UNIVERSITY OF TURKISH AERNAUTICAL ASSOCIATION
INSTITUTE OF SCIENCE AND TECHNOLOGY

HEAT TRANSFER ENHANCEMENT IN LAMINAR FLOW THROUGH CIRCULAR TUBE USING VARIOUS TWISTED TAPES

MASTER THESIS

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Institute of Science and Technology

Mechanical and Aeronautical Engineering Department

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30.11.2017

Wisam, HASSOON

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I am grateful to The Almighty GOD for helping me to complete this thesis. My Lord mercy and peace be upon our leader Mohammed peace be upon on him, who invites us to science and wisdom, and members of his family and his followers.

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November 2017 Wisam Qasim Hassoon

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LIST OF ABBREVIATIONS

Q	:	Electric power (Watt)
$\mathbf{Q_a}$	:	Adsorbed heat energy (Watt)
q''	:	Heat flux (W/m^2)
I	:	Electric current (Amp)
V	:	Electric voltage (volt)
$\dot{m}$	:	Mass flow rate (kg/s)
$\mathbf{C_p}$	:	Specific heat (kJ/kg.K)
f	:	Friction factor
d	:	Diameter (m)
H	:	Pitch (m)
h	:	Heat transfer coefficient ($W/m^2.°C$)
Nu	:	Average Nusselt number
Re	:	Reynolds number
Y	:	Twist ratio
A	:	Area (m^2)
L	:	Length (m)
W	:	Width (m)
t	:	Thickness (m)
de	:	Cutting depth
V	:	Average velocity inside the tube ($^{m}/_{sec}$)
k	:	Thermal conductivity (W/m.K)
re	:	Cutting Radius (m)
we	:	Cutting width (m)
enh	:	Enhanced
s	:	surface
fo	:	Outlet fluid
fi	:	Outlet fluid
c	:	Cross section
i	:	inside
o	:	outer
si	:	Inner surface
so	:	Outer surface
ρ	:	Density($\frac{kg}{m^3}$)
μ	:	Dynamic viscosity (kg/m.s)
η	:	Thermal enhancement factor
Δp	:	Pressure drop
TTT	:	Typical twisted tape
VCTT	:	V- cut twisted tape
UCTT	:	U- cut twisted tape
PTT	:	Perforated cut twisted tape

SCTT : Semicircular- cut twisted tape
TTT3 : Typical twisted tape with twist ratio of 3.0
TTT5 : Typical twisted tape with twist ratio of 5.0
VCTT3 : V- cut twisted tape with twist ratio of 3.0
VCTT5 : V- cut twisted tape with twist ratio of 5.0
UCTT3 : U- cut twisted tape with twist ratio of 3.0
UCTT5 : U- cut twisted tape with twist ratio of 5.0
PTT3 : Perforated cut twisted tape with twist ratio of 3.0
PTT5 : Perforated cut twisted tape with twist ratio of 5.0
SCTT3 : Semicircular- cut twisted tape with twist ratio of 3.0
SCTT5 : Semicircular- cut twisted tape with twist ratio of 5.0

ABSTRACT

HEAT TRANSFER ENHANCEMENT IN LAMINAR FLOW THROUGH CIRCULAR TUBE USING VARIOUS TWISTED TAPES

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In this thesis, an experimental investigation is implemented to evaluate the heat transfer and pressure drop characteristics for five variant types of twisted tapes including (typical, semicircular-cut, U-cut, V-cut and perforated) twisted tapes (TTT, SCTT, UCTT, VCTT, PTT) respectively equipped in plain tube. These various categories tested with two twist ratios (y=5.0, 3.0). The experiments carried out under laminar flow regime with Reynolds number (Re) varies from 566 to 1994. A copper plain tube of 14.2 mm diameter, 1000mm length and0.9mm thickness was exposed to uniform heat flux and is insulated by asbestos to avoid heat losses. The working fluid was water.

The main findings that were obtained from the present experimental work is that using of various categories of twisted tape mentioned above in plain tube produced a considerably enhancement in heat transfer with an increase in pressure drop compared with the tube without insert. In addition, decreasing the twist ratio for all categories produced higher Nusselt number (Nu). V-cut twisted tape of twist ratio of 3.0 (VCTT3) yielded the highest increase in Nu with value of 68.63 with heat transfer enhancement of 195% higher than the plain tube due to the generating of secondary flow and increase of swirl intensity. The lowest heat enhancement produced by perforated twisted tape of twist ratio of 5.0 (PTT5) with Nu of 48.75 and 105% comparing to the plain tube. Furthermore, VCTT3 caused higher friction loses between the equipped

categories in the circular plain tube with friction factor of 0.574 at Re of 566 and it is 5.667 times higher than the plain tube while minimum friction losses yielded by PTT5 with friction factor of 0.162 at Re of 1994 over the range investigated.

In this study, the higher thermal performance factor was obtained by VCTT3 and it is 8.65 at Reynolds number of 1994, while UCTT3, SCTT3, TTT3 and PTT3 yielded 8.44, 8.4, 8.24and 8.04 respectively at the same conditions.

Keywords: Twisted Tapes, Laminar Flow, Uniform Heat Flux

ÖZET

ÇEŞİTLİ BÜKÜLMÜŞ BANTLAR KULLANILARAK DAİRESEL BORU İÇİNDEN LAMİNAR AKIŞTA ISI TRANSFERİNİN ARTTIRILMASI

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Bu tezde (tipik, yarım daire kesimli, U-kesikli, V-kesikli ve delikli) bükülmüş bantlar (TTT, SCTT, bükülmüş bantlar) dahil olmak üzere beş değişik tipte bükülmüş bantlar için ısı transferi ve basınç düşüşü özelliklerini değerlendirmek üzere deneysel bir araştırma gerçekleştirildi. UCTT, VCTT, PTT) sırasıyla düz tüp. Bu çeşitli kategoriler iki bükülme oranlarıyla test edildi (y = 5.0, 3.0). Reynolds sayısı (Re) ile laminer akış rejimi altında yapılan deneyler 566'dan 1994'e kadar değişmektedir. 14.2 mm çapında, 1000 mm uzunluğunda ve0.9 mm kalınlığında bakır düz boru, düzgün ısı akısına maruz bırakıldı ve ısı kayıplarını önlemek için asbest ile izole edildi. Çalışan sıvı suydu.

Mevcut deneysel çalışmadan elde edilen ana bulgular, yukarıda belirtilen bükülmüş bandın çeşitli kategorilerinin düz tüp içinde kullanılması, ilaveten olmayan tüp ile karşılaştırıldığında basınç düşüşünde bir artış ile ısı transferinde belirgin bir iyileşme meydana getirdiğidir. Buna ek olarak, tüm kategorilerdeki bükülme oranının azaltılması, daha yüksek Nusselt sayısı (Nu) üretti. 3.0 (VCTT3) büküm oranının V-kesim bükülmüş bandı (VCTT3), Nu'da 68.63 değerinde en yüksek artışa neden olup, ikincil akışın üretilmesi ve girdap yoğunluğunun artması nedeniyle ısı iletimi iyileştirme düz borudan %195 daha yüksek olmuştur. 5.0 (PTT5) bükme oranının perfore bükülmüş bandı ile Nu 48.75 ve% 105 ile düz boruya kıyasla en düşük ısıl iyileştirme. Ayrıca VCTT3, direnç faktörü 0,574 olan dairesel düz tüp içindeki

donanım kategorileri arasında daha yüksek sürtünme kaybına neden olmuş ve re 566 Re'da 5,667 kat daha fazladır, PTT5 tarafından minimum sürtünme kayıpları ise Re'de 0,116 sürtünme faktörü ile bulunmuştur 1994 yılı aralıklarla araştırıldı.

Bu çalışmada, yüksek termal performans faktörü VCTT3 ile, Reynolds sayısı 1994'de 8.65 iken, UCTT3, SCTT3, TTT3 ve PTT3, aynı koşullarda sırasıyla 8.44, 8.4, 8.24 ve 8.04'ü vermiştir.

Anahtar Kelimeler: Bükülmüş Bantlar, Laminer Akış, Düzgün Isı Akısı

CHAPTER ONE

INTRODUCTION

Thermal systems are considered one of the most important systems that have many manufacturing applications. Hence, there are many research and studies are conducted to obtain the appropriate technique, which yield better heat transfer and thermal performance in these systems. The development of heat exchanger and enhanced its rate of heat transfer can obtained through the use of one of the augment methods that depends on the surface adjustments which has significant effect in increase the rate of heat transfer. This enhancement in heat transfer which depend on utilize enhanced surfaces occurs accordingly to several conditions. These conditions include increase the area of heat transfer, growing turbulence degree by interrupting development of boundary layer, and producing of swirling flows.

Commonly, there are numerous motives for utilizing augmented heat transfer surfaces. Enhanced surfaces aid in decreasing the size of heat exchangers that could lead to saving in their costs. In addition, they decrease the pumping power that is required for a certain thermal exchange processes. Moreover, they enhanced the value of heat transfer coefficient of the heat exchangers that supports in either work to minimize the mean temperature difference for the heat transfer or gaining an enhancement heat exchange rate for fixed the working fluid inlet temperatures. In turn, this improves the effectiveness and efficiency of thermal processes and results in operating cost saving [1].

The industry of heat exchanger has been motivated for developed thermal contact (enhanced heat transfer coefficient) and decrease pumping power in order to increase the thermo-hydraulic efficiency of heat exchangers [2].

1.1 Heat Transfer Enhancement

Heat exchangers are tools, which are ordinarily used to exchange heat between two or more fluids of different temperatures. They are used in many various applications, such as power engineering, air-conditioning systems, refrigeration, and other thermal processing plants.

1.1.1 Classification of Heat Transfer Augmentation Techniques

The methods of enhancement heat transfer can classified into three categories, which are as following:

(a) Active method

(b) Passive method

(c) Compound method

The following subsections explain the three methods and give examples on each one.

a- Active Method:

The enhancement of heat transfer by this method required for a consumption of external power input. Some of the noticeable examples of active methods are induced pulsation by cams and reciprocating plungers as well as the use of a magnetic field to disturb the seeded light particles in a flowing stream. This method is not widely used due to its complex design and the difficulty to provide external power in many applications.

b- Passive Method:

This method is called passive because it does not require external power input and instead, it takes the power needed in enhancing the heat transfer from the overall power of the system. The disadvantage in this method is that it causes a pressure drop in fluid. Generally, passive methods involve surface or geometrical modification such as the use of inserts, rough surfaces as well as extended surfaces. Table 1.1 shows some examples of the two above methods [2].

c- Compound Method:

This technique considered as a hybrid or a compound from two of the above techniques. It is comprise two or more of these techniques applied together to produce an enhancement that is larger than that performed by discrete technique when applied individually such as fins and electric fields, electric fields in a bunch of treated tubes, radically grooved rotating disk etc. [3].

Table 1.1: Classification of heat transfer enhancement techniques [4].

Active method	*Passive method*
Surface vibration	Extended surface
Jet impingement	Roughness surface
Mechanical aids	Treated surface
Fluid vibration	Surface tension devices
Injection	Swirl flow devices
Suction	Displaced enhancement devices
Electrostatic fields	Coiled tubes
	Additives for liquids
	Additives for gases

1.1.2 The Principles of Heat Transfer Augmentation through Passive Techniques

As acknowledged high rate of heat transfer happened in the entrance region of flows in channels, this is for the reason of development both hydrodynamic and thermal boundary layers at this region. The increase in thickness of both these boundary layers remote from the entrance in flow direction of the channel make poor transfer of heat since the main mode by which heat transfer happened is diffusion [5]**.** So, it is desired to constrain the development of hydrodynamic and thermal boundary layer through repeatedly interruption for these two layers and promote turbulences, consequently a chain of entry lengths produced and heat transfer rate will increase. This can be achieved by providing various roughen surfaces or tabulators in addition to adding vortex generators, which is, make three-dimensional fluid mixing through generating transverse or longitudinal vortices in the flow field.

These phenomena has considerably effect on temperature field and sizeable augmentation on transfer of heat occurred in assessment with smooth channel with no tabulators. The enhancement in heat transfer penalty is supplemented by such increase in pressure drop. Therefore, the critical balance between the increment level in heat transfer and pressure drop is the primary goal for any enhancement study, all studies aimed to gain high thermal performance enhancement by increasing the rate of heat transfer as much as possible and minimizing pressure drop [6]. Several of passive techniques methods are shown in Figure 1.1.

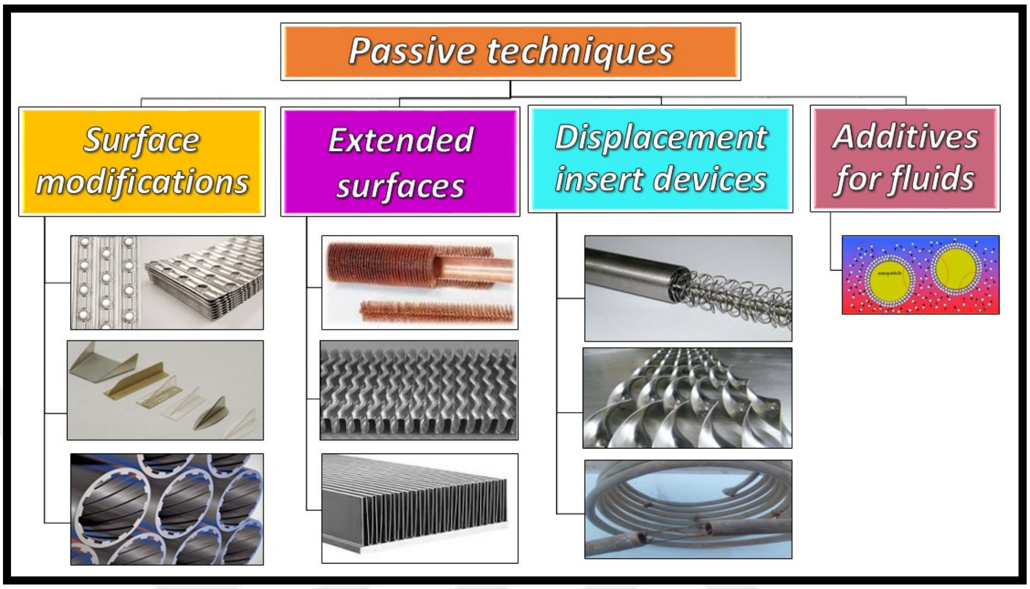


Figure 1.1: Different methods of passive techniques.

1.2 Heat Transfer with Uniform Heat Flux Condition

The heat exchange with constant heat flux condition is usually happens when a tube surrounded with electrical heater Figure 1.2, a tube in tube (double pipe) heat exchanger at which the outer or external heat transfer coefficient is low. Hence, in case of heating tube purposes, as the temperature of the fluid increase along the tube length the temperature of the wall tends to decrease, while the wall temperature and the fluid temperature tends to increase along the tube length in cooling tube application [7]. Figure 1.3 shows the case of heating fluid where the temperature difference (ΔT) between the tube surface and fluid remains constant to achieve constant heat flux condition.

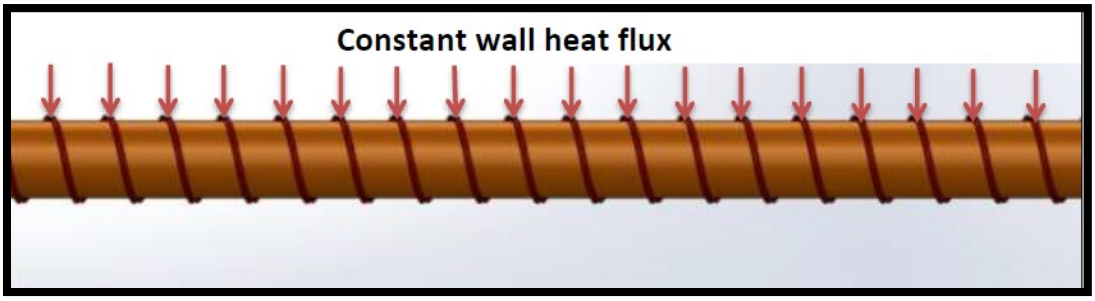


Figure 1.2: Uniform heat flux condition (horizontal plain tube surrounded with heater tape).

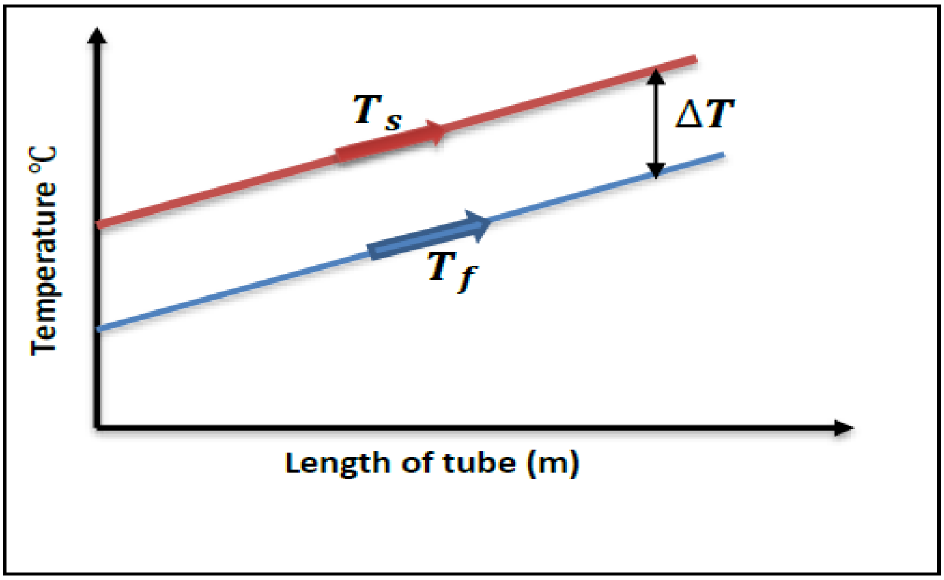


Figure 1.3: Heating fluid case.

