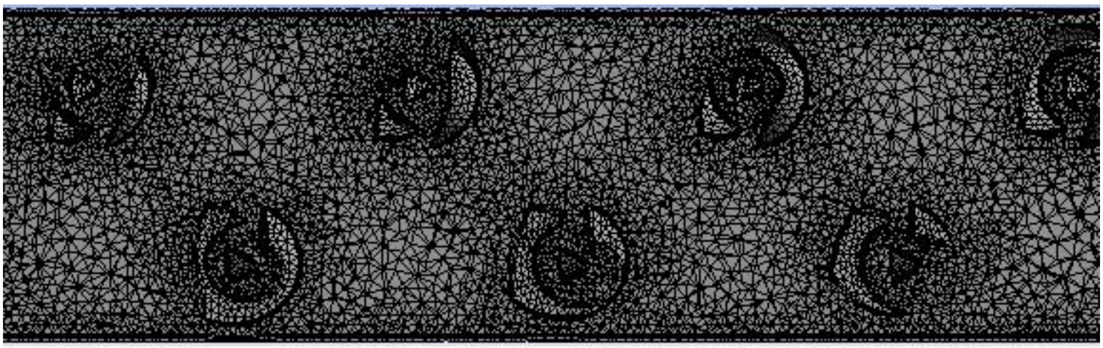


Figure 4.37 The longitudinal mesh of pipe with triangular wire coil insert around triangular wire coil type one

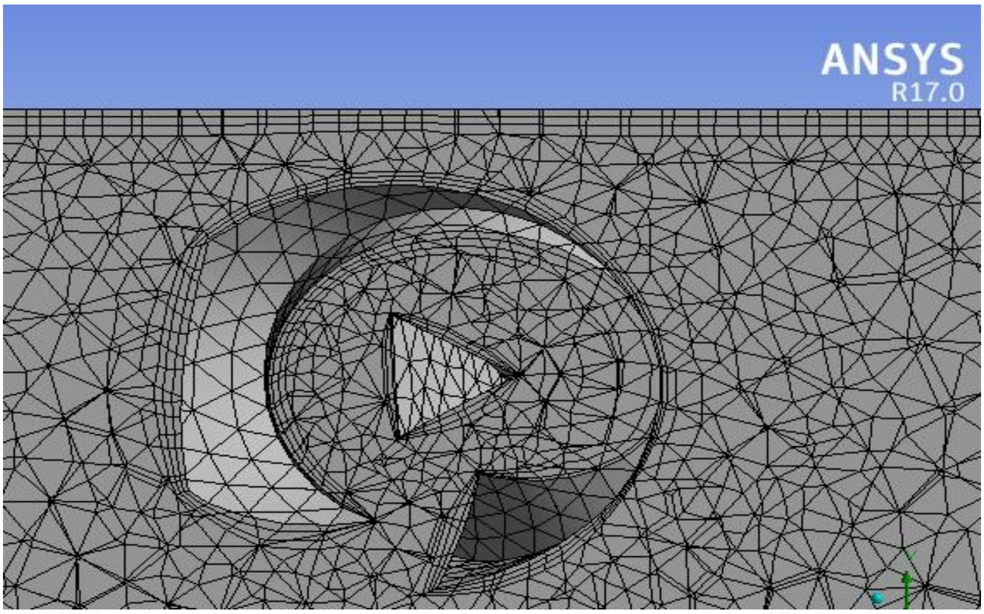


Figure 4.38 Inflation layers mesh around two triangular wire coil insert type one

4.6.3 Numerical Setup of Triangular Wire Coil Insert Around Triangular Wire Coil Type One

In the stream study, The mercantile CFD solver ANSYS Fluent v17 was used for numerical analysis to solve the governing equations with a pressure setupsolver. Semi implicit pressure linked equation method (SIMPLE) algorithm for pressure velocity coupling and $k-\varepsilon = 10^{-3}$for turbulence model were used. The convergence criterion of, for energy and of =$10^{-6}$for momentum, continuity. and were used .Moreover, the geometry of the computational domains and the generated mesh were made with ANSYS Fluent v17. A grid independency of the solution was done for all this case studies to ensure that the obtained results.

Table 4.19 Numerical setup procedure for triangular wire coil insert around triangular wire coil type one

Setup and solution methods	Type second order , and solution degree
Material	Air
Model	$k-\varepsilon$ turbulence model
Solution method	SIMPLE algorithm
Convergence criteria	Energy= 10^{-6},Momentum, continuity and $k-\varepsilon = 10^{-3}$

Equation solver	second order up wind for momentum and Energy equation

4.6.4 Boundary Condition for Triangular Wire Coil Insert Around Triangular Wire Coil Type One

No slip boundary condition is specified for the triangular wire coil insert around triangular wire coil type one and tube surfaces and is set as a wall. The tube wall of the test section is subjected to uniform constant heat flux, which is equal to 500 W/m^2 and The wall of the tube is assumed to betotally smooth with zero roughness, and temperature inlet 288k of the air.

Table 4.20 Boundary conditions of triangular wire coil insert around triangular wire coil type one

Boundary condition	
Reynolds number range	5000-25000
Working fluid	Air
Temperature inlet	288k
Heat flux	$500w/m^2$

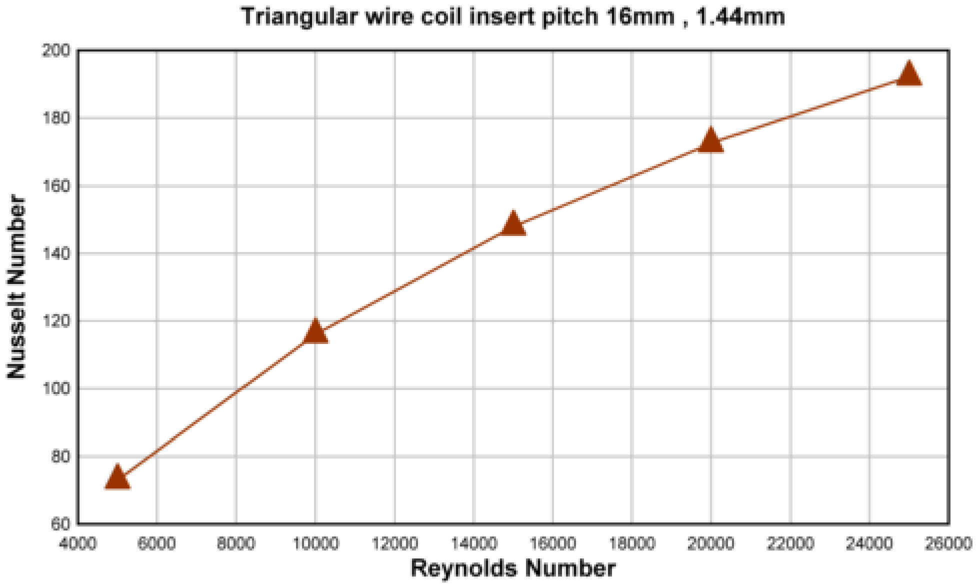


Figure 4.39 Reynolds number versus Nusselt Number of triangular wire coil insert around triangular wire coil type one

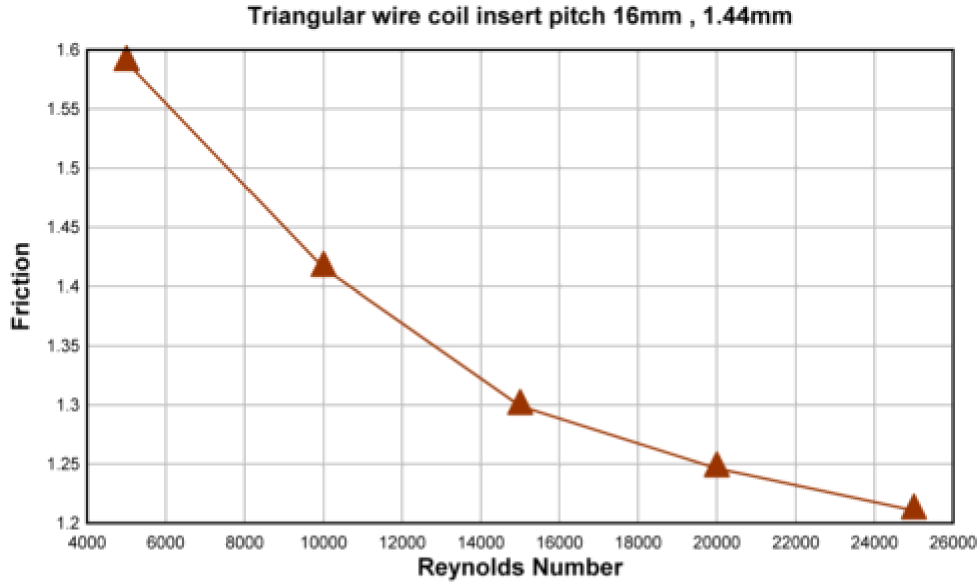


Figure 4.40 Reynolds number versus friction of triangular wire coil insert around triangular wire coil type one

As understanding from Figure 4.39, Nusselt number increased with decrease pitch and increasing Reynolds number. I seen the improvement in heat transfer in triangular wire coil insert around triangular wire coil type one more than square wire coil around square wire type one.The stararting point of Nusseltnumberwas 73 atReynolds number 5000 and last point of Nusselt number reached 192.2475 atReynolds number 25000 approximately.

The As understanding from Figure 4.40, friction increasing with decrease pitch and Reynolds Number,the friction of primary pitch 16mm and secondary pitch 1.44mm in triangular wire coilinsert around triangular wire coil type one is higher than square wire coil around square wire coil type one. At lower Reynolds number1.589576 to 1.210, respectively.

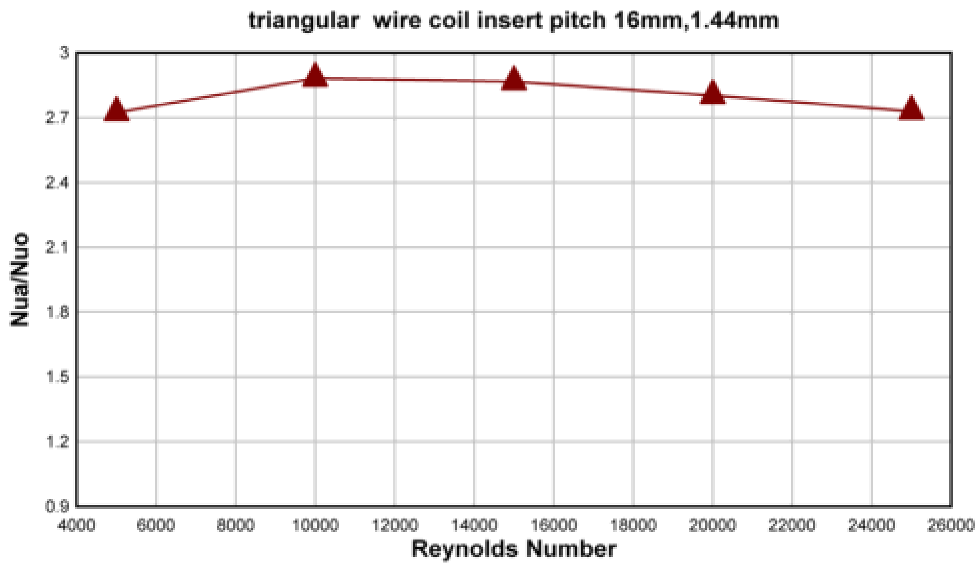


Figure 4.41 Reynolds number via Nua/Nuo for triangular wire coil insert around triangular wire coil type one

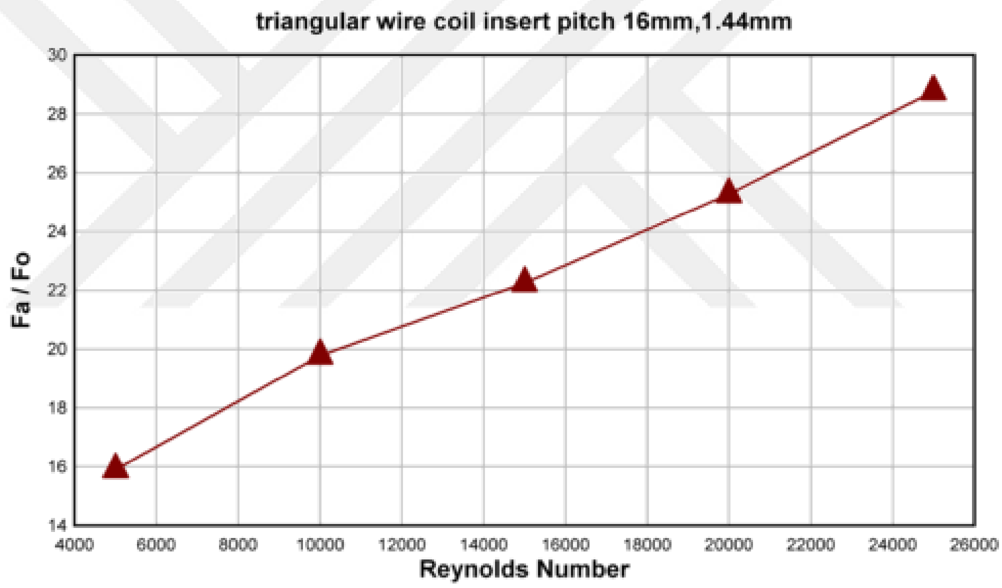


Figure 4.42 Reynolds Number via Fa/Fo for triangular wire coil insert around triangular wire coil type one

As understanding from Figures4.41and 4.42, Nusselt numberincreasing with decreased Reynolds number. Nu_a/Nu_o(R3) changed from 2.7242 to 2.729The highest value of was taken at Reynolds number 5000. The Fa/Fo, changed from 15.90 to28. 766The highest value of Fa/Fo was taken at Reynolds number 25000. The figures shows that the triangular wire coil insert around triangular wire coil type one and smooth tube has the highest heat transfer72% to 191.247% , respectively.