1.3 Swirl Flow Device

Swirl flow devices are considered one of heat transfer enhancement methods and it is listed under passive techniques. By using these devices, swirl flow or secondary flow is generated in the fluid. Swirl flow devices contain a number of geometric arrangement or tube inserts for forced flow (forced convection) that generate rotating or secondary recirculation flow on the axial flow inside the tube. These devices include, twisted tape inserts, axial core inserts, helical strip, longitudinal strip, mesh inserts, brush inserts, louvered strip inserts, conical ring inserts and wire coils.

These devices caused enhancement in heat transfer by many effects:

1. Increased path length of the flow.
2. Secondary flow effects.

3. The fin effects in case of tapes (it contact area between tape edge and inner tube wall).

Generally, these inserts are fitted inside the tube to enhance the heat transfer rate that will cause flow blockage, secondary flow, division of the flow and reduction the hydraulic diameter of flow passage, which depend upon the shape of the tape insert if it is snugly, loosely, or tightly fitted inside the tube.

Flow blockage increases viscous effects due to reduction in the free flow area that will cause an increase in pressure drop and the flow velocity. Secondary flow generates swirl, that provides a better thermal contact between the internal surface of the tube and the fluid flow inside it and that will improve temperature gradient and fluid mixing, which finally guides to a high heat transfer coefficient [2][8].

1.4 Twisted Tape

Twisted tape and wire coil inserts are the most effective passive techniques on heat transfer enhancement. In case of laminar flow inside heat exchanger, the twisted tape becomes more effective to enhance heat transfer as compared with wire coil “Twisted tapes are the metallic strips twisted with some suitable techniques with desired shape and dimension, inserted in the pipe” [10].

Twisted tape mixes the bulk flow well by inducing swirl flow for the fluid inside the tube and offers a modest increase in heat transfer at low additional pressure loss, but in turbulent flow, twisted tape blocks the flow and causes a large pressure drop. Wire coil preforms better in turbulent flow because its random roughness at high Reynolds numbers[9]. Furthermore, twisted tape inserts show a number of advantages with respect to other augmentation techniques:

1. Better thermal hydraulic performance in single-phase flows and improved boiling and condensation forced convection.
2. Low cost
3. Easy to install and remove.
4. They preserve the original plain tube mechanical strength.
5. They can installed in an existing smooth tube heat exchanger.

1.4.1 Twisted Tape Technical Details

Many types of metals can be used to manufacturing twisted tape such as copper, stainless steel, aluminum, etc. The following details are very important to more knowledge about twisted tape manufacturing:

1. Pitch (H): it is the length of one twist in twisted tape for 180° rotation angle.
2. Width (W): it is the width of the twisted tape.
3. Twist ratio (Y): it is the ratio of pitch length to the width of the twisted tape Y=H /W
4. The rotations number: it is the ratio of twisted tape length to the pitch length. Figure 1.4 shows the twisted tape configuration.

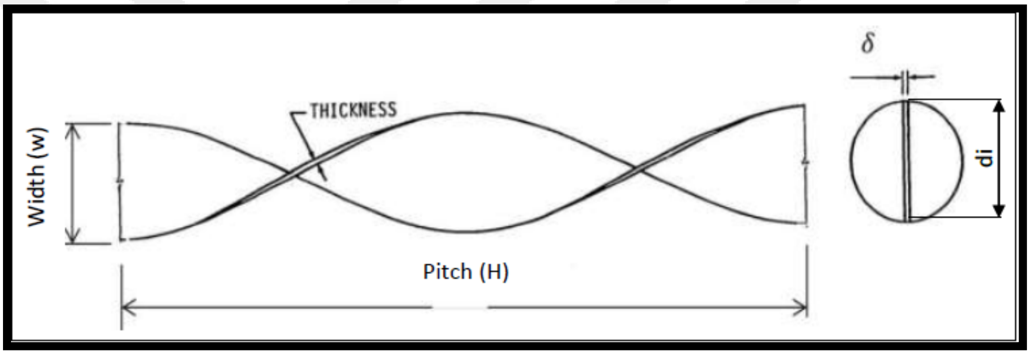


Figure 1.4: Twisted tape configuration [7].

1.4.2 Different Types of Twisted Tape

This review will analyze the following types of twisted tapes:

a) Full length twisted tape: The tapes lengths of these kind are equal to the test section, Figure 1.5 illustrate this type:

Figure 1.5: Full length twisted tape.

b) Variable length twisted tape: These types of tape have Quarter (1/4), half (1/2), or three quarters (3/4) of the length, etc. of test section.
c) Twisted tapes with regularly spaced: These types made with short length tapes with variant pitches spaced by linking together.
d) Baffles twisted Tape: twisted tape can united with baffles at some spaces to accomplish better enhancement as shown in Figure 1.6

Figure 1.6: Attached baffles twisted tape

e) Slotted tapes or perforated tapes: Slots and holes of appropriate dimensions made in the twisted tape so as to produce more turbulence as shown in Figure 1.7

Figure 1.7: Holes twisted tape.

f) Different surface modifications tapes: Tapes can delivered with some isolating material so that fin influence can averted or several types of cuts can add to tape surface material construction such as Square- cut twisted tape.

1.5 The Objectives of the Present Work

The present work goal is to make experimental study to evaluate the effect of equipped variant twisted tape in horizontal plain tube with the variation in Reynolds number under laminar flow condition on the characteristics of heat transfer, pressure drop and thermal performance factor. The present work also make comparison to the effects to variant modifications include different shapes of cuts to the typical twisted tape (TTT) and different twist ratio that explained in chapter three in order to select the proper design that provide the better performance in heat exchangers.

1.6 Thesis Outline

The second chapter presents previous studies and literature review related to the current work to get more comprehensive to the details associated to the use of twisted tapes in passive method.

The third chapter, includes two main sections, the first section included the main parts of the experimental testing device with the function of each part as well as conducting the experiment implementation while the second section produced the mathematical model and reduced the data.

The fourth chapter presents and discusses the experimental results. The experimental work involves the performance of test section in terms of heat transfer (Nusselt number) and pressure drop (friction factor) across the tested tube with using twisted tapes.

The fifth chapter displays the conclusions and recommendations to future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Recently, Thermal performance improvement of the heat exchanger gained a considerable attention because of its use in many industrial applications such as automobile manufacturing, electric power generators and industrial processes, which apply one of the techniques of heat transfer augmentation. This augmentation of heat transfer can achieved through some modifications to obtain appropriate heat exchanger designs that ha a significant economic role in reducing the size; saving the cost and increasing the efficiency of these heat exchangers.

The authors in Ref. [11] gave a comprehensive survey and estimate of several heat transfer augmentation techniques used in the heat transfer system. Twisted tape can represented one of the better economic improvement methods in the group of enhanced heat transfer techniques due to the considerably offered beneficial results in the previous studies. In this chapter, a review of various studies carried out related to the heat transfer enhancement using different types of swirl device.

2.2 Swirl Flow Device

In the last years, important effort has be made to more improvement and enhancement of heat transfer methods in order to improve the overall performance factor of heat exchanger. The usage of augmentation techniques to increase convective heat transfer coefficient inside tubes has be studied for several years.

Eiamsa-ard [12] implemented experimental study to evaluate the effect of twisted tape with (ODWT) Oblique, delta-winglet and twisted tape with (SDWT) straight delta-winglet modification fitted in circular tube on the heat transfer, friction losses and thermal performance characteristic. The experiment under turbulent flow condition with Reynolds number (Re) selected between 3000 and 27,000 and the water used as working fluid under uniform wall heat flux. Three various twist ratio (y= 3.0, 4.0 and 5.0) with three (DR) wing depth ratio (d/w= o.11, 0.21 and 0.32) was tested. The result concluded:

1. Rising the twisted ratio (y) caused a decrease in the Nusselt number (Nu) and friction factor (f).
2. As depth of wing cut ratio (DR) Increase, increase in (Nu) and (f) happens.
3. utilizing O-DWT give rise to a higher heat transfer coefficient than the S-DWT
4. compared to a tube fitted with a typical twisted tape (TTT) over the (Re) range used in the study, the O-DWT results were as follow:

a) Nusselt number: (1.04 - 1.64) times higher
b) Friction factor: (1.09–1.95) times higher
c) Thermal performance factor: (1.05–1.13) times higher

Naga [13] applied experimental study to evaluate the effect the width reduction of twisted tape inserts in a horizontal rounded tube on the heat transfer characteristics. The experiments conducted under turbulent flow with range of 6000 to 13500 variation of Reynolds number. Three different twist ratio (y = 3.0, 4.0 and 5.0) was tested and the air was the working fluid in a tube of 27.5mm inner diameter. Each of these tapes has five various widths (10,14, 18, 22 and 26 mm-full width) Figure **2.1** shows the varying width-cut twisted insert and twist ratio Table 2.1 summarizes the percentage upsurge in Nusselt numbers gained due to twisted-tape inserts comparing to plain tube. It can observed that the heat transfer increases with the decreasing in twist ratio.

Table 2.1: Percentage increase in nusselt numbers due to twisted-tape inserts naga [13].

Twist ratio	W=10	W=14	W=18	W=22	W=26
Y=3.0	11-22%	16-31%	24-34%	39-44%	58-70%
Y=4.0	5-12%	9-22%	13-30%	23-36%	36-42%
Y=5.0	2-8%	6-12%	9-19%	14-27%	22-37%

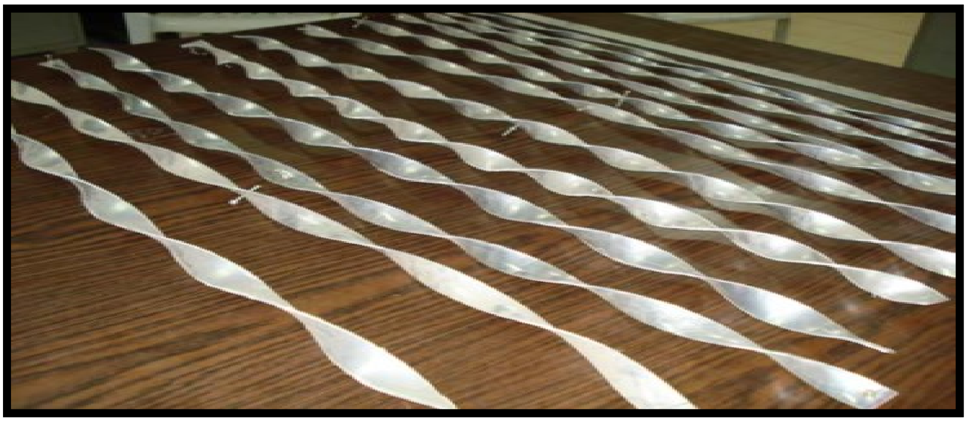


Figure 2.1: The varying width-cut twisted insert naga [13].

Kapatkar [14] implemented experimental investigation to study the influence of fitting full length twisted tape inserts with three various materials in round pipe on the heat transfer, friction losses and thermal performance characteristic. The experiment carried out with to two various twist ratio of y= 3.4 and 5.2 under laminar flow regime with (Re) varies from 200 to 2000.the result concluded that the effect of typical twisted tape of variant materials on Nusselt number enhancement was as the following:

1. For Aluminum twisted tapes the enhancement between 50% to 100%
2. For Stainless steel twisted tapes the enhancement between 40% to 94%
3. For Insulated twisted tapes the enhancement between 40% to 67%

While the friction losses with full length twisted tape inserts was 340% to 750 % higher than those of plain pipe flow with twist ratios of y=5.2,3.4 respectively.

Bodius [15] implemented experimental study to evaluate heat transfer coefficient of water on tube side for turbulent flow. The tube is circular and is equipped with twisted tape insert made of stainless steel and twist ratio of 5.3. Nichrome wire covered with fiberglass was wrapped around the test section in order to retain a uniform heat flux condition. The temperature of the tube outer surface in the test section was measured at five different spots. T-type thermocouples were used to measure the temperature with a thermometer placed in a mixing chapter at the outlet section. The study was conducted over a range of 9500-20000 of Reynolds numbers. Heat flux was varied from 9.0 to 18 kW/m² for smooth tube and 15 to 31 kW/m² for tube with twist tape insert. It was noticed that over the same Reynolds number, twist tape insert caused an improvement in Nusselt number by 2.9 to 4.0 times when compared to the smooth tube.

Sami [16] modeled, simulated and analyzed the effect of Parabolic-Cut Twisted tape (PCT) inserts fitted in a circular tube on the heat transfer rate using Computational Fluid Dynamics (CFD) modeling. Figure 2.2 shows the Parabolic-cut twisted insert. A commercial CFD package (FLUENT-6.3.26) was used to carry out the simulation. The modeled circular tube is a constant heat-fluxed tube having a laminar flow. Three different twist tapes were considered in the simulation with cut depth (w =1.5, 1 and 0.5cm) and twist ratio (y=4.89, 3.91 and 2.93). It was discovered that the Nus and the (f) in the tube fitted with PCT increase with the decrease of cut depth (w) and twist ratio (y).

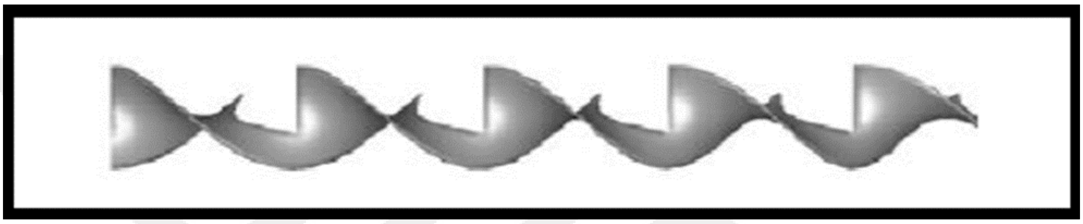


Figure 2.2: Parabolic-cut twisted insert [16].

Selvam [17] implemented experimental study to evaluate the effect of variant twist pitch to the width of the twisted tape ratios (y) for (TTP) twisted tape with pins and (TTPB) twisted tape with pins bonded on the heat transfer, friction losses and thermal performance characteristic. The twist ratio y=3.33, 4.29, and 5.71 with study the variation of Nusselt number with Reynolds number. The study fining is:

1. The smallest twist ratio y=3.3 produced higher values of heat transfer of about 23.86% than plain tube.
2. Similarly for y=4.29 and 5.71 the enhancement were 19.9% and 14.4%.
3. Friction factor for twist ratio of (y=3.3) is higher than those of (y=4.29 and 5.71) because the effect of higher contact surface area of the tabulators.

In Ref. [18], the authors investigated the effect of wire coil inserts made by different materials fitted in a double pipe heat exchanger on the heat transfer and friction factor (f) characteristics. The experiment implemented under turbulent flow condition with Reynolds number varies between 4000 and 13000. The three various materials was copper, aluminum and stainless steel. The main finding was compared with smooth tube and it is as follows:

1. For copper the heat transfer enhancement is 1.58 higher, while (f) is higher between 4.3 to 5.4 times.
2. For aluminum, the heat transfer enhancement is 1.41 higher, while (f) is higher between 5.4 to 6.7 times.
3. For stainless steel the heat transfer enhancement is 1.31 higher, while (f) is higher between 4.8 to 5.9 times

Bodius Salam [19] produced experimental investigation to evaluate the enhancement of heat transfer coefficient, heat transfer efficiency and friction factor (f) of round tube side equipped with rectangular-cut twisted tape insert. The working fluid is water under turbulent flow regime, uniform heat flux conditions. Rectangular cut twisted tape insert of 5.25 twist ratio made of stainless steel placed in plain tube. The rectangular cut of 8 mm depth and 14 mm width. The test section wrapping by Nichrome wire and wire surrounded by fiberglass isolated. Five T-type thermocouples were be used to measure the outer surface the tube and two thermocouples for measuring water bulk temperatures. Reynolds number (Re) varied from 10000 to 19000.

The study concluded:

1. At the same condition of Re, the tube with rectangular-cut twisted tape insert provided higher Nusselt numbers by 2.3 to 2.9 times at the cost of increase of (f) by 1.4 to 1.8 times compared to that of smooth tube.
2. The enhancement of thermal performance was higher by a range of 1.9 to 2.3 times than the smooth tube.

Numerical study by Anucha 2017 [20] was presented to make a comparison the performance of two types of inserts, the first one is was square cut twisted tapes placed in a circular tube and the other was classical or typical twisted tapes. The work was under a turbulent flow and uniform heat flux. The geometries of square cut twisted tapes contain five different WR ratios (the width of perforated to the width of tape ratio) which is 0.5, 0.6, 0.7, 0.8 and 0.9 with three different LR (the ratio of perforated length to tape width) which equal to 0.7, 0.8 and 0.9 were studied and he concluded:

1. The decreasing perforated width to tape width ratio (WR) and perforated length to tape width ratio (LR) caused increase in heat transfer and pressure loss.
2. Thermal performance factor increases as WR increases.

3. The twisted tapes with square cut at the largest WR ratio (WR = 0.9) and the smallest LR ratio (LR = 0.7) gave the highest thermal enhancement factor of 1.37 at (Re= 7000)
4. The twisted tapes with square cut produced higher thermal performance factor with 1.32 times over than those obtained by the typical twisted tape.

N. Piriyarungrodsa [21] carried out experimental investigation on a tube fitted with tapered twisted tape (T-TT) to evaluate their thermal and friction characteristics. Four different taper angle (θ = 0.0˚, 0.3˚, 0.6˚ and 0.9˚) and at each taper angle, the tapered twisted tapes were twisted at three various twist ratios (y=p/w) of 4.5, 4.0 and3.5. The study were be tested implemented under Re varied from 6000 to 20,000. The result was be compared with plain tube that also studied. The main findings can concluded as the following:

1. Comparing with the plain tube, the utilization of tube equipped with tapered twisted tapes yielded higher heat transfer.
2. As the taper angle decrease, Heat transfer augmentation and friction loss increase. Lower Nusselt number gotten from tapered twisted tape (T-TT) with θ = 0.9˚ than the ones with θ= 0.0˚, 0.3˚ and 0.6˚ by 2.09%, 3.49% and 6.99%, respectively where the friction factor of the tapes with θ = 0.90 was lower than those of the ones with

θ = 0.0˚, 0.3˚ and 0.6˚ by around 41.97%, 30.61% and 14.94%.