4.6.5 Performance Evaluation Criteria for Triangular Wire Coil Insert Around Triangular Wire Coil Type One

PEC for triangular wire coil insert around triangular wire coil type one was calculated with using equation31.Figure 4.43 show the PEC of triangular wire coil insert around triangular wire coil type two versus Reynolds Number.As understanding from Figure 4.43, when Reynolds number increased, PEC considerably decreased. PEC was lower than unity because of the friction penalty of the pipe. The friction of smooth pipe is lower than triangular wire coil insert aroundtriangular wire coil type one in pipe. The highest PEC (1) was observed at 5000 Reynolds number, approximately. PEC range was between 1 and 0.89 in the range of Reynolds number for this study. but in square wire coil insert around square wire coil type one PEC from 1 to 0.80.

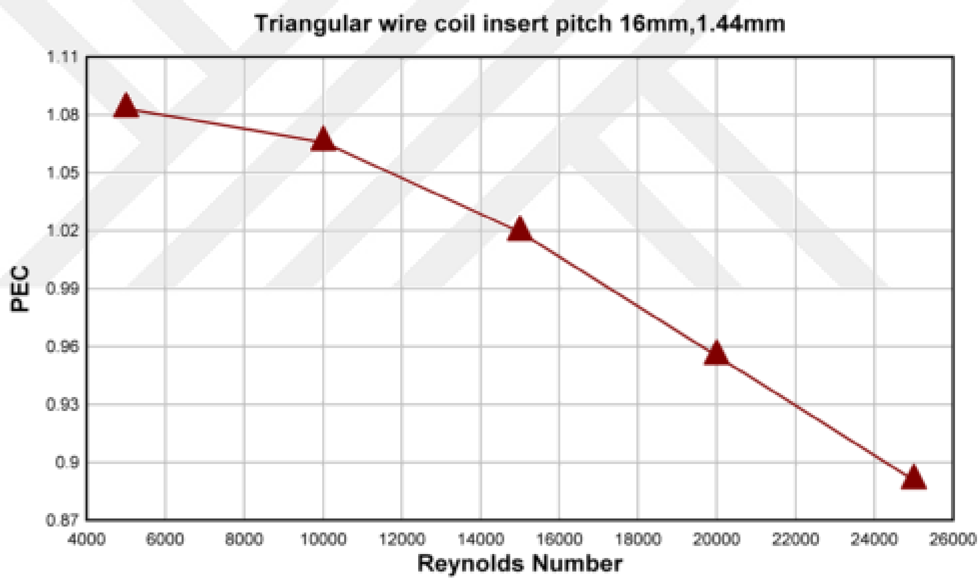


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Figure 4.43 Reynolds Number via PEC for triangular wire coil insert around triangular wire coil type one

4.6.6 Results and Discussion for Triangular Wire Coil Insert Around Triangular Wire Coil Type One

As understanding from Figure 4.41 variation of Nusselt number with Reynolds number for tube fitted with triangular wire coil insert around triangular wire coil type one . From Figure 4.41 can be seen that Nusselt number for the tube fitted with triangular wire coil insert around triangular wire coil type one are higher than that of smooth tube into for specific Reynolds number.Nua/Nuo(R3) changed from 2.72432 to 2.7294The highest value of was taken at Reynolds number from 5000 to

25000. This is because triangular wire coil insert around triangular wire coil type one interrupts the augmentation of boundary layer of the fluid flow near the wall of test section hence it increases fluid temperature in the radial trend .sufficient due to impinge impact surface area the heat transfer rate increases.It also distinguishes between turbulence and rotational motion to the air when is flowing inside the experiment section. The whirling product flow to be a lot turbulent, which leads to development convection heat transfer .As a Reynolds number increases for a given triangular wire coil insert around triangular wire coil type one,the Nusselt number also increases indicating enhanced heat transfer. It is else observed from Figure 4.41 that Nusselt number for a specified Reynolds number is higher from square wire coil insert around square wire coil type one because R3 in this design from 2.3160 to 2.223and R3 in circular wire coil insert around circular wire coil type one from 1.864 to 1.7765,respectively. Usually the friction factor decreases with the rising Reynolds number for diverse pitches. From Figure. 4.42 it can be seen that friction factor for the tube fitted with triangular wire coil insert around triangular wire coil type one are significantly higher than smooth tube for a given Reynolds .It indicates that friction factor for a given Reynolds number increases with decreasing pitch due to vortex flow generated by triangular wire coil insert around triangular wire coil type one and reaches a maximum for primary pitch coil 16 mm and secondary pitch coil 1.44 mm .From Figures 4.8 and. 4.26 it can be seen that friction factor of circular wire coil insert around circular wire coil type one and Square wire coil around Square wire coil type one is less when compared with triangular wire coil type one . so more area is available for air to flow in the test section. The friction factor of triangular wire coil type one11.9899 to 22.3453 times of the plane tube. square wire coil type one cause friction factor of 12.420 to 20.730 times to plane tube and circular wire coil type one has friction factor of 10.680 to 17.592 times smooth tube.

4.7.1 Numerical Solution for Triangular Wire Coil Insert Around Triangular Wire Coil Type Two

Table 4.21 Geometrical parameters for triangular wire coil insert around triangular wire coil type two

Geometrical parameters	
D pipe	16 mm
d insert	14mm
Length of pip , L	510mm
Length of coil, l	500mm
pitch primary coil	16mm
pitch secondary coil	2.72 mm
Pp/D	1 mm
Ps/D	0.17 mm
ep /D, es/D	0.075 mm, 0.0625 mm
dp wire coil,ds wire coil	1.2 mm, 1 mm

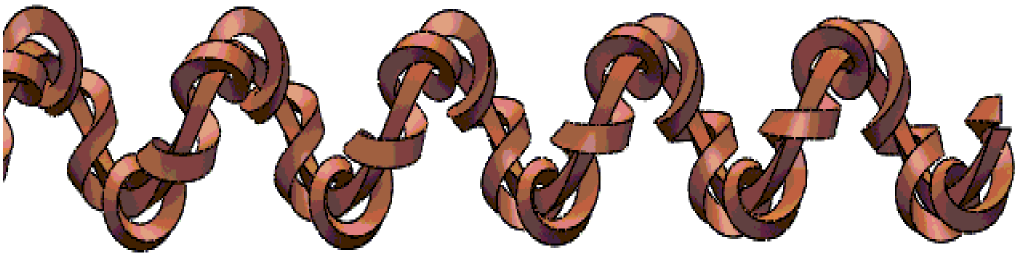

Figure 4.44 Triangular wire coil insert around triangular wire coil type two

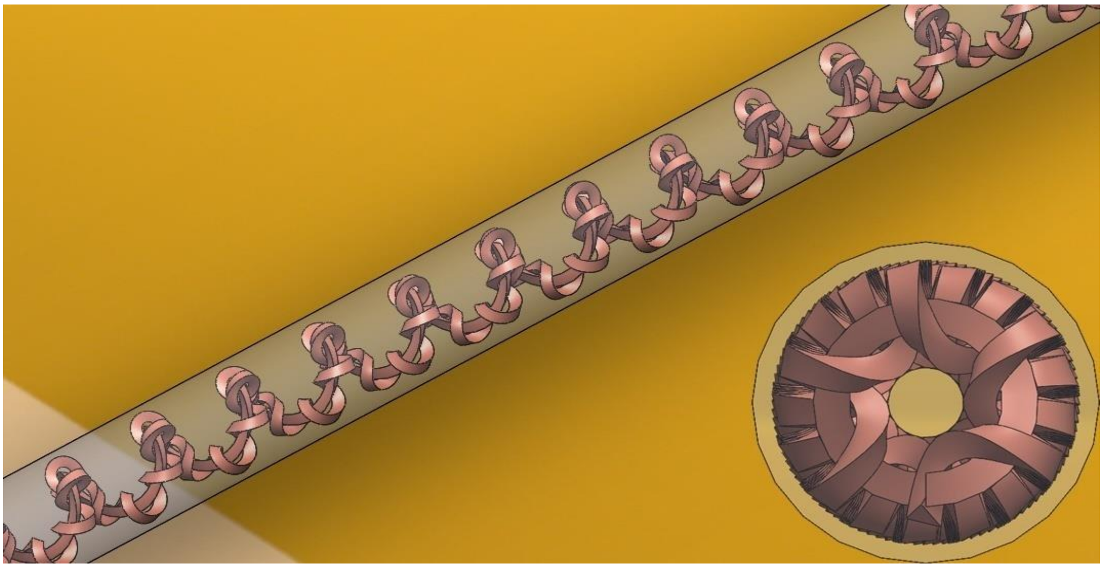

Figure 4.45 Geometry of the triangular wire coil insert around triangular wire coil in tube fitted type two

4.7.2 Mesh for Triangular Wire Coil Insert Around Triangular Wire Coil Type Two

two different meshes are applied on the triangular wire coil insert around triangular wire coiltype two geometry for mesh independence study the numbers are 4835492and 4603684 for the case of triangular wire coil insert around triangular wire coil type two ,As understanding .Table 4.22 Nusselt numbers are lower than 0.6% there for 4835492 mesh elements are selected for numerical analysis of triangular wire coil insert around triangular wire coil type two.

Table 4.22 Shows the mesh independency of the triangular wire coil insert around triangular wire coil type two

NUMBEROF MESHELEMENTS	REYNOLDS NUMBER	NUSSELT NUMBER	FRICTION
4835492	5000	69.83055592	1.198439267
4603684	5000	69.3635502	1.196511786

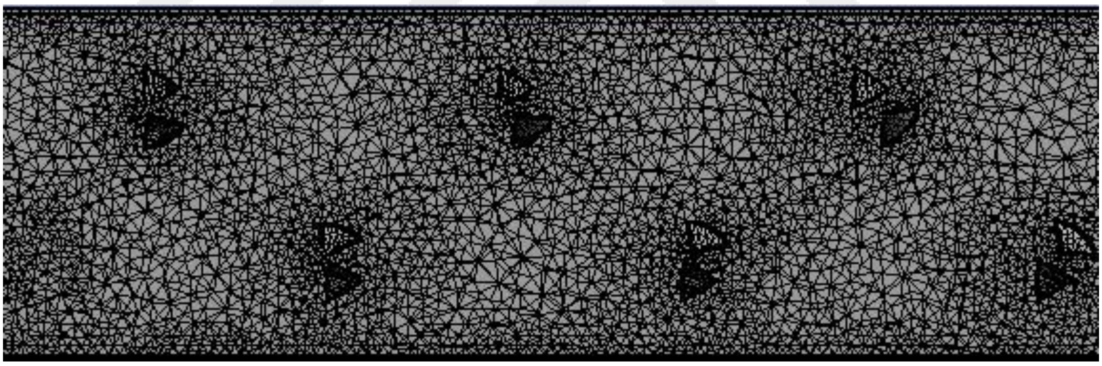

Figure 4.46 The longitudinal mesh of pipe with triangular wire coil insert around triangular wire coil type two

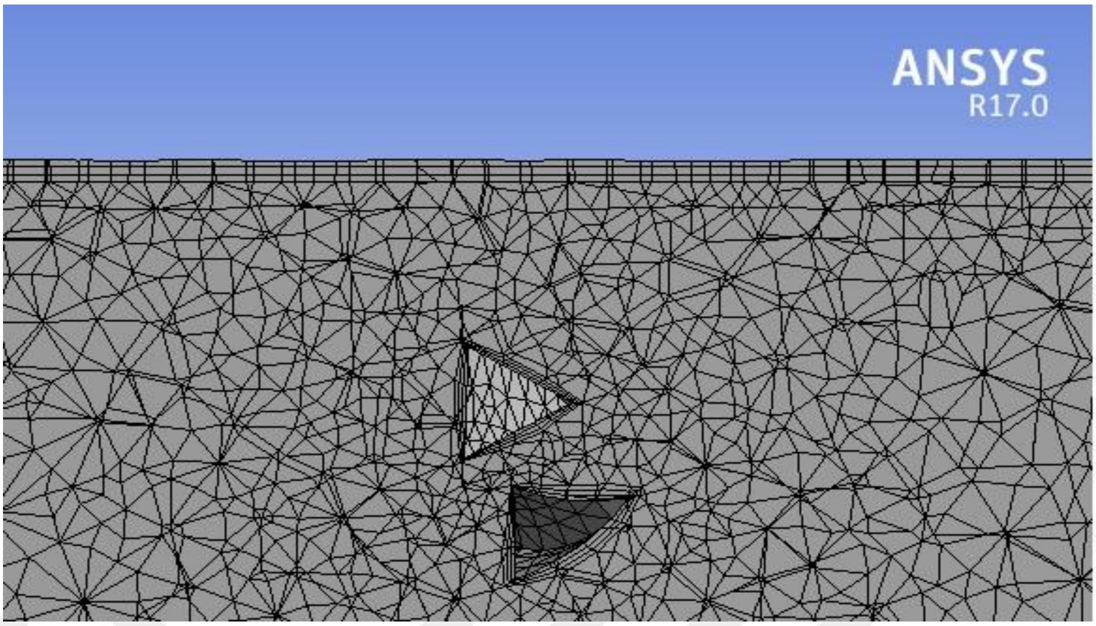

Figure 4.47 Inflation layers mesh around two triangular wire coil insert type two

4.7.3 Numerical Setup of Triangular Wire Coil Insert Around Triangular Wire Coil Type Two

The $k-\varepsilon$ turbulence model was used in this case .the program solved momentum, energy , continuity , and k-e equation .The order of convergence criteria for continuity and $k-\varepsilon = 10^{-3}$. However ,convergence criteria for energy equation is 10^{-6}. The pressure -velocity coupling is solved by SIMPLE algorithm. Momentum and energy equitation are solved by second order upwind The summary of setup is listed Table.