1. As the twist ratio, decrease both of heat transfer enhancement and friction losses increase. Lower Nusselt number gotten from (T-TT) with y= 4.5 than the ones of y=3.5and 4.0 by around 10.98% and 6.05%, respectively where the friction factor of the tapes with y=4.5was lower than those with y=3.5and 4.0 by around 15.70% and 6.22%, respectively.
2. As the taper angle increase and tape twist ratio decrease thermal performance factor (η) increase. For this study, the tape with θ of 0.9˚and y=3.5 gave the better η of 1.05 and at Re of 6000. Figure 2.3 shows the tapered twisted tape.

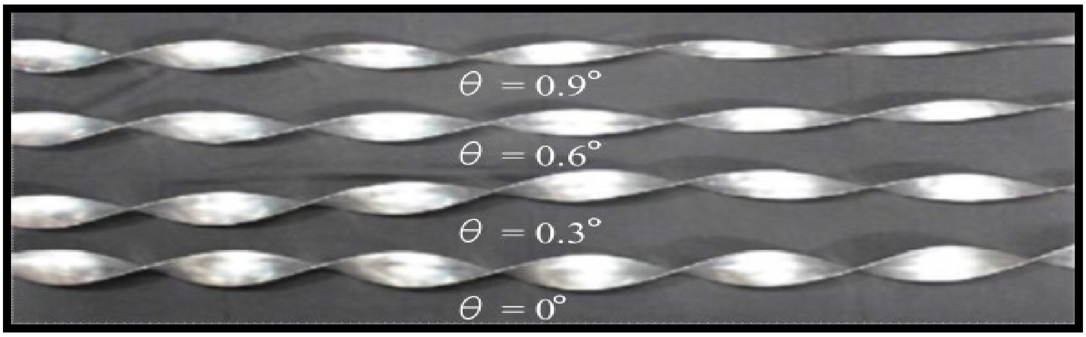


Figure 2.3: Tapered twisted tape with different taper angle (θ).

Bhuiya [22] implemented experimental study to evaluate the effect of perforated twisted tape inserts put in smooth tube on the heat transfer, friction losses and thermal performance characteristic. The experiment was under turbulent flow regime and select Re variation between 7200 and 49,800 under uniform heat flux and the air was the working fluid. Four variant porosities of Rp = 1.6, 4.5, 8.9 and 14.7% was selected to study its effect. The result showed that the use of perforated twisted tape has the flowing:

1. Significant rise in heat transfer with increase of 110 –340 % upper than smooth tube.
2. Friction factor rises between 110 –360% upper than smooth tube.
3. Thermal performance gains between 28–59% upper than the smooth tube.

Gawandare [23] carried out experimental investigation on a copper square jagged twisted tape have thickness of 3mm with three different twist ratio y= 5.2,4.2 and 3.2 as shown in Figure 2.4. The test contains the evaluation of heat transfer coefficient, friction factor (f) or different twisted tapes by changing twists and changed materials under turbulent flow condition with Reynolds number (Re) varied from 5000 to 16000, and he concluded:

1. When the inserts put in the track of the fluid flow, produce a high turbulence degree which causing an increase in the pressure drop and heat transfer rate.
2. The copper insert of 3mm thick and 3.2 twist ratio shows enhancement of 76% in Nusselt number (Nu) values while the rise in (f) is only 19.5% in comparison to the plain tube values.

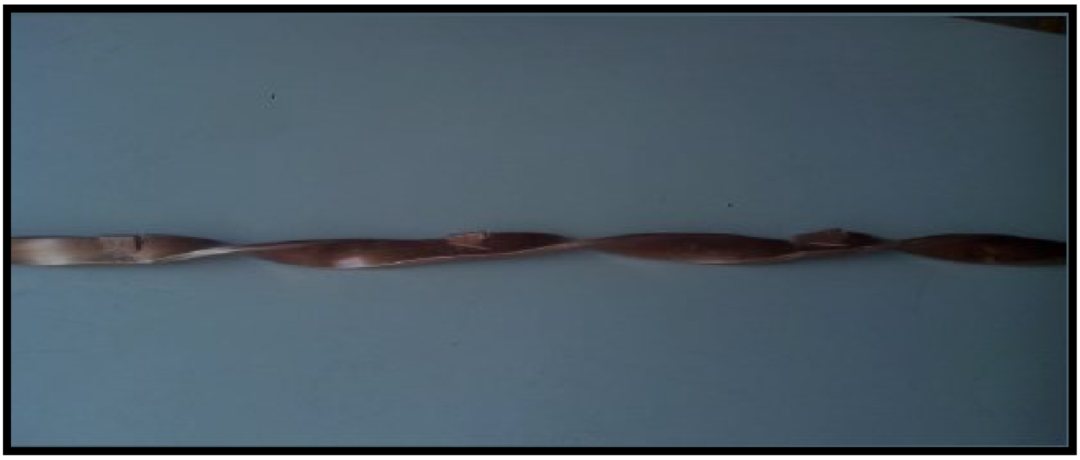


Figure 2.4: Copper square jagged Twisted tape (y=5.2) Gawandareet [23].

The authors in Ref. [24] studied the heat transfer (Nu),friction factor(f) and thermal performance factor (η) behaviors and working for comparative study to two types of twisted tapes in a heat exchanger. The two types are a regularly spaced twisted tape (RS-TT) and a full-length twisted tape or (typical) twisted tapes. Two various twist ratios of 6.0 and 8.0 for both two types of (TTT) and regularly spaced twisted tape (RS-TT) with three free space ratios (s=S/P=1.0, 2.0, and 3.0) were employed for comparative study as shown in Figure 2.5. The study concluded:

1. Under the same conditions, the values of (Nu), (f) and (η) of typical or full length twisted tapes (s=0) are higher than those of regularly spaced (s=1.0, 2.0 and 3.0).
2. As the space ratio increase, the enhancement of (Nu), (f) and (η) decreased.
3. The heat transfer augmentation of (TTT) (s=0), a regularly spaced twisted tape (s= 1.0, 2.0 and 3.0) are 56.8%, 46.2%, 30.5% and 22.6% respectively, where the pressure drop and friction factor were increase up to 4.22, 3.78, 3.17, and 2.63 times as compared to those in the plain tube.
4. As the twist ratio increase, the enhancement of (Nu), (f) and (η) decreased, The heat transfer augmentation of y=6.0 and 8.0 are 46.2% and 34.6% respectively where friction factors increased up to 3.78 and 3.21 times in compare with those of plain tube.
5. The study founded that regularly spaced twisted tape (RS-TT) with y=6.0 and s=1.0 have the same Nusselt number of typical (full length) twisted tape with y=8.0. This happens due to the stronger swirl intensity and turbulence intensity of y=6.0 recompense the swirl decaying of the RS-TTs with y=8.0

and produce their overall turbulence equal of that typical twisted tape of Y=6.0.

6. RS-TTs with large free space ratio (s=3.0) at both twist ratios of 6.0 and 8.0 producing lower heat transfer rate than other tapes as a result to the important reduce of swirl flows.

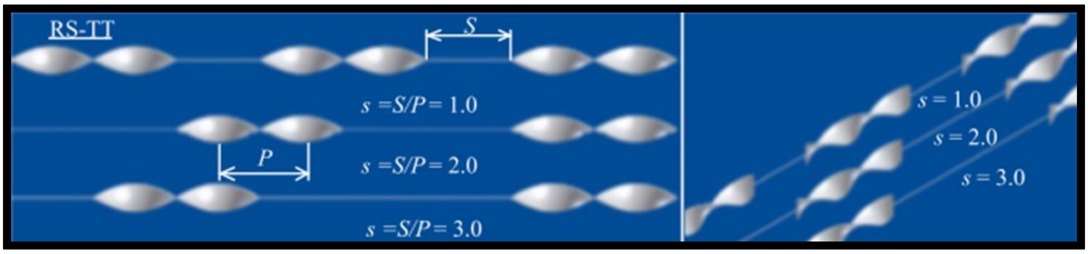


Figure 2.5: Regularly spaced twisted tape (RS-TTs) insets [24].

The authors in Ref. [25] implemented an experimental study to evaluate the effect of fitted three variant configurations of double twisted tape in micro-fin pipes on heat transfer and pressure drop characteristics. The tests were implemented under turbulent flow region with Reynolds number variation of 5650 to17, 000 with constant heat flux. The results concluded that the twisted tapes with opposite directions configuration for counter swirl yielded higher heat transfer rate, friction factor and thermal performance factor because of the generation of strong swirl flow/turbulence in this arrangement.

The authors in Ref. [26] implemented experimental investigation to study the characteristics of heat transfer and friction losses due to equipped variant types of twisted tapes in horizontal rectangular and square ducts. The variant types of twisted tapes included short length, full length and regularly spaced with two different twist ratio of (y=2.692 and 4.615). The short length tapes were 0.5, 0.7 and 0.9 times the length of the duct while the space ratio for the regularly twisted tape were 2.692 – 4.615 and the duct space ratio wee (1, 0.5 –0.333). The working fluid was viscous oil and the test was under laminar flow regime. The stainless steel ducts that heated electrically were utilized for heat transfer measurements. The study concluded that:

1. The twisted tape of full-length placed in rectangular and square ducts ducts yielded better performance than those of the short length twisted tape.

2. The twisted tape of full-length yielded worse performance than regularly spaced twisted tapes.
3. The short length twisted tape placed in rectangular and square ducts yielded poorer performance than those with the twisted tape of full-length.

Bharadwaj [27] implemented experimental study to evaluate the effect of equipped twisted tape inserts in 75 start spirally grooved tube on the heat transfer rate and hydro-thermal performance characteristics. The test included both clockwise and counter- clockwise direction twisted tapes with three different twisted ratio of y=3.4, 7.95 and 10.15. The experiments carried out under both laminar and turbulent flow regime conditions. The results was as the following:

1. The heat transfer enhancement of spirally grooved tube without inserts was 140% and 400% in turbulent and laminar flow conditions respectively.
2. The spirally grooved tube fitted with inserts produced heat transfer augmentation of 600% and 140% in laminar and turbulent flow respectively.
3. The twisted direction effect on the thermo-hydraulic performance.
4. There is a deceasing in the rate of heat transfer in the region of Reynolds number varies between 2500 and 9000.
5. Among the kinds of twisted tapes which tested, the higher heat transfer augmentation was obtained by the clockwise twisted tape with twist ratio of y= 7.95.

Murugesan [28] investigated the effect of square cut modification on twisted tape and compare with the normal typical twist tape equipped in double pipe heat exchanger on the characteristic of heat transfer, pressure drop and thermal performance. The test implemented under turbulent flow with Reynolds number select between 2000 to 12000.the twist ratio was 6.0, 4.4 and 2.0 and water was the working fluid. It was concluded that utilizing square cut twisted tape produced a considerable rise in heat transfer, with a cost of increase in friction losses and better thermal performance comparing with the plain tube. The increase in generating of secondary flow and disturbance near the wall of tube make the use of this type provided better performance. Figure 2.6 show square cut with different twist ratio.

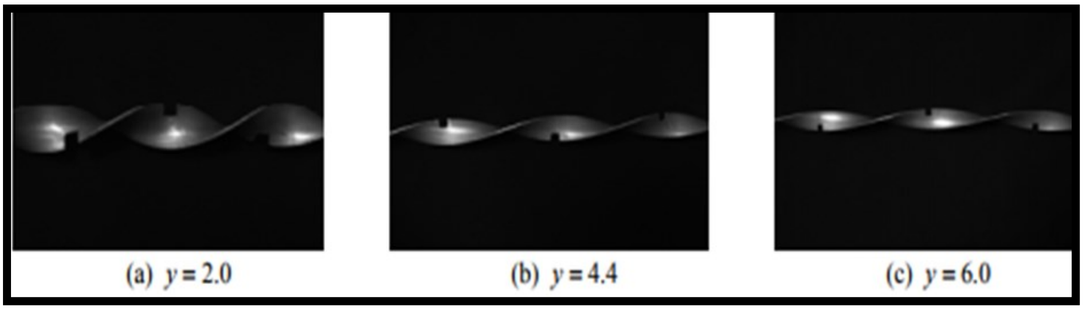


Figure 2.6: Square cut with different twist ratio Murugesan et al. [28].

2.3 Summary

From the literature reviewed, there is no experimental comparisons between variant modifications in twisted tape to make evaluation and get better performance. Therefore, this study suggest investigating the effect of various modification in twisted tape under laminar flow condition. These modifications include perforated, Semicircular-cut, U-cut, and V-cut twisted tapes in addition to typical twisted tape.

CHAPTER THREE

EXPERIMENTAL SETUP AND EXPERIMENTAL PROCEDURE

3.1 Introduction

Two main section included in this chapter, the first section explained the main part of the experimental test rig and the second section produced the mathematical model.

3.2 Experimental Apparatus and Work Procedure

In this section, the experimental test rig and utility associated with the present study are be described in details. Experimental system was performed to investigate the heat transfer by predicting Nusselt Number (Nu) and pressure drop by determining the friction factor (f) for laminar flow rate with twisted tape enhancement technique that included typical twisted tapes (TTT) and Cut twisted tapes (CTT) insert devices to augment heat transfer rate.

The experimental work in this study is implemented with the following cases:

1. Horizontal plain tube with constant wall heat flux with (distilled water) as working fluid.
2. Plain tube under constant wall heat flux with TTT insert (distilled water).
3. Plain tube under constant wall heat flux with different modification including PTT, SCTT, UCTT, VCTT inserts (distilled water).

3.3 Experimental Test Rig Description

The experimental apparatus are consists of the following as shown in

Figure 3.1, Figure 3.2 show a photograph to the experimental apparatus and schematic diagram.

a) The water chiller system.

b) The measurement devices.

c) The test section.

Most of those portions are designed and manufactured. Great care was be taken in connecting parts to control and prevent any water leakage in the connected sections during operation.

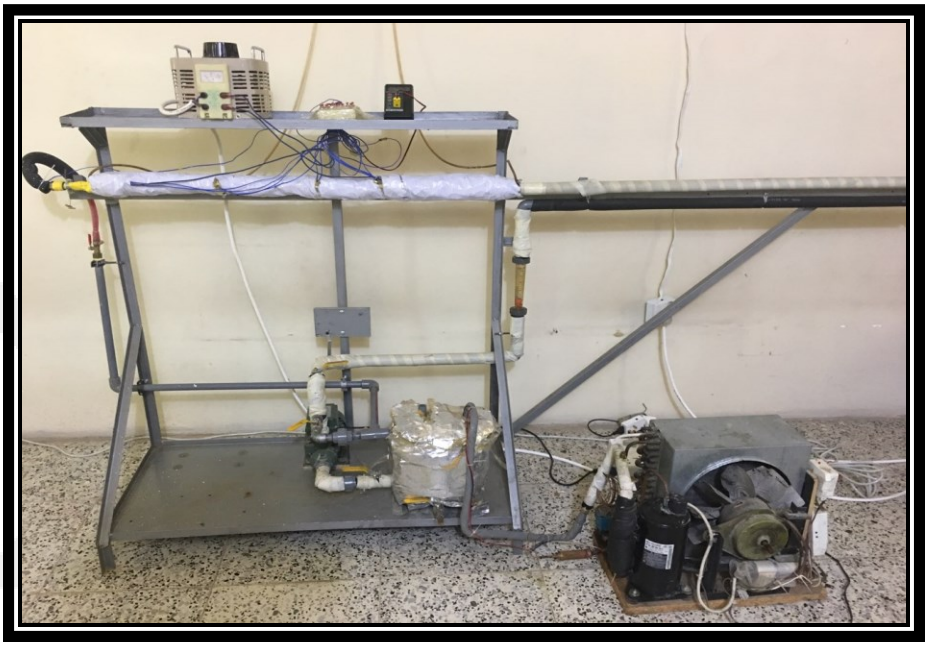


Figure 3.1: Photograph to the experimental apparatus.

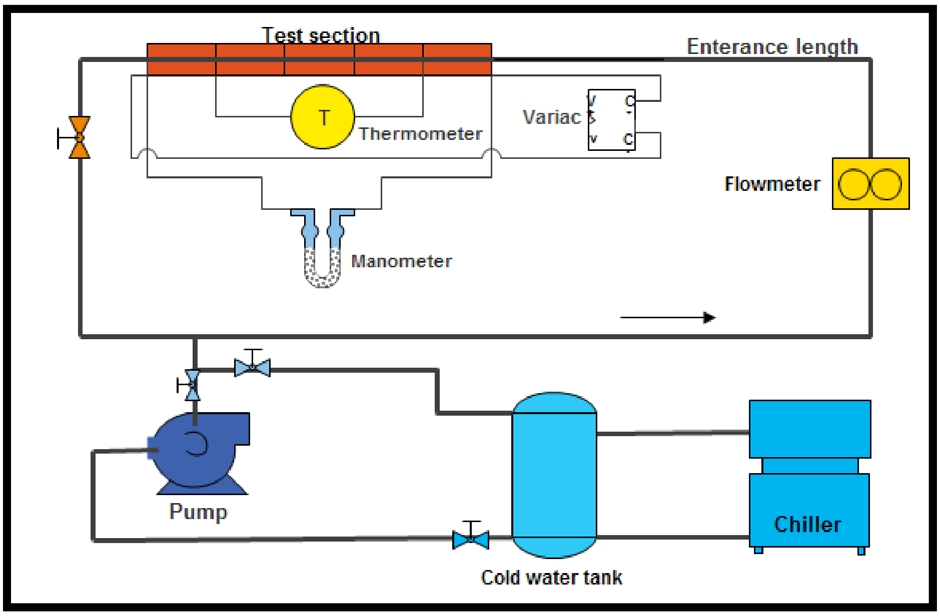


Figure 3.2: Schematic diagram to the experimental apparatus.

3.3.1 Chilled Water Unit

This unit consist of the following portions:

3.3.1.1 Cold water storage tank

A storage tank with 3.5-liter capacity is utilized for storing and deliver a desirable cold water to the test section. This tank is insulated by fiberglass with a thickness of (5) CM and thermal conductivity of 0.04 W / m. ° C and connected to the cooling system to get the desired input water temperature to the test section with 20°C.

3.3.1.2 Refrigeration system

To maintain the water temperature inlet to approximately 20 ° C, Refrigeration system is be joined to the storage tank, and it contains the following portions:

1. Compressor
2. Condenser provided by fan.
3. Evaporator
4. (Expansion valve) capillary tube.
5. Accumulator
6. Solenoid control valve Functions

Freon R-22 utilize as refrigerant fluid to flow inside this closed cycle. The storage tank provided by the evaporator coil where the heat transfer will occur between the distilled water and the coolant, then the coolant transforms from the low-pressure liquid state into vapor, while the water will cooled and its temperature decreases to the desired.

Then, the refrigerant arrive at the compressor that works two different functions;

1. It keeps the coolant vapor pressure low enough in the evaporator line to absorb the preferred heat rate and eliminates the coolant vapor from evaporator coil.

2. The compressor increases the vapor pressure of the coolant to ensure that its temperature is high enough to release the heat when it reaches the condenser where the coolant mutate to the liquid state.

Freon R-22 Rotary compressor with a capacity of 3/4 T.R was used in this refrigeration System. The inlet port of compressor was be connected to an accumulator to ensure that the compressor does not pull liquid coolant that might have collect inside the evaporator and just pull the vapor coolant. The latent heat of the coolant was expelled to environment by using air-cooled condenser provided by a fan connected electrical controller to keep the condenser temperature at about 45°C.

In order to keep the water temperature in the storing tank at 20°C, two capillaries tube with an open solenoid valve was connected to the system. The open solenoid valve connect to electrical controller to control the coolant flow to the evaporator line. Then the controller will close the valve and cut off the coolant flow when the water temperature reach to the desired. This case is impractical due to the cutting coolant vapor line will cause heat increase in compressor that will lead system shutdown. For this reason, the first capillary tube located before the solenoid valve and linked directly to evaporator line in order to cool the compressor with the continuous coolant vapor flow. the second capillary tube located after the solenoid valve to regulator the liquid coolant volume, reduces coolant pressure and connects the condenser exit high pressure line with the evaporator enter low pressure line. Each of the mechanical parts that mentioned above are be designed to manufacturing chiller system, which can withstand electrical power heater of 700 watts.Figure 3.3 show the water chiller component, Table 3.1 shows the characteristics of chiller system parts.

3.3.2 Water Pump

Centrifugal pump driven by an electrical motor is used to circulate the water through the experimental test rig. The water pump characteristic shown in Table 3.2.

3.3.3 Pipes

Polyvinyl chloride pipes (PVC) with (1/2 in) are used to connect all the chief parts of the test rig (the storage tank and the inlet of test section with pump, storage tank with the outlet of the test section).

3.3.4 Valve

The water cycle is equipped with three globe valves to control water flow rates, first one at the main pumping line, the second for bypass line and the third to control the outflow line, as shown in Figure 3.1.

3.3.5 The Measuring Devices

During the experimental test, the main variables that measured are listed below:

1. Inlet and outlet water temperature (T_{fo}, T_{fi}).
2. Pressure drop (Δp).
3. Mass flow rate of the working fluid (water).
4. Surface temperature along the test tube section (T_s).
5. Voltage and current across the heater (V, I).

For measuring these variables, many devices are used. These devices discuss in details in the next section.

3.3.5.1 Thermocouples

Five thermocouples (K- Type, range: 0°C to 800°C) are used and fixed at the following positions:

1. Two thermocouples are fixed at the inlet and outlet of test plain tube to measure the temperature of the water at the inlet and outlet of test section.
2. Three thermocouples are fixed at the outer surface of test tube with equal distance locations to measure the wall tube temperature.

3.3.5.2 Variac voltage transformer

In order to control and regulate the wanted heat flux, Variac voltage transformer is used to supply the required voltage and current by connect it to the AC power as shown Figure 3.4.

3.3.5.3 Water flow meter

One water flow meter with a range of 16 to 160 (lit/hr) is placed at the inlet test tube to measure the flow rate circulation through the test rig. Mostly, these devices depend on basis operation on the gravity. Then, it must be take the vertical orientation. Figure 3.5 (a) shows the flow meter area.

3.3.5.4 Digital thermometer

Thermocouples are connected to digital thermometer temperature reader of K-type to measure the temperature of the thermocouples during the experiments. Figure 3.5 (b) shows digital thermometer with the K-type thermocouple.

3.3.5.5 Pressure measurement

In order to measure the pressure drop along the horizontal tube, U-Tube manometer (80cm) is used, the port P1 is fixed at the tube inlet of the tube and port P2 at the exit. The liquid used in manometer is water.

3.4 Test Section

The test section is a straight circular copper tube with the dimension of 14.2mm inner diameter, 1000mm length, 0.9mm thickness. Three thermocouples with an equal distance are fixed, soldered and well insulated on the outer surface of the tube. Asbestos as heat resistance insulation with thickness of 0.5mm is surrounded the tube in order to isolate it from the heater tape electrically. The copper tube wounded tightly by an electrical heater with rating of 1000W, (2*0.16) mm cross- section, 3.2 meter length and 4.9 Ohm/meter resistivity for heating the tube to the desired heat flux. The electrical heater linked to voltage transformer to provide it by an electrically power. The provided voltage was be regulated by the Variac in order to get the desired uniform heat flux condition along the plain copper tube. Two types of insulation was be covered the tube to prevent heat losses, the first is a layer of fire resistant asbestos having (width of 30mm with thickness of 5mm)and the second is layer of fiber glass isolation of 50mm thickness. The test section provided by two pressure taps of 4mm height at its entrance and exit to evaluate the friction factor. The test tube also provide by entrance length before test section and it has enough long to ensure that the flow enters the test section is hydro-dynamically fully developed.

3.5 Experimental Procedure

In the experimental test, the following steps have been applied:

1. Filling the storage tank with three liters of distilled water.

2. Running the chiller water system by supplying it with AC current and wait (5 minutes) to ensure that water temperature in the storage tank reaches to 20°C.
3. Running the centrifugal pump and get the required water amount to the flow meter scale by the main valve of pump and by pass valves
4. Running the heated section by adjusting the electric current across the heater coils using Variac voltage transformer to obtain the wanted uniform heat flux.

Water with about 20°C is driven to the test section where it is supplying by a constant heat flux from the heater tape, and then the heated water goes back to the storage tank linked to the chiller system to cool it and pumped again to the next test. The procedure steps mentioned above are repeated for the ten types of twisted tapes insert that mentioned in section (3.4) with alteration in the mass flow rates five times from (0.00555 kg/sec to 0.02222 kg/sec) and the electric power supplied from (135Watt to 390Watt).

3.6 Twisted Tapes Dimensions

During the experimental study, ten various twisted tapes inserts are used by changing their twist ratio, and cutting shape modification. Twisted tapes are manufacture from copper material with the following dimensions:

1) Typical Twisted Tape (TTT5) with tape width (w=12mm), tape thickness (t=**2**mm), tape length (l=1100mm) and twist ratio (Y=**5**) at which the twist ratio is defined as the pitch length of twisted tape (H) to the tape width (w). Pitch is the distance length of one twist in the twisted tape for rotation angle of 180°; Figure 3.6 Show Photograph for Typical Twisted Tape.

2) Typical Twisted Tape (TTT3) with tape width (w=12mm), tape thickness (t=2mm), tape length (l=1100mm) and twist ratio (Y=3), Figure 3.6 shows Photograph for Typical Twisted Tape.

3) V-cut Twisted Tape (VCTT5) with tape width (w=12mm), tape thickness (t=2mm), tape length (l=1100mm), twist ratio(Y=5) and v-cut cut shape with cutting depth (de=4mm) and cutting width (we=3mm). Figure 3.7 shows Photograph for V-cut Twisted Tape.

4) V-cut Twisted Tape (VCTT3) with tape width (w=12mm), tape thickness (t=2mm), tape length (l=1100mm), twist ratio(Y=3) and v-cut cut shape with cutting depth (de=4mm) and cutting width (we=3mm). Figure 3.7show Photograph for V-cut Twisted Tape.

5) U-cut Twisted Tape (UCTT5) with tape width (w=12mm), tape thickness (t=2mm), tape length (l=1100mm), twist ratio(Y=5) and u-cut cut shape with cutting depth (de=4mm) and cutting width (we=3mm). Figure 3.8 (a) shows Photograph for U-cut Twisted Tape.

6) U-cut twisted tape (UCTT3) with tape width (w=12mm), tape thickness (t=2mm), tape length (l=1100mm), twist ratio(Y=3) and u-cut cut shape with cutting depth (de=4mm) and cutting width (we=3mm). Figure 3.8 (a) shows Photograph for U-cut twisted tape.

7) Semicircular cutting twisted tape (SCTT5) with tape width (w=12mm), tape thickness (t=2mm), tape length (l=1100mm), twist ratio(Y=5) and semicircular cutting (radius re=4mm). Figure 3.8 (b) show Photograph for Semicircular-cut twisted tape.

8) Semicircular cutting twisted tape (SCTT3) with tape width (w=12mm), tape thickness (t=2mm), tape length (l=1100mm), twist ratio(Y=3) and semicircular-cut (radius re=4mm). Figure 3.8 (b) show Photograph for Semicircular-cut Twisted Tape.

9) Perforated twisted tape (PTT5) with tape width (w=12mm), tape thickness (t=2mm), tape length (l=1100mm), twist ratio(Y=5) and tow circular cutting with radius (r=2mm). figure 3.9 (a) shows Photograph for Perforated Twisted Tape.

10) Perforated twisted tape (PTT3) with tape width (w=12mm), tape thickness (t=2mm), tape length (l=1100mm), twist ratio(Y=3) and tow circular cutting with radius (r=2mm). Figure 3.9 (a) shows Photograph for Perforated Twisted Tape. Figure 3.9 (b) shows variant types of twisted tapes, and Table 3.3 illustrates the twisted tapes geometric details.

The twisted tape is manufactured by fixing one end of the tape and twisting the other end carefully to get the required twist ratio. Later, the manufactured twisted tapes are equipped in the test tube by the moving passage (flange) which placed at the exit of the test section.

Table 3.1: Chiller water system characteristics.

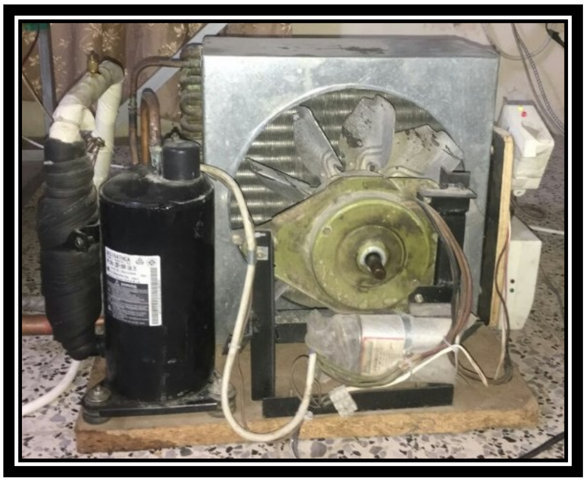
Condenser	**4.5kW full capacity**
Compressor	**3/4 ton, R22**
Evaporator	**Length=3m, OD=3/8inch**
Solenoid	**Supply=230VAC, Max. pressure=20bar, Normally open valve**
Capillary before solenoid	**Length=3m, ID=0.75mm**
Capillary after solenoid	**Length=1m, ID=1.5mm**

Table 3.2: Centrifugal pump characteristics.

Q max	Power	Number of rotation	Current(I)	Voltage(V)	Frequency
lit/min	kW	r.p.m	V	A	Hz
30	0.370	2850	220	2.5	50

Table 3.3: Illustrates the twisted tapes geometric details.

Insert set	Pitch (H)mm	Width mm	Number of revolution	Thickness mm (t)	Twisted ratio (Y)	Metal	Cut dimension
Typical twisted tape (TTT5)	60	12	17	2	5	copper	……
Typical twisted tape (TTT3)	36	12	27	2	3	copper	……
V-cut twisted tape (VCTT5)	60	12	17	2	5	copper	depth cut (de=4mm width cut (we=3mm)
V-cut twisted tape (VCTT3)	36	12	27	2	3	copper	depth cut (de=4mm width cut (we=3mm)
U-cut twisted tape (UCTT5)	60	12	17	2	5	copper	depth cut (de=4mm width cut (we=3mm)
U-cut twisted tape (UCTT3)	36	12	27	2	3	copper	depth cut (de=4mm width cut (we=3mm)
Perforated twisted tape (PTT5)	60	12	17	2	5	copper	Radius cut=2.5mm
Perforated twisted tape (PTT3)	36	12	27	2	3	copper	Radius cut=2.5mm
Semicircular-cut twisted tape (SCTT5)	60	12	17	2	5	copper	Radius cut=4mm
Semicircular-cut twisted tape (SCTT3)	36	12	27	2	3	copper	Radius cut=4mm



(a)Fan and Compressor

(b) Condenser

(c) Solenoid and Capillaries

Figure 3.3: Water chiller component.

Figure 3.4: Variac voltage transformer.

(a) Flowmeter **(b) Thermometer**

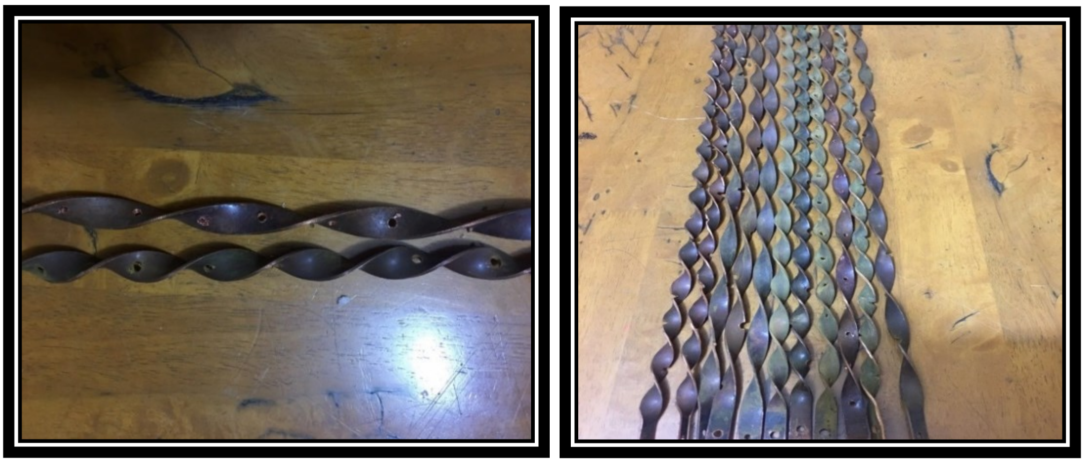
Figure 3.5: Mesureing devices.

Figure 3.6: Photograph for Typical twisted tape types with different twist ratio.

Figure 3.7: Photograph for V-cut twisted tape types with different twist ratio.

(a) (b)

Figure 3.8: (a) Photograph for U- cut twisted tape (b) Photograph for Semicircular- cut twisted tape.



(a) (b)

Figure 3.9: (a) Photograph for perforated twisted tape types (b) Photograph for variant twisted types.

3.7 Mathematical Model

The mathematical models and the basic equations that used to calculate heat transfer for heated tube under constant heat flux condition and friction factor in addition to thermal performance factor are described in this section.

3.7.1 Heat Transfer

In the test section, in order to obtain the desired constant heat flux, the Variac is regulated to deliver the required electrical power at the surface of the tube to accomplish heating effect, and it is calculated by:

$$Q_{(\text{electric power})} = I * V \tag{3.1}$$

Where:

I: electrical current which provided by the electrical heater (A).

V: Electrical voltage which provided by the electrical heater (V).

Assumed that the outer surface of the tube is well isolated (heat losses is neglected) hence, the heat energy transmit to absorb by the working fluid:

$$Q_{(\text{electric power})} = Q_{a\ (\text{absorbed heat energy})} = \dot{m}\, C_p\, (T_{fo} - T_{fi}) \tag{3.2}$$

Where:

$\dot{m}$: The mass flow rate of the water (kg/s).

C_p: The specific heat of water (kJ/kg.K).

T_{fo}: Outlet water temperatures for the tube (K).

T_{fi}: Inlet water temperatures for the tube (K).

Heat transfer Coefficient inside the Heat Flux Tube:

Heat transfer coefficient (h) is the most significant factor in any case of heat transfer convection and it estimated by using the Newton's law of cooling.

Experimentally, the inside average heat transfer coefficient is measured as in [29] [30].

$$h_i = \frac{Q_{(\text{absorbed heat energy})}}{A_S(\overline{T}_s - T_m)} \tag{3.3}$$

Where:

h_i: The average of heat transfer coefficient inside tube ($W/m^2.°C$).

$$A_S = \pi d_i L \tag{3.4}$$

$$T_m = \frac{T_{fi} + T_{fo}}{2} \tag{3.5}$$

surface temperature[31]

$$\overline{T}_s = \frac{T_{s1} + T_{s2} + T_{s3}}{3} \tag{3.6}$$

Then, to calculate the average of inner Nusselt's number (Nu) used

$$Nu = \frac{h_i * d_i}{k} \tag{3.7}$$

k: Thermal conductivity (W/m.K) based on T_m (mean bulk fluid temperature).

The flow inside the test tube is laminar with Reynolds number varies from 566 to 1994 and it is calculate with the following equation:

$$Re = \frac{4\dot{m}}{\pi d_i \mu} \tag{3.8}$$

Where:

μ: Dynamic viscosity (kg/m.sec) based on T_m(mean bulk fluid temperature).

The value of thermal resistant [$R_{thermal} = \ln({}^{d_0}/_{d_i})/(2\pi kl)$] inside the wall of tube is too small hence, where the internal surface temperature is approximately equivalent to the external surface temperature [$T_{SO} = T_{si}$]; therefore, it is neglected during the surface temperature calculation.

3.7.2 Friction Factor

In order to calculate the friction factor coefficient (f) which is related to the pressure drop (Δp) along the test tube, it can used the following relation [30].

$$f = \frac{2\Delta p d_i}{L\rho v^2} \tag{3.9}$$

Where:

$$v = \frac{\dot{m}}{\rho A_c}, \quad A_c = \frac{\pi d_i^2}{4} \tag{3.10}$$

Where:

v: Mean velocity in the tube (${}^{m}/_{sec}$).