Table 4.23 Numerical setup procedure for triangular wire coil insert around triangular wire coil type two

Setup and solution methods	Type second order , and solution degree
Material	Air
Model	$k-\varepsilon$ turbulence model
Solution method	SIMPLE algorithm
Convergence criteria	Energy= 10^{-6},Momentum, continuity and $k-\varepsilon = 10^{-3}$
Equation solver	second order up wind for momentum and Energy equation

4.7.4 Boundary Condition for Triangular Wire Coil Insert Around Triangular Wire Coil Type Two

No slip boundary condition is specified for triangular wire coil insert around triangular wire coil type two and tube surfaces and is set as a wall. The tube wall of the test section is subjected to uniform constant heat flux, which is equal to 500 W/m^2.

Table 4.24 Boundary conditions of triangular wire coil insert around triangular wire coil type two

Boundary condition	
Reynolds number range	5000-25000
Working fluid	Air
Temperature inlet	288k
Heat flux	$500 w/m^2$

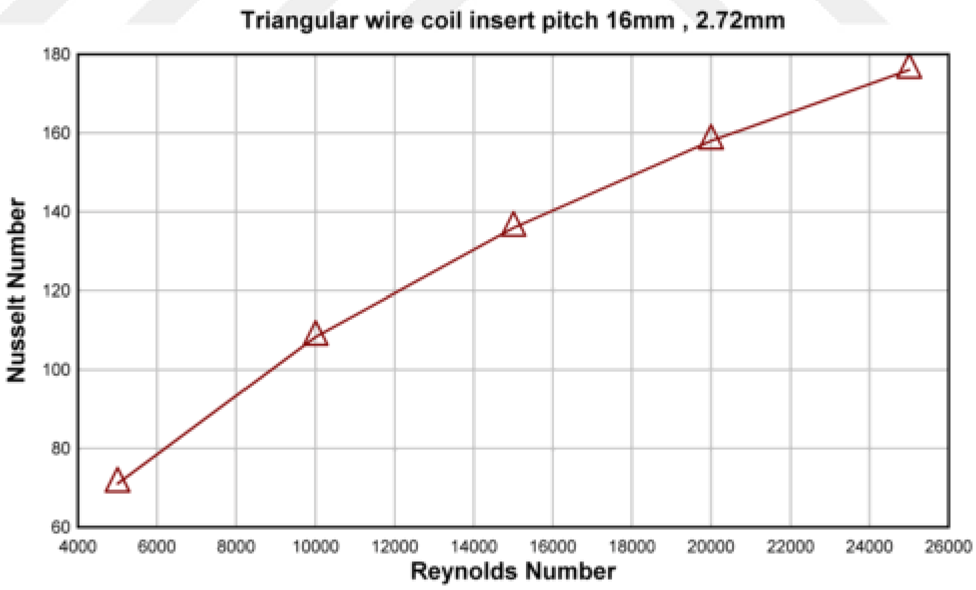

Figure 4.48 Reynolds number versus Nusselt Number of triangular wire coil insert around triangular wire coil type two

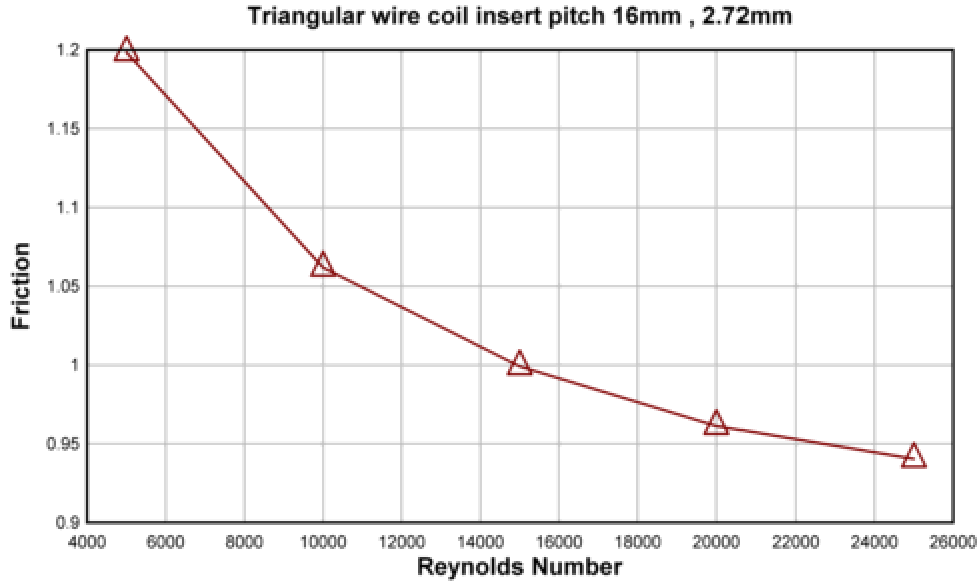

Figure 4.49 Reynolds number versus Friction of triangular wire coil insert around triangular wire coil type two

As understanding from Figure 4.48, Nusselt number decreased with increasing pitch and increasing Reynolds number, the Nusselt number of primary pitch 16mm and secondary pitch 2.72 mm in triangular wire coil insert around triangular wire coil type two theNusselt number higher than square wire coil around square wire coil type two from 70.06% to 175.6%, respectively and higher than circular wire coil insert around circular wire coil type two from 70% to175 % approximately , respectively.

The understanding from Figure 4.49, friction decrease with increasing pitch and Reynolds Number,the friction of primary pitch 16mm and secondary pitch 2.72mm in triangular wire coil insert around triangular wire coil type two is higher than square wire coil around square wire coil type two. At lower Reynolds number1.19 to 0.94, respectively.