A_C: Cross section area of tube (m^2).

ρ: Density ($\frac{kg}{m^3}$) based on T_m(mean bulk fluid temperature).

3.7.3 Thermal Performance Evaluation

The evaluation of thermal performance is an important element in any heat exchanger system utilizing any type of swirl devices then it is important to determine the thermal performance factor (η) that associated to Nusselt number and the friction factor under especial fluid flow condition. Thermal performance factor can be calculated by the equation for laminar flow [31][32].

$$\eta = \left[\frac{{}^{Nu_{enh}}/_{Nu_o}}{\left({}^{f_{enh}}/_{f_o}\right)^{\left(\frac{1}{3}\right)}}\right] \tag{3.11}$$

where, $\mathbf{Nu_0}$, $\mathbf{f_o}$ are the Nusselt number and friction factor for plain circular tube in laminar flow without inserts for base fluid, and Nu_{enh}, f_{enh} are the enhances Nusselt number and friction factor for fluid with twisted tapes. The reference Nusselt number ($\mathbf{Nu_0}$) and friction factor ($\mathbf{f_o}$), for the laminar regime are expressed as following [33].

$$f_o = \frac{64}{Re}, Nu_o = 4.363$$

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The Experimental results have discussed in this chapter. The experimental work involves the performance of test section in terms of heat transfer (Nusselt number) and pressure drop (friction factor) across the tested tube with using twisted tapes.

4.2 Comparison to the Experimental Results with Published Work

The present experimental results are compared with Ghajar [34] and Hallquist [7] under constant heat flux condition in tubes to ensure the accuracy of the experimental work results. Figure 4.1 shows the variation of Nusslet number against the Reynolds number in laminar flow condition along the smooth tube. The behaviors of present experimental curves, which implemented under different conditions, show a logical agreement with Ghajar and Hallquist results.

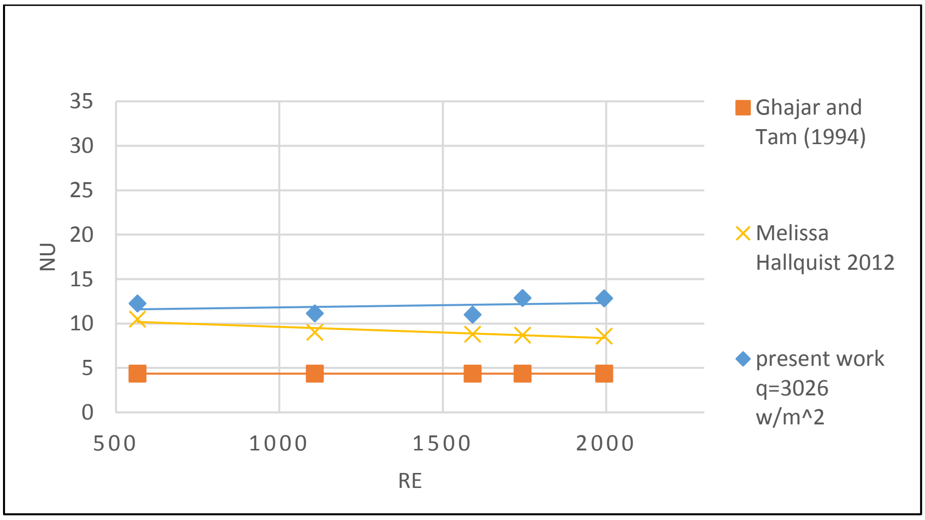


Figure 4.1: Comparison of nusslet number against the reynolds number with other published work.

Friction factor results also validated by comparing the experimental results with Hagen- Poiseuille's laminar flow equation results, as shown in Figure 4.2 that shows a logical agreement between the results.

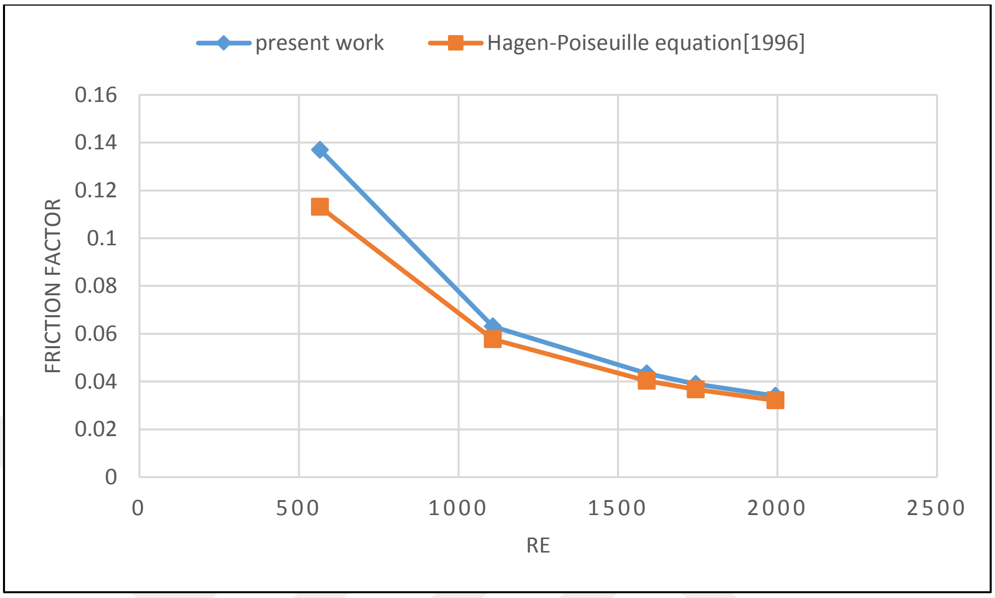


Figure 4.2: Comparison the experimental friction factor results with Hagen- Poiseuille's equation.

4.3 Heat Transfer

The effect of changing heat flux and twisted tape geometries on heat transfer in the horizontal tube have discussed in the following paragraphs.

4.3.1 The Effect of Heat Flux Variation on Plain Tube

Figure 4.3 shows the relation between Reynolds number (Re) and Nusselt number (Nu) and the effect of increase the value of heat flux. There is no enhancement in Nu with the increase of Re in laminar flow region with constant heat flux of 3026 W/m², it is stay approximately equal to 12 but the value of Nu increase with the increase the value of heat flux up to 8742 W/m² and it is becomes approximately equal to 19. This accrues because of the augment in heat transfer coefficient (h) where Nusselt number depends on it. As mentioned in the previous chapter in equation (3.7) the relationship show that Nusselt number depends on (h) and the inner diameter of the plain tube, which is constant, and there is no significant enhance in the thermal conductivity (k) of the distilled water.

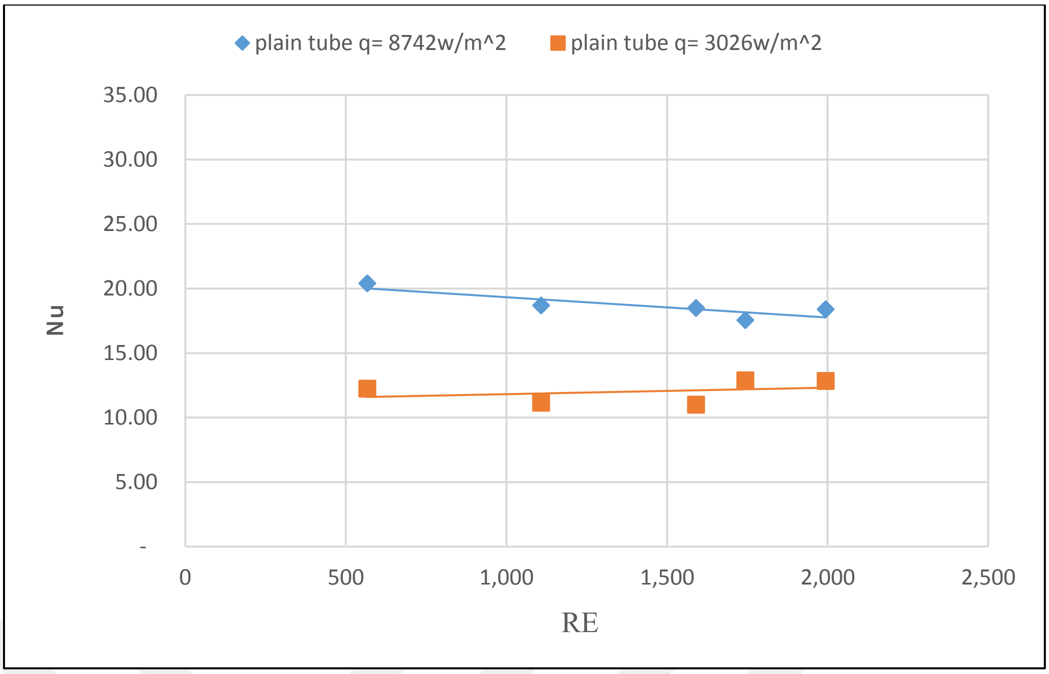


Figure 4.3: The effect of increase heat flux on the Nu.

4.3.2 The Influence of Typical Twisted Tape (TTT) on Heat Transfer

Figure 4.4, Figure 4.5 and Figure 4.6 show the effect of equipped typical twisted tape (TTT) in the copper plain tube with two various twist ratios of y=3.0 and 5.0 on Nusselt number (Nu) and heat transfer coefficient (h) with the variation of Reynolds number (Re). From figure 4.4, it can see that the increase in value of Re caused an increase in Nu value due to the effect of fitted typical (TTT5) while the equipped of (TTT3) caused a considerable enhancement in heat transfer because the decrease of twist ratio. This means that the lower twist ratio produced higher Nusselt number. This can explained that the lower twist ratio caused stronger swirl and increase in the swirl intensity while the enhancement in heat transfer that caused by the typical twist tape happens due to the creation of secondary flow. It is also effect on the boundary layer thickness, which becomes thinner hence, better heat transfer produced across the thinner boundary layer. In addition, the increase in swirl intensity caused increase in the residential time of flow that gave the flow more time for transfer the heat between the core and the surface of the plain tube. The enhancement in Nu for TTT with the two different twist ratios of y = 3.0 and 5.0 are respectively 2.789 and 2.1 times higher than that for the plain tube.

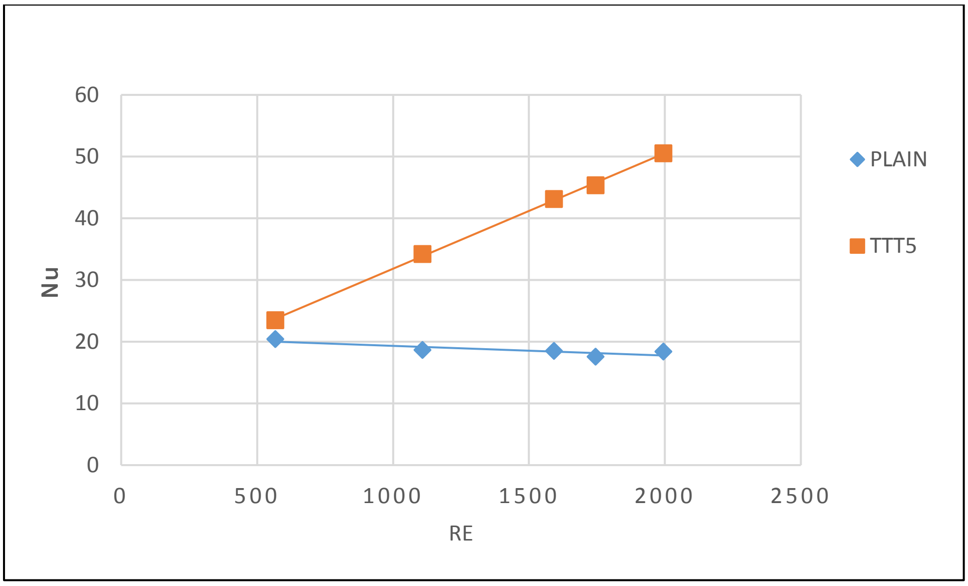


Figure 4.4: Effect of TTT with twist ratio(y=5) on Nu with the variation of Re.

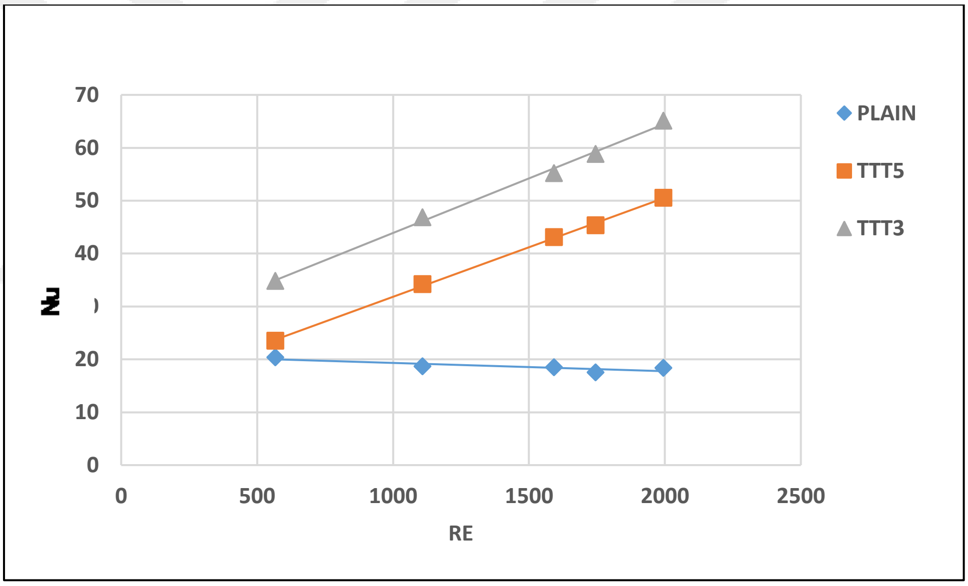


Figure 4.5: Effect of TTT with different twist ratio on Nu with the variation of Re.

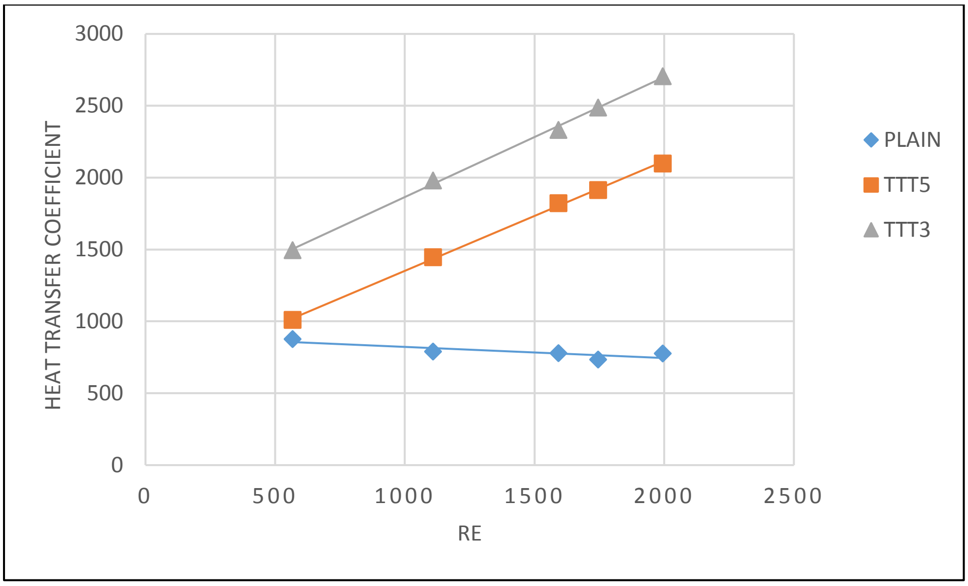


Figure 4.6: Effect of TTT with different twist ratio on (h) with the variation of Re.

4.3.3 The Influence of Perforated Twisted Tape (PTT) on Heat Transfer

Figure 4.7, Figure 4.8 and Figure 4.9 show the effect of equipped Perforated twisted tape (PTT) in the copper plain tube with two various twist ratios of y=3.0 and 5.0 on Nusselt number and heat transfer coefficient with the variation of Reynolds number. From Figure 4.7, it can see that the increase in Reynolds number caused an increase in Nusselt number due to the effect of fitted perforated twisted tape with twist ratio of 5.0 (PTT5) while the equipped of (PTT3) caused a considerable enhancement in heat transfer because the decrease of twist ratio. The enhancement of Nusselt number at two different twist ratio for PTT are 2.718 and 2.05 times higher than that of the plain tube. For comparing these results with the typical twisted tape (TTT), perforated twisted tape (PTT) produces lower Nusselt number in the same conditions as shown in the Figure 4.10. This can explained that the existing of holes on the surface of (PTT) which cause the weakened to the secondary swirl flow because of the flow of fluid moves straight and axial through the holes.

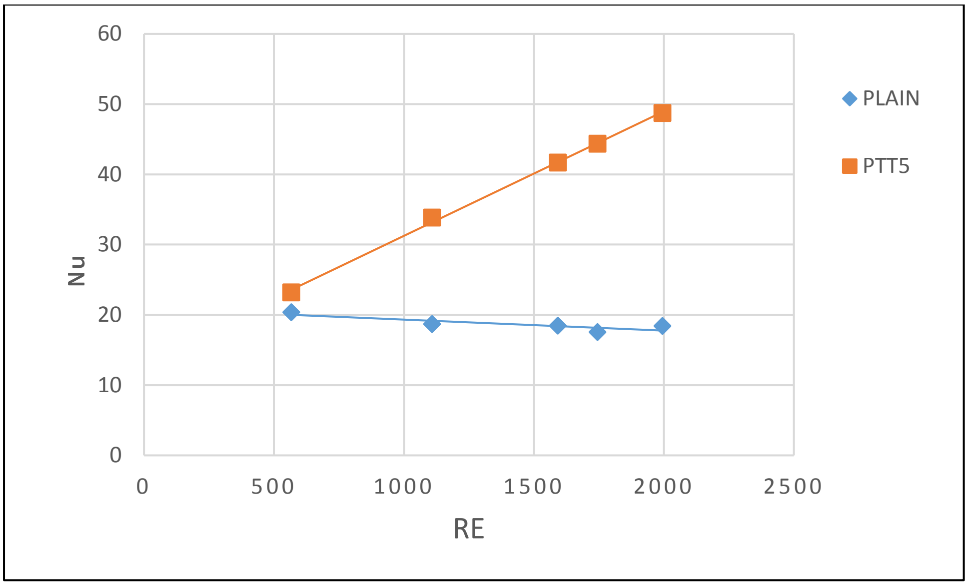


Figure 4.7: Effect of PTT at twist ratio of (y=5) on Nu with the variation of Re.

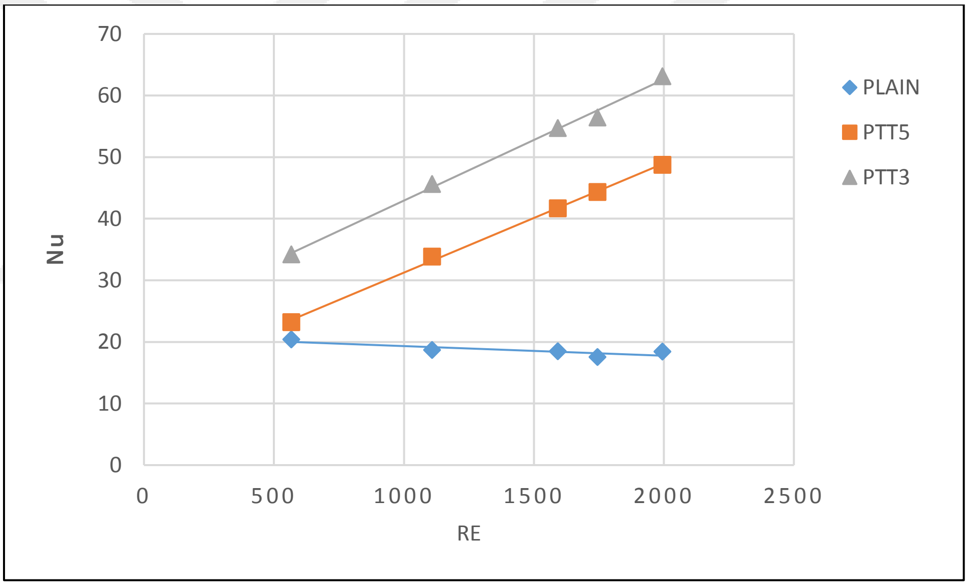


Figure 4.8: Effect of PTT at two various twist ratio on Nu with the variation of Re.

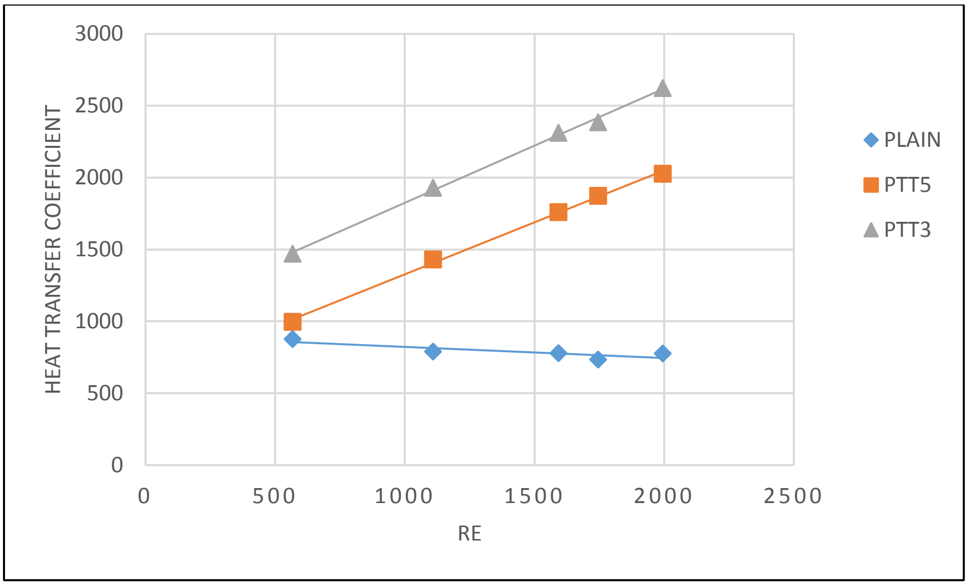


Figure 4.9: Effect of PTT with different twist ratio on with the variation of Re.

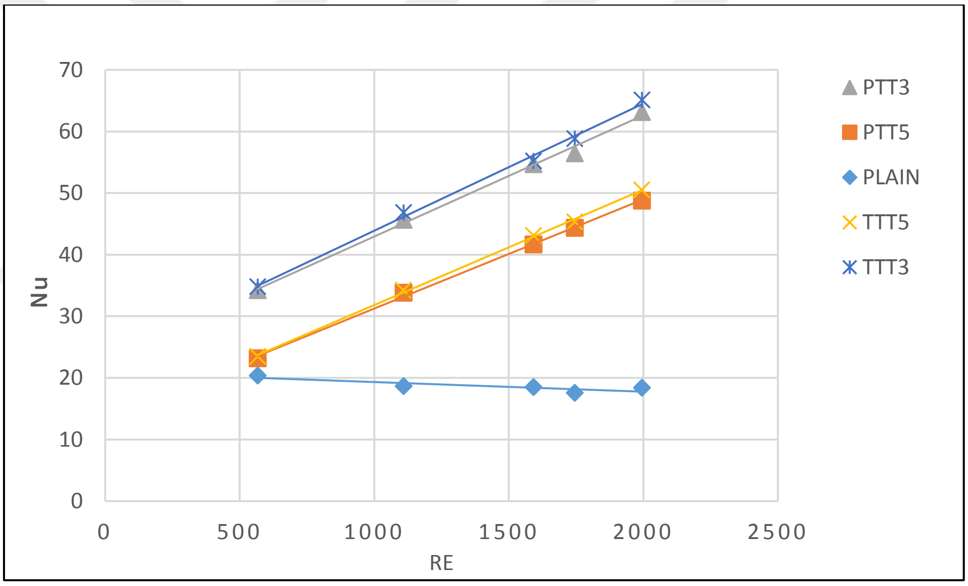


Figure 4.10: Comparison between the effect of TTT and PTT on Nu with Re.

4.3.4 The Influence of Semicircular Cut Twisted Tape (SCTT) on Heat Transfer

The effects of and the semicircular cut twisted tape (SCTT) on the variation of heat transfer (h) coefficient and Nusselt number (Nu) versus Reynolds number (Re) are shown in Figure 4.11, Figure 4.12 and Figure 4.13. As shown, as the Re increase the Nu and (h) increase. The enhancement of heat transfer for SCTT3 and SCTT5 is much higher than the plain tube and it is 2.82 times and 2.2 times higher respectively. Usually, the (TTT) produces only a whirling flow, but in case of addition many cuts along the edge of twisted tape creates many local swirls at each cutting sector that offers an brilliant mix for the viscid boundary layers in all directions along the pipe which shows higher increase in heat transfer augmentation. In general, Reynold number (Re) that is defined as the ratio of inertia forces to viscous forces has controlled the physical nature of the flow inside pipes. Then, from the figures, it is obvious that the mean Nusslet number, which represented the heat transfer, increases with the increase of Reynold number (Re). Therefore, at higher values of Reynold number (Re), inertia forces becomes more effect than viscous forces. That leads to thinner viscosity boundary layer because of turbulence degree increase hence enhanced heat transfer happens between the working fluid (water in this study) and the inner surface of the tube.

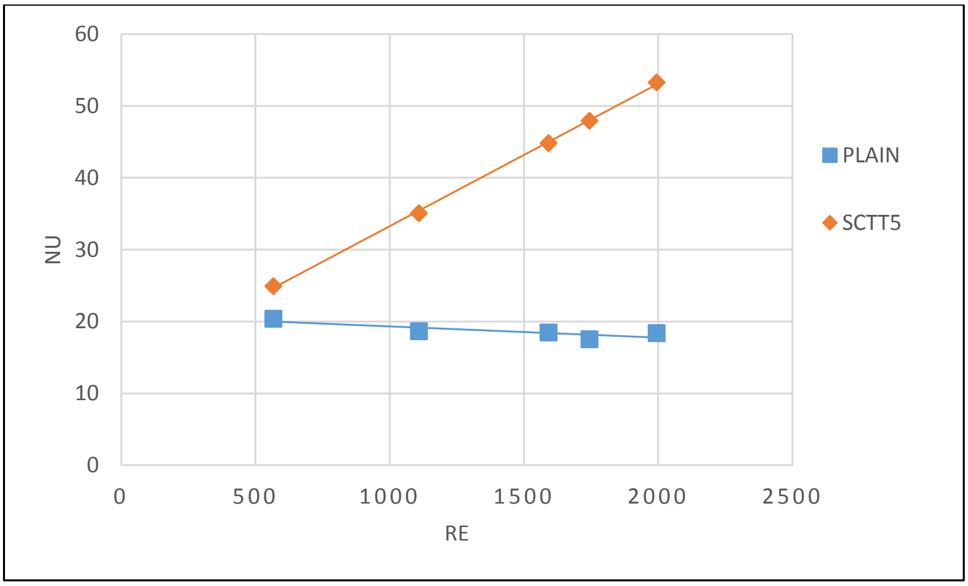


Figure 4.11: Effect of SCTT at twist ratio of (y=5) on Nu with the variation of Re.

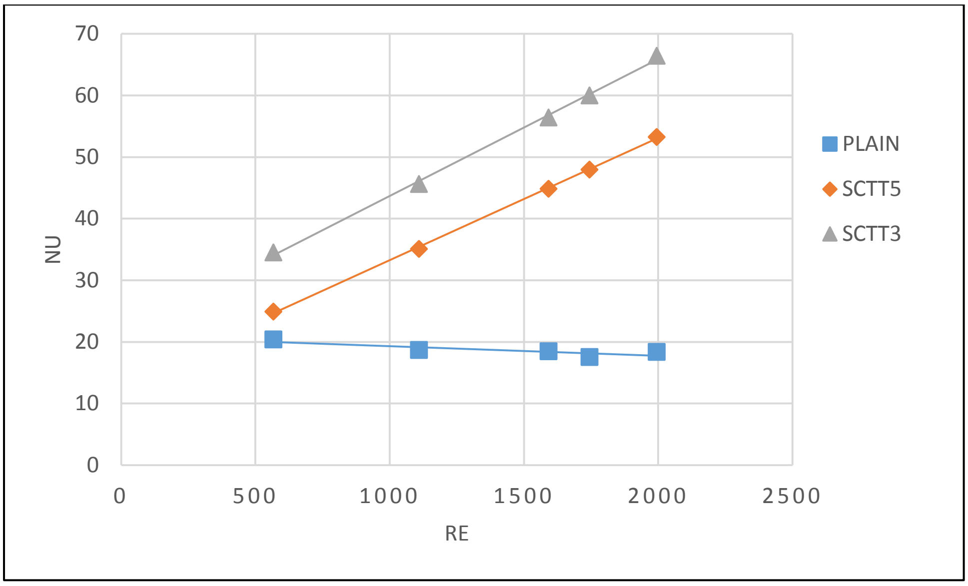


Figure 4.12: Effect of SCTT at two various twist ratio on Nu with the variation of Re.

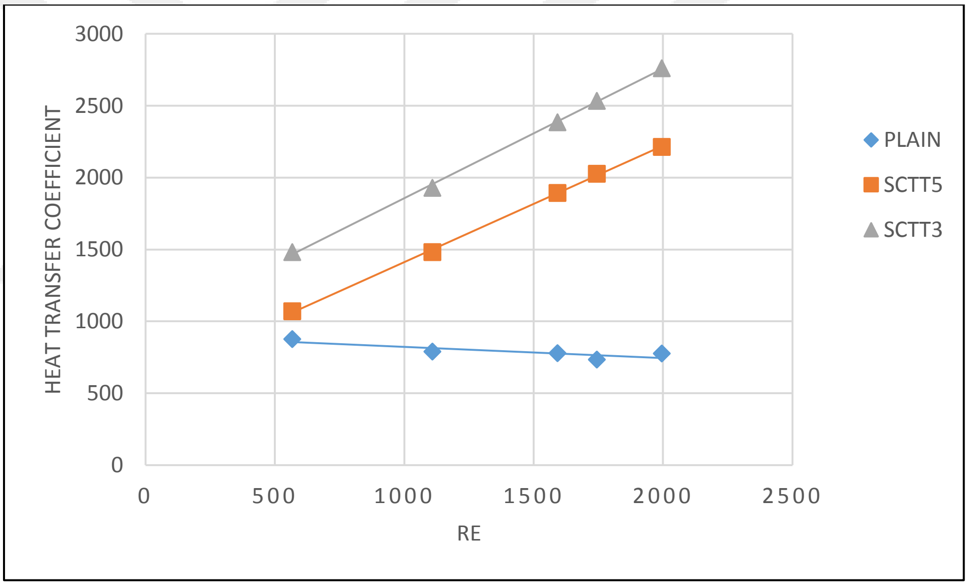


Figure 4.13: Effect of SCTT at two various twist ratio on (h) with the variation of Re.

4.3.5 The Influence of U-cut Twisted Tape (UCTT) on Heat Transfer

The effects of and the U-cut twisted tape (UCTT) on the variation of heat transfer coefficient and Nusselt number versus Reynolds number are shown in Figure 4.14, Figure 4.15 and Figure 4.16. From figures it can be observed that the increase of Reynolds number cause increase in heat transfer coefficient and Nusselt number. The mean Nusselt number for UCTT with twist ratios y = 3.0 and 5.0 are 2.86 and 2.25 times respectively better than that for the plain tube. This enhancement is better than the enhancement of semicircular cut twisted tape (SCTT). This can explained that the shape of the cutting has influence on the rate of heat transfer enhancement and it is governors the strength of vortex produced that means the vortices that were formed due to the U-cut are stronger and more efficient than of those that were formed due to a semi-circular cut.

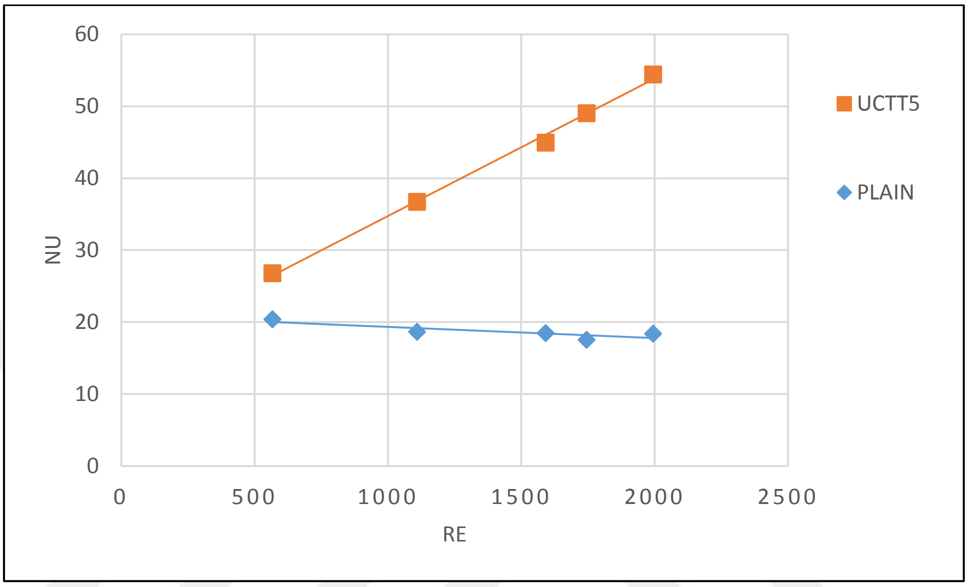


Figure 4.14: Effect of UCTT at twist ratio of (y=5) on Nu with the variation of Re.

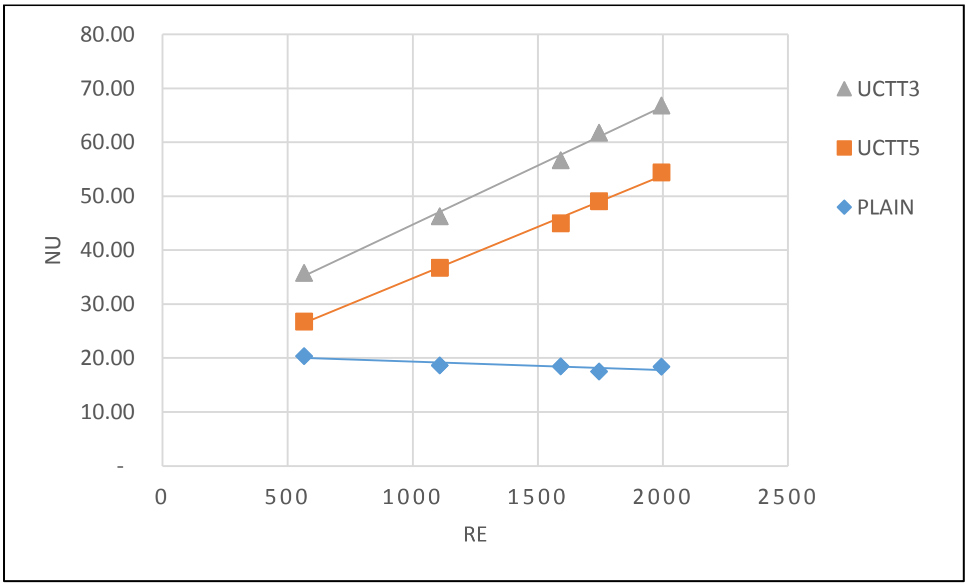


Figure 4.15: Effect of UCTT at two various twist ratio on Nu with the variation of Re.