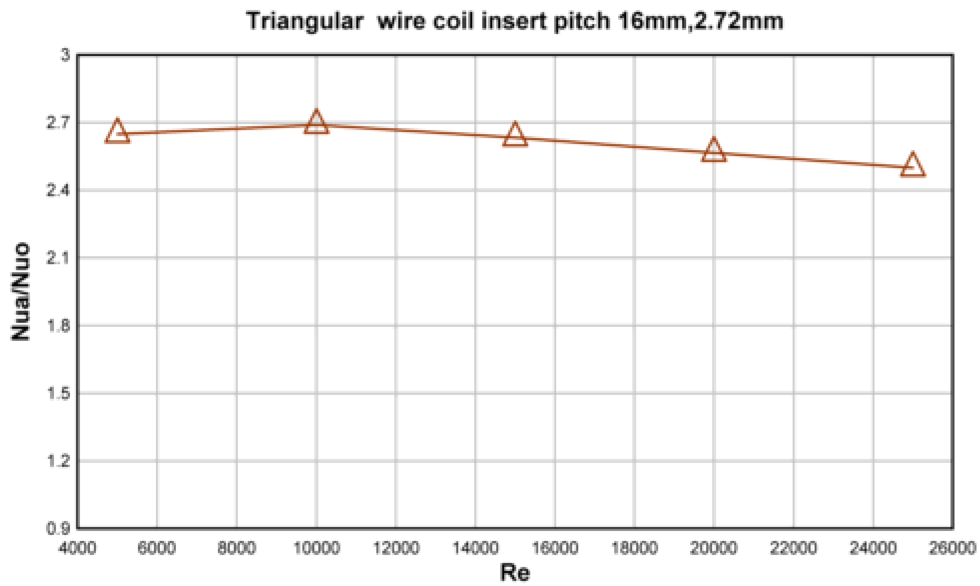

Figure 4.50 Reynolds Number via Nua/Nuo for triangular wire coil insert around triangular wire coil type two

As understanding from Figure 4.50, Nusselt number decreased with increasing Reynolds number. Nua/Nuo(R3) changed from 2.649 to 2.499The highest value of was taken at Reynolds number 5000.and figure The Fa/Fo, changed from 11.99 to 22.345 The highest value of Fa/Fo was taken at Reynolds number 25000, from figures shows that the triangular wire coil insert around triangular wire coil type two and smooth tube has the highest heat transfer 70% to 175%, respectively.

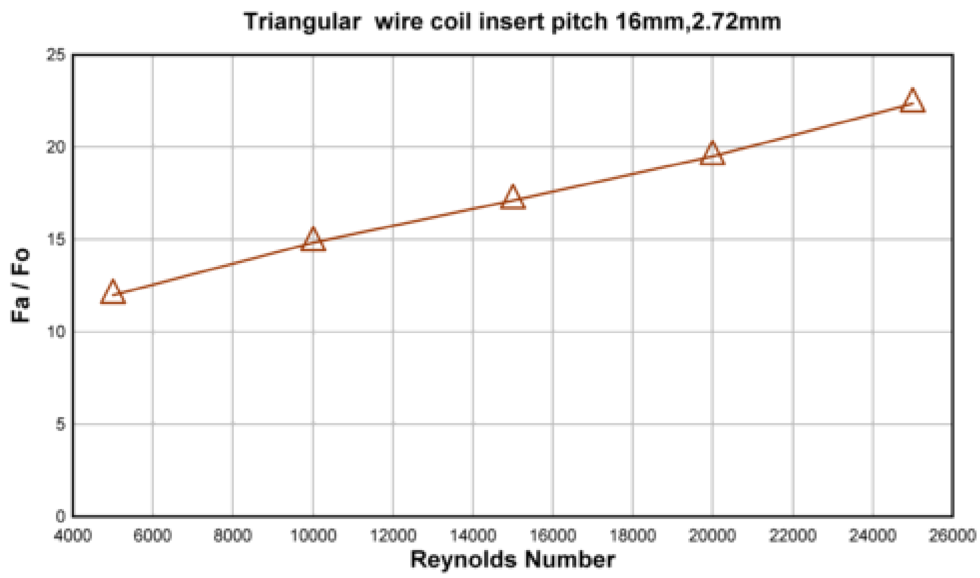

Figure 4.51 Reynolds Number via Fa/Fo for triangular wire coil insert around triangular wire coil type two

4.7.5 Performance Evaluation Criteria for Triangular Wire Coil Insert Around Triangular Wire Coil Type Two

PEC for triangular wire coil insert aroundtriangular wire coil type two was calculated with using equation 31.Figure 4.52show the PEC of triangular wire coil insert around triangular wire coil type two versus Reynolds Number.

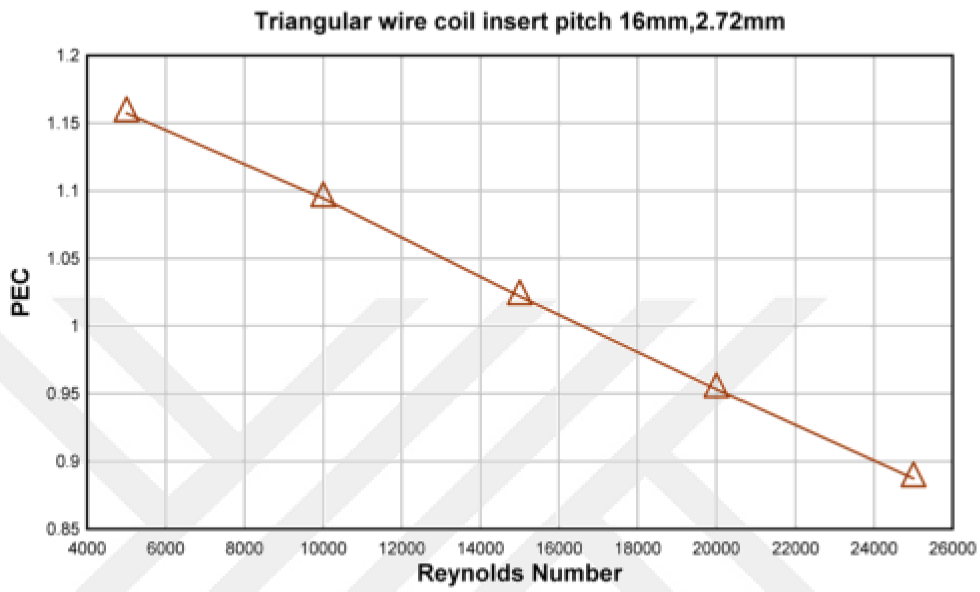

Figure 4.52 Reynolds Number via PEC for triangular wire coil insert around triangular wire coil type two

As understanding from Figure 4.52, when Reynolds number increased, PEC considerably decreased. PEC was lower than unity because of the friction penalty of the pipe. The friction of smooth pipe is lower than triangular wire coil insert aroundtriangular wire coil type two in pipe. The highest PEC (1.157) was observed at 5000 Reynolds number, approximately. PEC range was between 1.157 and 0.887 in the range of Reynolds number for this study. but in square wire coil insert around square wire coil type two PEC from 1.13 to 0.85 and in circular wire coil insert around circular wire coil type two from 1.13 to 0.89.