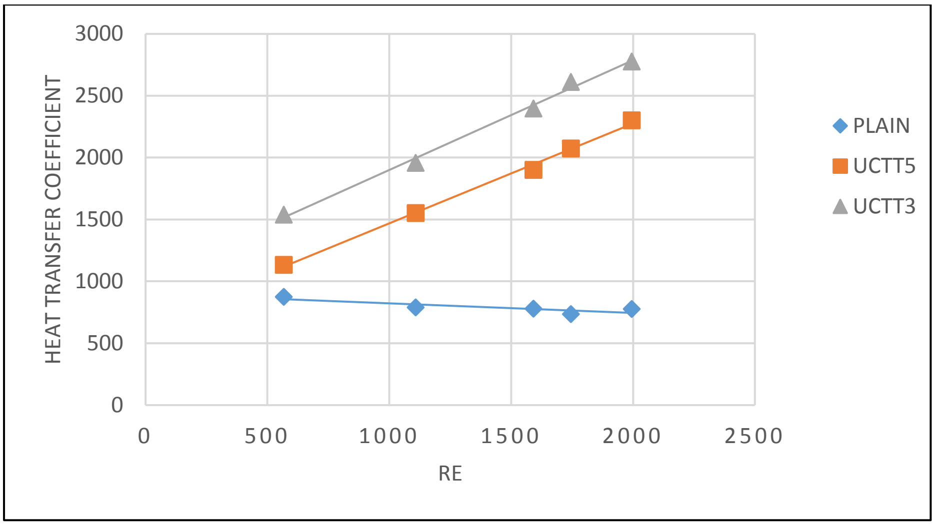


Figure 4.16: Effect of UCTT at two various twist ratio on (h) with the variation of Re.

4.3.6 The Influence of V-cut Twisted Tape (VCTT) on Heat Transfer

The effects of the V-cut twisted tape (VCTT) on the variation of heat transfer coefficient (h) and Nusselt number (Nu) versus Reynolds number (Re) are shown in Figure 4.17, Figure 4.18 and Figure 4.19. From the figures it can be observed that the increase of Re cause increase in (h) and (Nu). Figure 4.19 shows a good enhancement in (h) for (VCTT3) reaches to 2851$(W/m^2.°C)$ comparing to that of plain tube, which is approximately 777.3$(W/m^2.°C)$. The increase in mean Nusselt number for VCTT with twist ratios (y = 3.0 and 5.0) are 2.95 and 2.32 times respectively better than that for the plain tube.

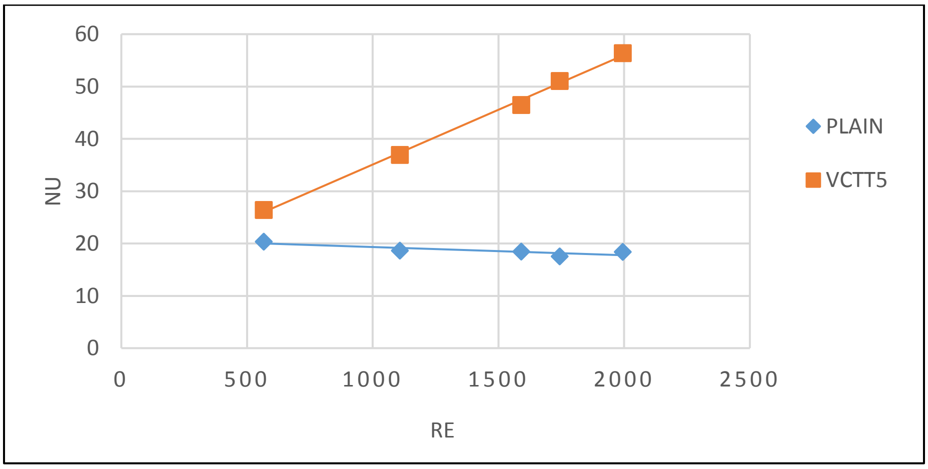


Figure 4.17: Effect of VCTT with twist ratio(y=5) on Nu with the variation of Re.

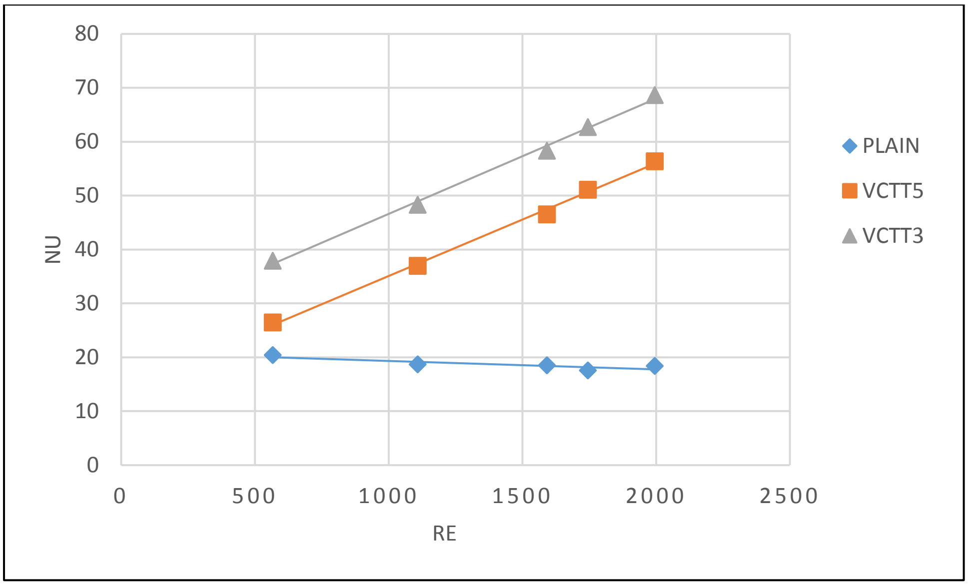


Figure 4.18: Effect of VCTT at two various twist ratio on Nu with the variation of Re.

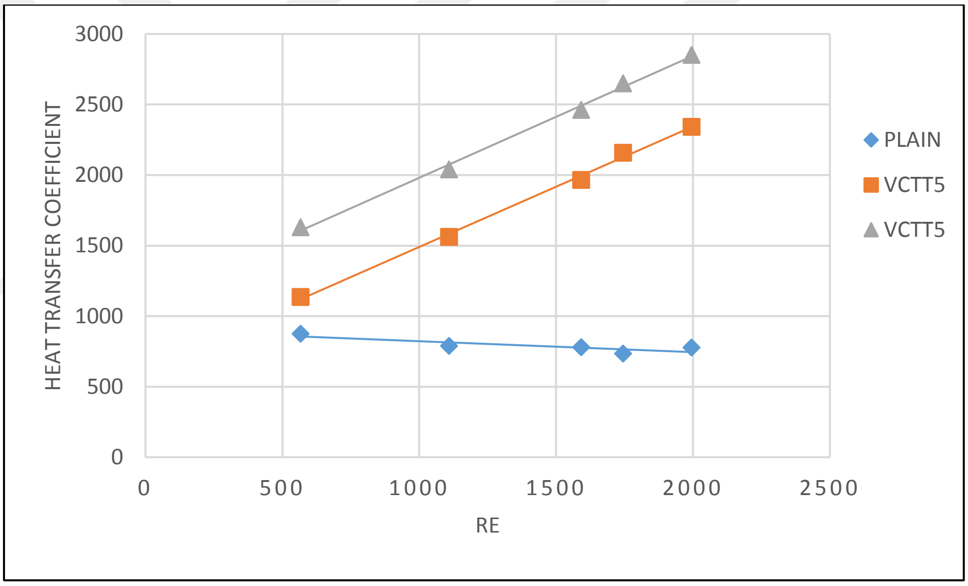


Figure 4.19: Effect of VCTT at two various twist ratio on (h) with the variation of Re.

4.3.7 Comparison to Nusselt Number for Various Twisted Tapes

Figure 4.20 shows a comparison Nusselt number variation with Reynolds number for all twisted tapes that studied in present work. From this figure, It is indicated that the highest Nusselt number was 68.63 which obtained from V-cut twisted tape with twist ratio of y=3.0 (VCTT3) at Reynolds number of 1994. U-cut twisted tape of 3.0-twisted ratio (UCTT3) yielded lower Nusselt number than

(VCTT3) with (Nu) of 66.81 at the same Reynolds number while it is higher than the Nusselt number of (SCTT3) which produced (Nu) of 66.46.

The lowest Nusselt number at twist ratio of 3.0 produced by (PTT3) with Nusselt number (Nu) of 63.14, while Typical twisted tape (TTT3) yielded higher Nusselt number with (Nu) of 65.09 at the same condition and twist ratio. The other results of Nusselt number (Nu) of twist ratio y=5.0 was 48.75, 50.51, 53.28, 54.46and 56.37 for PTT5, TTT5, SCTT5, UCTT5 and VCTT5 respectively.

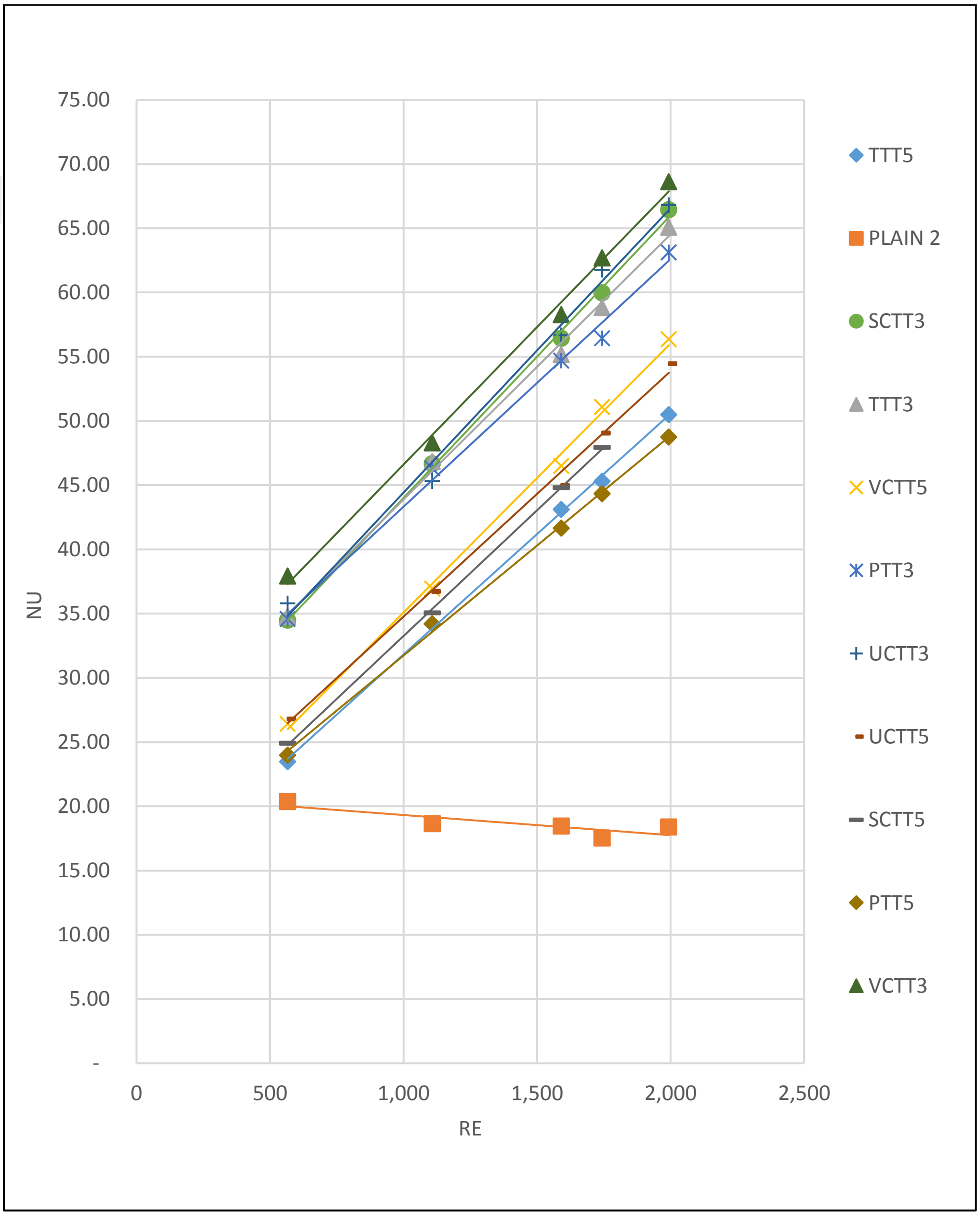


Figure 4.20: Comparison the effect of different twisted tapes on Nu with variation of Re.

4.4 Pressure Drop

In this suction, the effect of insert twisted tapes on pressure drop and friction factor is be discussed according to the experimental results.

4.4.1 Friction Factor Variation for Typical Twisted Tape (TTT)

Figure 4.21 shows a comparison to friction factor (f) behavior of typical twisted tape (TTT) at two different twist ration and plain tube versus the variations of Reynolds number (Re). It can observed that the increase in value of (Re) cause decrease in a friction factor (f). The stronger swirl flow created by the TTT at lower twist ratio for (y =3.0) is caused higher friction factor than that of the higher twist ratio (y = 5.0). It can see that friction factors for the TTT inserts are 5.54 and 4.86 times more than those without insert at twist ratios of y = 3.0 and 5.0 are respectively.

For more explanation, in case of plain tube the value of (f) decrease with the increase of the value of (Re) because the rise in pressure drop where when typical twisted tape (TTT) inserted there is a significant increase in friction losses. Furthermore, the decrease in twist ratio cause more increase in friction factor with the same condition and values of Reynolds number. This can explained that the twisted tape vortex mixing effect on the tangential and axial viscous boundary layers that enhances the shear forces near the tube surface.

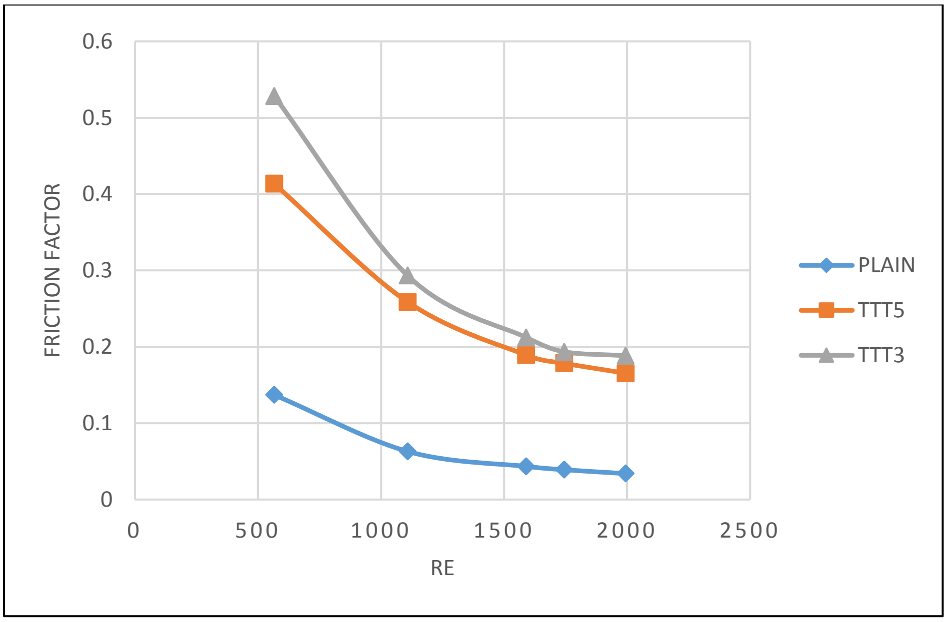


Figure 4.21: Effect of TTT at different twist ratio(y=3.0, 5.0) on friction factor with the variation of Re.

4.4.2 Friction Factor Variation for Semicircular Cut Twisted Tape (SCTT)

Figure 4.22 shows a comparison to friction factor (f) behavior of Semicircular cut twisted tape (SCTT) and plain tube versus the variations of Reynolds number (Re). It can observed that the (f) decrease with the increase in Re. The friction factors for the SCTT with twist ratio y = 3.0 and 5.0 are respectively 5.58 and 4.99 times higher than that for the plain tube.

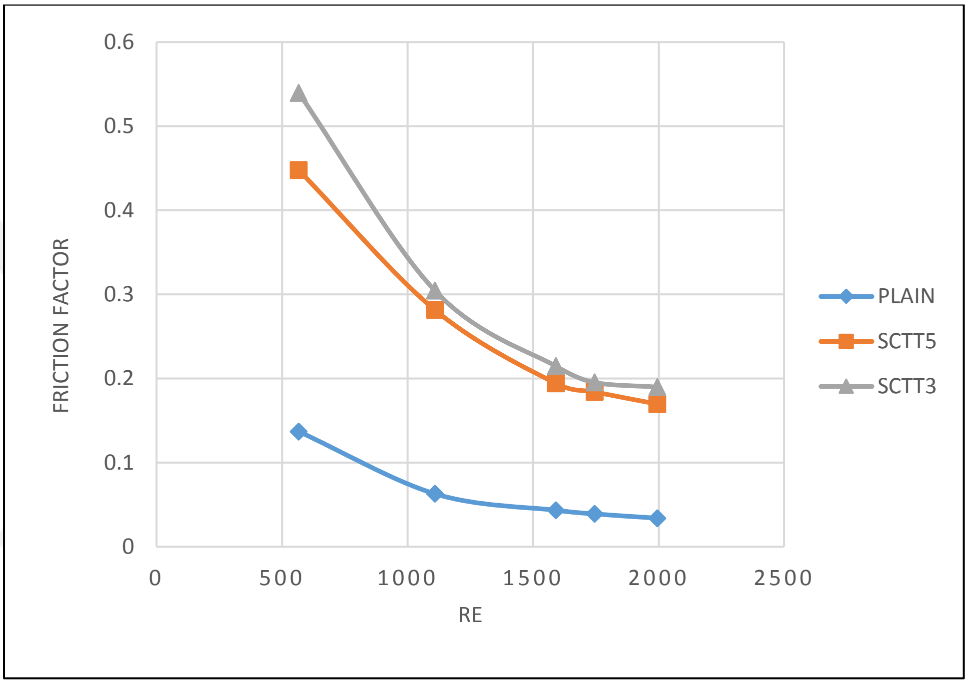


Figure 4.22: Effect of SCTT at different twist ratio(y=3.0, 5.0) on friction factor with the variation of Re.