4.7.6 Results and Discussion for Triangular Wire Coil Insert Around Triangular Wire Coil Type Two

As understanding from Figure 4.48 variation of Nusselt number with Reynolds number for tube fitted with triangular wire coil insert around triangular wire coil type two . If results are compared between triangular wire coil insert around triangular wire coil type two and smooth pipe I seen the improvement in heat transfer in triangular wire coil insert type two more than smooth pipe The corresponding increase in mean Nusselt numbers in the heat exchanger is about 70% to 175% with smooth pipe, respectively.Nua/Nuo (R3) changed from 2.649 to 2.499The highest value of was taken at Reynolds number from 5000 to 25000. It is else observed from Figure 4.50 that Nusselt number for a specified Reynolds number is higher from square wire coil insert around square wire coil type two because R3 in this design from 2.263 to 2 and R3 in circular wire coil around circular wire coil type two from 1.7837 to 1.538.

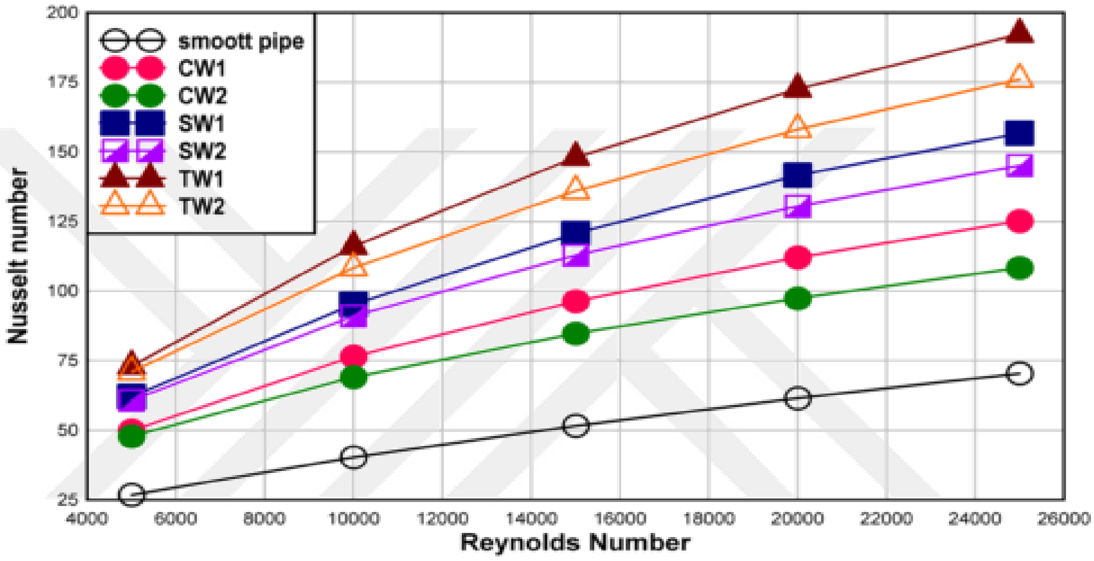

Figure 4.53 Reynolds number versus Nusselt Number for all study

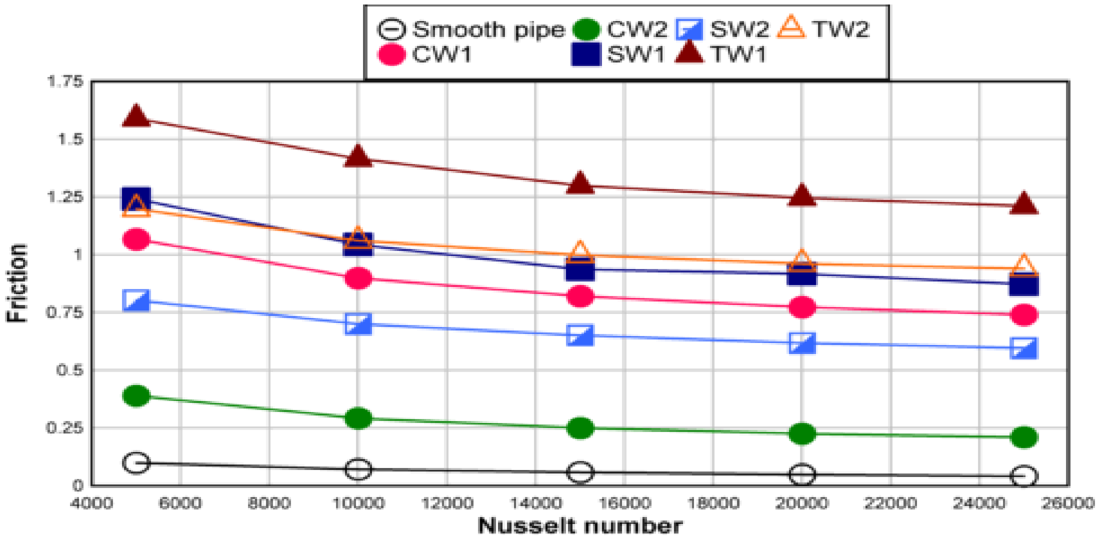

Figure 4.54 Reynolds number versus Frictionfor all study

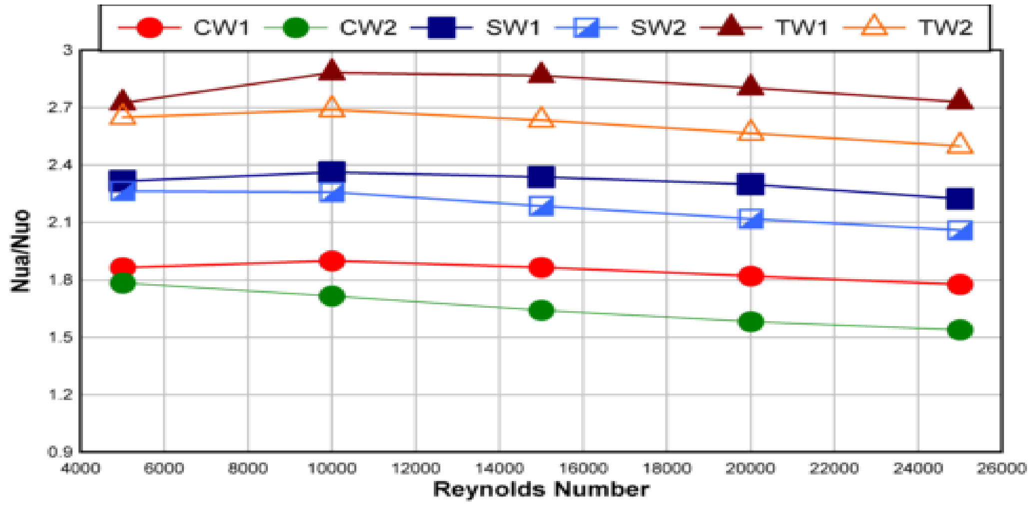

Figure 4.55 Reynolds Number versus Nua/Nuo for all study

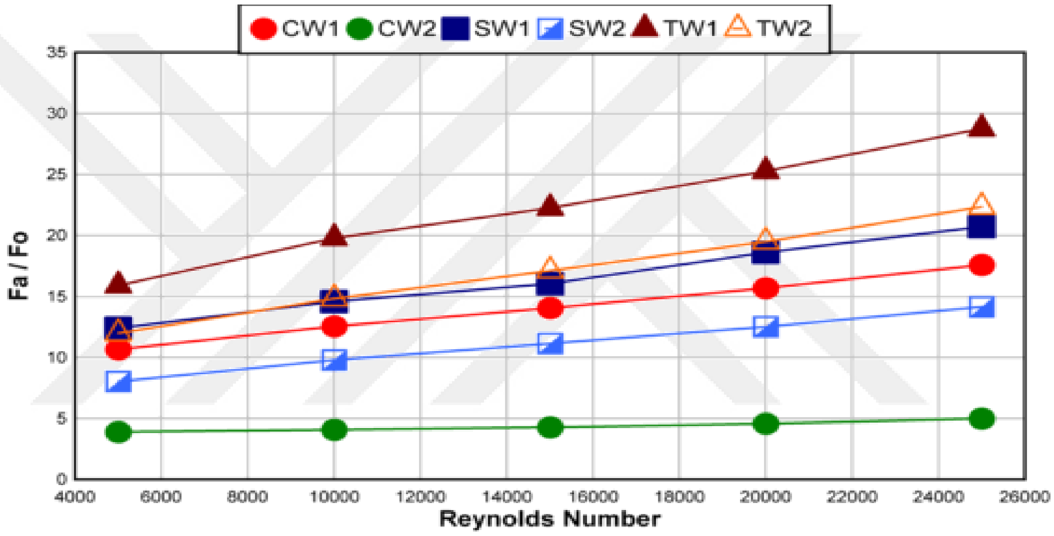

Figure 4.56 Reynolds Number versusFa/Fo for all study

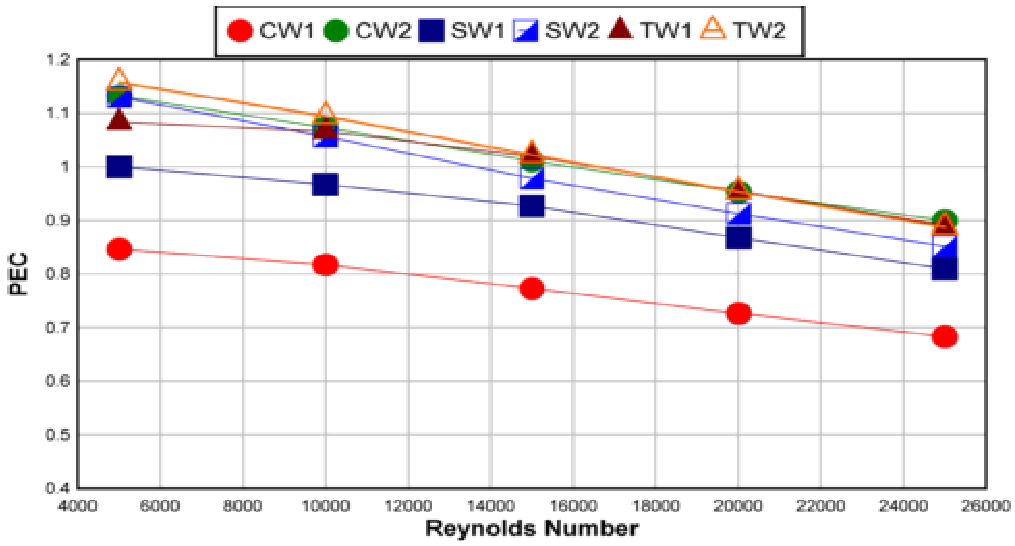

Figure 4.57 Reynolds Number versusPEC for all study

CHAPTER 5
CONCLUSION

Six differentgeometries were studiedand applied to heat transfer enhancement by using Ansys Fluent v17. In the first geometry study, pitch ratio effect was examined. Different geometry insert was examined in the second geometry study. The geometryt study was the wire coil insert around wire coil were examined numerically in the present work, the following results can be concluded.

1-According to high performance results, the proposed method of-side heat transfer enhancement by wire coil insert around wire coil can be considered as a promising method of promoting heat transfer in the tube heat exchanger.

2- For both tube and wire coil insert around wire coil heat transfer enhancement, Nusselt number and friction factor are more concern on Reynolds number at low values than high ones.

3- Friction factor and heat transfer in enhanced wire coil insert around wire coil are affected by the shape and pitch and diameter insert.

4- In triangular wire coil insert around triangular wire coil enhancement, the performance of wirecoils is better than circular wire coil insert around circular wire coil insert and square wire coil insert around square wire coil through all calculations.

5- The R3 increased with decreasing Reynolds number. The highest R3 is observed on lowest pitch for the triangular wire coil insert around triangular wire coil type one of primary pitch 16mm and secondary pitch 1.44mm.The R3 value of type one higher than type two approximately 1.724% to 1.729.R3 of square wire coil insert around square wire coil type one higher than type two in the range 1.30% to

1.22%.R3 of circular wire coil insert around circular wire coil type one higher than type two in the range 0.8640 % to 0.77%.

6- The fraction ratio (Fa/Fo) increases with increasing Reynolds number and Fa/Fo also increase with decreasing pitch value. The Fa/Fo of the triangular wire coil insert around triangular wire coil type one of primary pitch 16mm and secondary pitch 1.44mm higher than type two approximately 14.9% to 27.766%.The Fa/Fo of square wire coil insert around square wire coil type one higher than type two approximately 11.420% to 19.73%. The Fa/Fo of circular wire coil insert around circular wire coil type one higher than type two approximately 9.680 % to 16.5921.

7- The Nusselt number of triangular wire coil insert around triangular wire coil type one and type two were higher than smooth pipe in the range of 72% to 191.247,and 70% to 175%, respectively.

8- The Nusselt number of square wire coil insert around square wire coil type one and type two were higher than smooth pipe in the range of 61.133% to 155.636,and 59.73% to 144% ,respectively.

9- The Nusselt number of circular wire coil insert around circular wire coil type one and type two were higher than smooth pipe in the range of 49% to 124.13% and 46.851% to 107.382%, respectively.

10-The highest PEC was observed on the highest pitch.

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CHAPTER 6
FUTURE WORK

The following points are suggested for future work:

1-Numerical study on wider Reynolds number than the one used in this study that covers all of flow regions laminar, transition and turbulent flow with larger diameter of wire coil insert around wire coil.

2-Experimental study on flow behaviors and heat transfer in pipes with the wire coil insert arond wire coil may be investigated and compared with the results of this study.

3-Numerical study for the diamond wire coil insert around diamond wire coil may be investigated to increase the surface contact between the helical wire and the tube so that the helical wire can work a surface of heat transfer.

4-Study further coilgeometries parameters, such as pitch and diameter insert.

5- The effect of new design inserts on the two-phase flow and vaporaziation of liquid medium flow should be also investigated.

6- The combined effect of nano-particles and new inserts should be investigated.

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