4.4.3 Friction Factor Variation for Perforated Twisted Tape (PTT)

Figure 4.23 shows a comparison to friction factor (f) behavior of perforated twisted tape (PTT) and plain tube versus the variations of Reynolds number (Re). It can noticing that the value of (f) decrease with the increase in value of Re. The plan of using perforated twisted tape in plain tube, in general, contains ideas that holes located along the heart of a tube can reduce the loss of pressure inside the tube compared to a typical twisted tape. Figure 4.23 shows that the friction factors for the PTT with twist ratio y = 3.0 and 5.0 are respectively 5.498 and 4.82 times higher than that for the plain tube, and it is lower than those with (TTT).

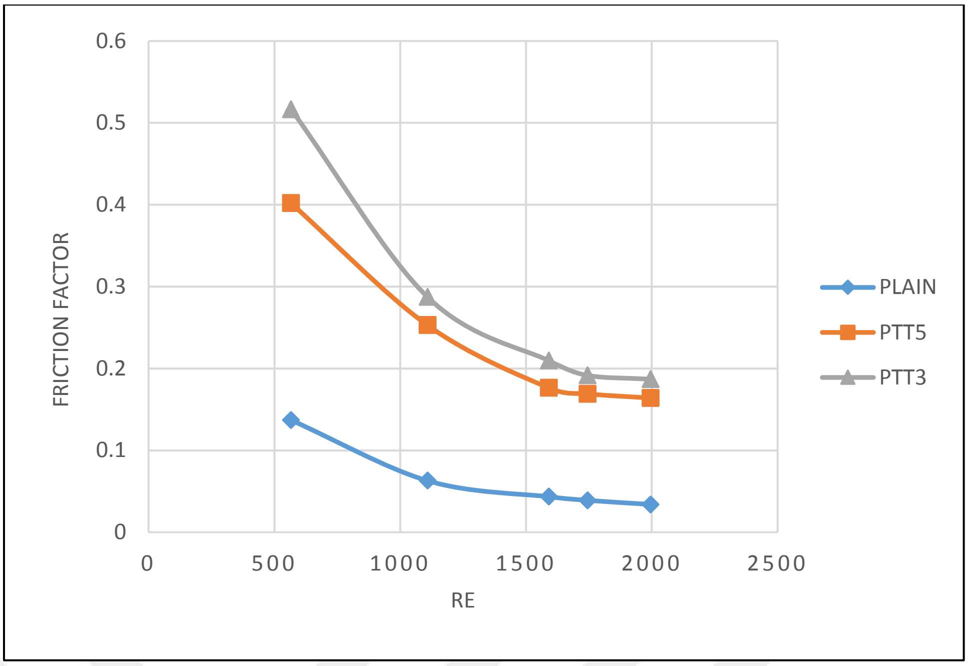


Figure 4.23: Effect of PTT at different twist ratio(y=3.0, 5.0) on friction factor with the variation of Rey.

4.4.4 Friction Factor Variation for U-cut Twisted Tape (UCTT)

Figure 4.24 shows a comparison to friction factor (f) behavior of U-cut twisted tape (VCTT) and plain tube versus the variations of Reynolds number (Re). It can noticing that the value of (f) reduce with the increase in value of Re. Figure 4.24 shows that the friction factors for the UCTT with twist ratio y = 3.0 and 5.0 are respectively 5.625 and 5.117 times higher than that for the plain tube. The Explanation to the increase in value of (f) to the tube with U-cut (UCTT) comparing with that of the typical twisted tape TTT and plain tube is because of the extra disturbance to the chief swirl flow in the form of turbulence.

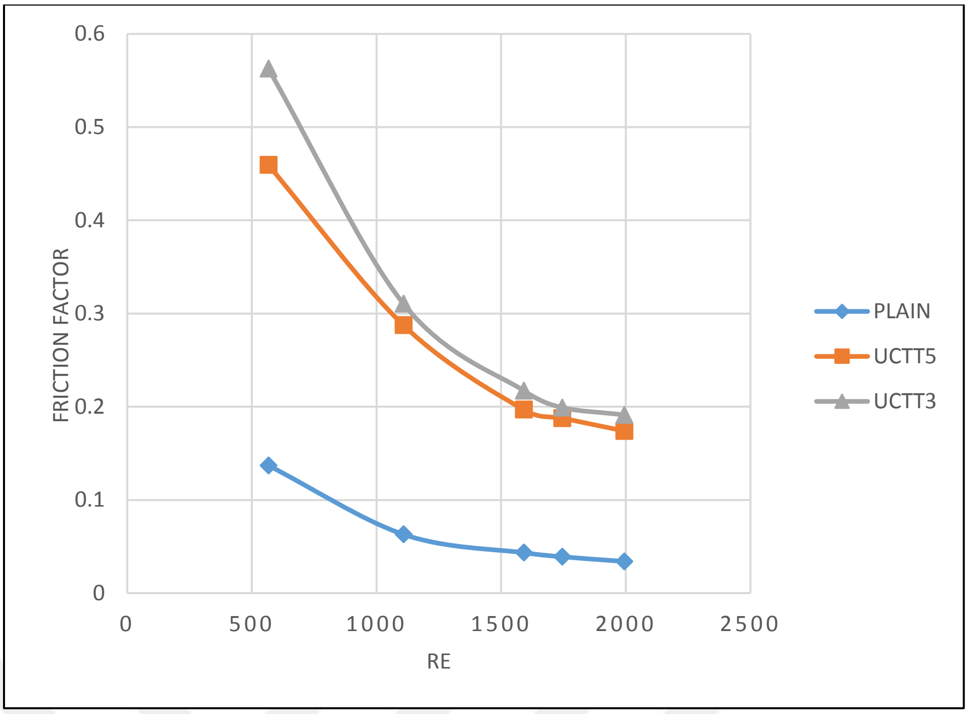


Figure 4.24: Effect of UCTT at different twist ratio(y=3.0, 5.0) on friction factor with the variation of Re.

4.4.5 Friction Factor Variation for V-cut Twisted Tape (VCTT)

Figure 4.25 shows a comparison to friction factor (f) behavior of V-cut twisted tape (VCTT) and plain tube versus the variations of Reynolds number (Re). It is also can noticing that the value of (f) reduce with the increase in value of Re. Figure 4.25 shows that the friction factors for the VCTT with twist ratio y = 3.0 and 5.0 are respectively 5.667 and 5.2 times higher than that for the plain tube. The modified twisted tape with V-cut or another cut shape produce addition local vortices, which boost an extra shear stress due to an increase in the mixing of the flow between the viscous boundary layers of the water which is the working fluid at the tube wall, and edge the twisted tape.

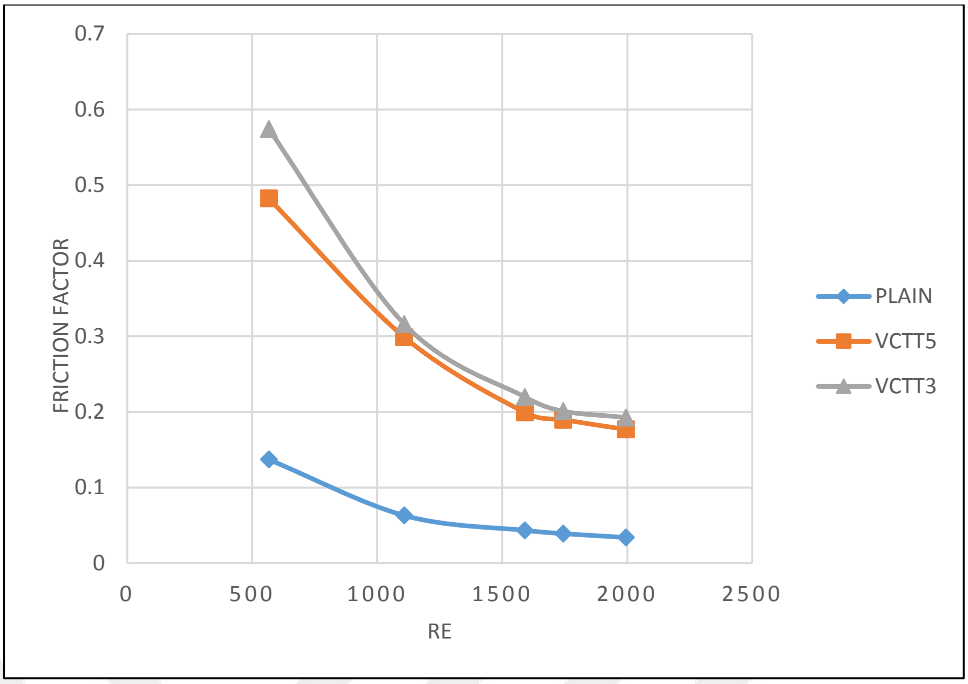


Figure 4.25: Effect of VCTT at different twist ratio(y=3.0, 5.0) on friction factor with the variation of Re.

4.4.6 Comparison to the Variation of Friction factor for Different Twisted Tape Insets

Figure 4.26 shows a comparison to the twisted tapes the variation of friction factor versus Reynolds number for different twisted tapes that presented in this study. V-cut twisted tape with twist ratio (y= 3.0) (VCTT3) is produced the highest friction losses and pressure drop with friction factor varies from 0.574 at Reynolds number of 566 and 0.1927 at Reynolds number of 1994. The lowest friction losses and pressure drop is get from perforated twisted tape with twisted ratio (y=5.0) (PTT5) with friction factor varies from 0.401 at Reynolds number of 566 and 0.164 at Reynolds number of 1994.

That is mean to get the minimum pumping losses the perforated twisted tape is the favorite selection but it is also yielded lower heat transfer comparing with other modified twisted tape. Hence, it is produced lower thermal performance from the others.

U-cut twisted tape with twist ratio y=3.0 (UCTT3) yielded lower friction losses from the (VCTT3) by 2% and 1% at the same condition with friction factor varies from 0.56 at Reynolds number of 566 and 0.1912 at Reynolds number of 1994.

Semicircular cut twisted tape with twist ratio y=3.0 (SCTT3) yielded lower friction losses from the (VCTT3) and (UCTT3) by (6% to 1.5%) and (4% to 1.5%) respectively from low Reynolds number (566) to higher Reynolds number (1994). The friction factor varies from 0.56 at Reynolds number of 566 and 0.1912 at Reynolds number of 1994.

Typical twisted tape (TTT3) yielded lower friction losses from the (VCTT3) by values varies from (8.6% to 2.2%) respectively from low Reynolds number (566) to higher Reynolds number (1994).

Perforated twisted tape (PTTT3) yielded lower friction losses from the (VCTT3) by values varies from (10% to 3.0%) respectively from low Reynolds number (566) to higher Reynolds number (1994).

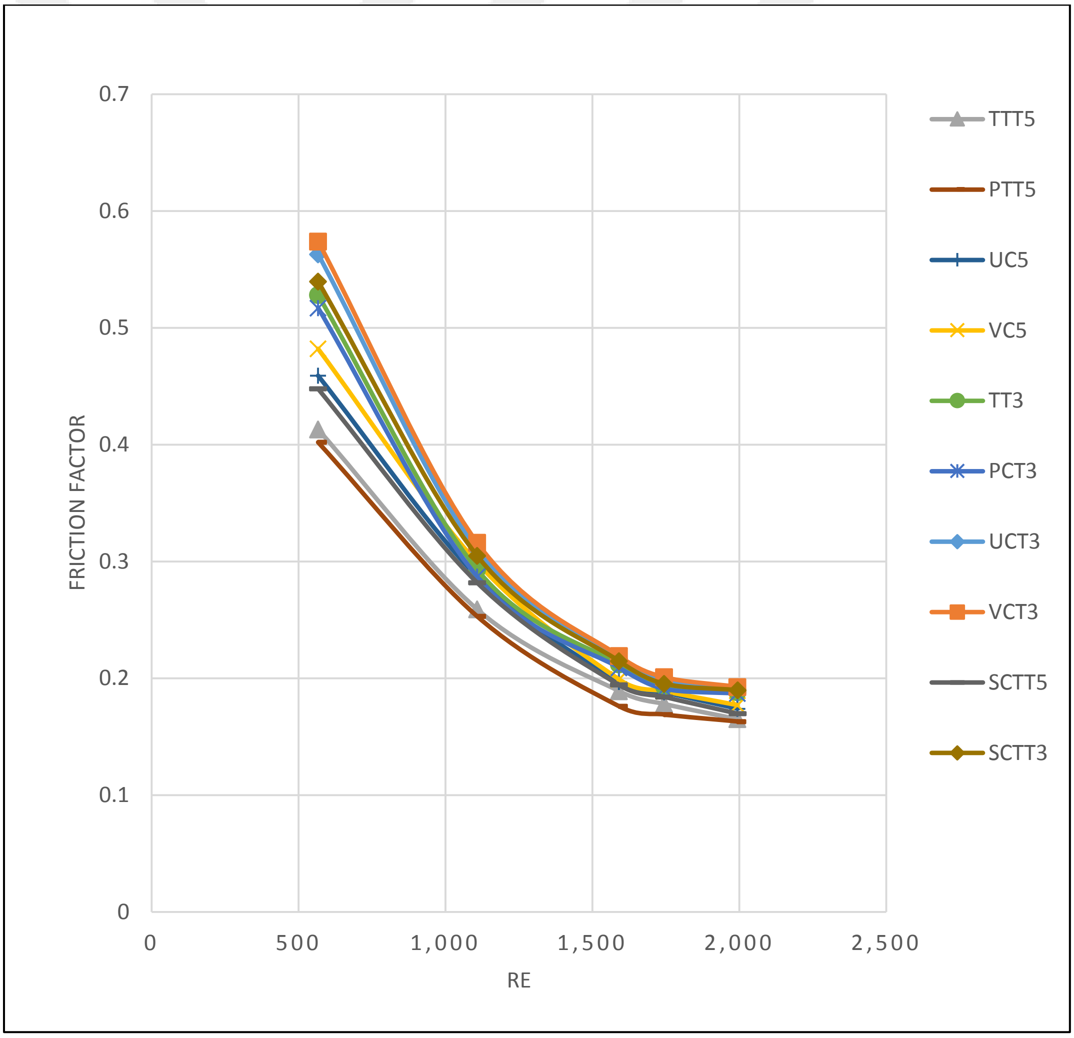


Figure 4.26: Comparison Friction factor for different twisted tapes and twist ratios with Reynolds number variation.

4.5 Thermal Performance Factor (η)

The last parameter used for estimating the practical use of the twisted tape is thermal performance factor (η). This factor is very useful and effective due to instead of study the Nusselt number and friction factor characteristics to variant twisted tapes separately; the performance factor does this job effectively.

4.5.1 Thermal Performance Factor (η) for Typical Twisted Tape (TTT)

Figure 4.27 present the variation of the thermal performance factor (η) with Reynolds number (Re) for Typical twisted tape (TTT) with different ratio(y=3.0, 5.0). It is observed that, as the (Re) increase the value of (η) increase because of the significant enhancement in Nusselt number and heat transfer coefficient that provided by the use of twisted tape in the plain tube. In addition, it is significant to refer to the enhancement in heat transfer and thermal performance that presented by decreasing the twist ratio (y) from y= 5.0 to y=3.0 due to the increase in swirl intensity. This average enhancement of twist ratio effect is 28%. The value of (η) of (TTT5) varies from 3.49 to 6.7 at the Reynolds number variation from 566 to 1994 respectively while the value of (η) of (TTT3) varies from 4.769 to 8.27 at the same range of (Re).

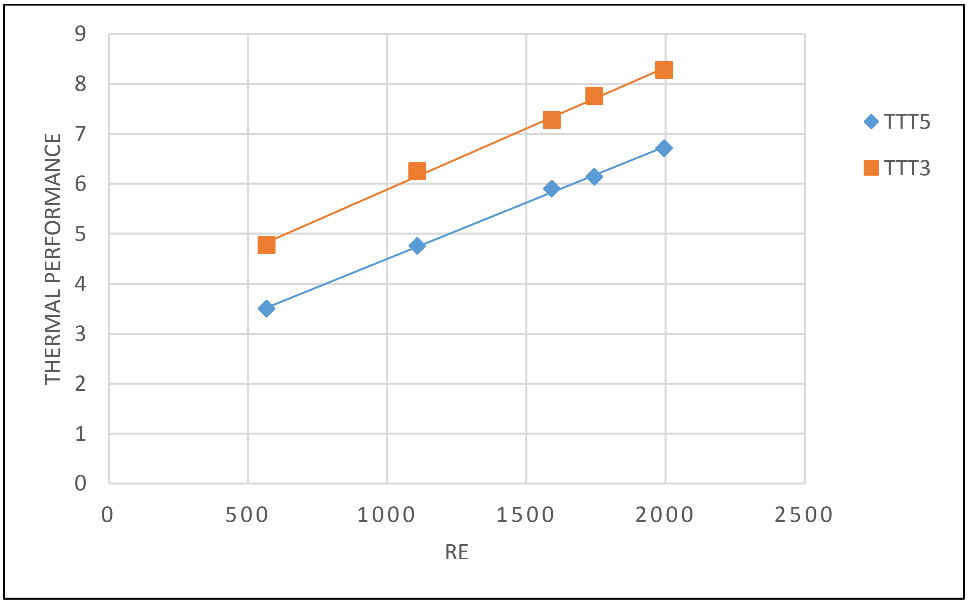


Figure 4.27: Thermal performance for (TTT) at different twist ratio with Reynolds number.

4.5.2 Thermal Performance Factor (η) for Perforated Twisted Tape (PTT)

Figure 4.28 present the variation of the thermal performance factor (η) with Reynolds number (Re) for Perforated twisted tape (PTT) with different ratio(y=3.0, 5.0). It is observed that, the value of (η) increase with the increase in (Re) because of the enhancement in heat transfer that provided by the use of perforate twisted tape in the plain tube. The decreasing of twist ratio (y) from y= 5.0 to y=3.0 yielded a significant enhancement in heat transfer and thermal performance due to the increase in swirl intensity. This average enhancement of twist ratio effect is about 28%. The value of (η) of (PTT5) varies from 3.47 to 6.5 at the Reynolds number variation from 566 to 1994 respectively while the value of (η) of (PTT3) varies from 4.72 to 8.04 at the same range of Reynolds number.

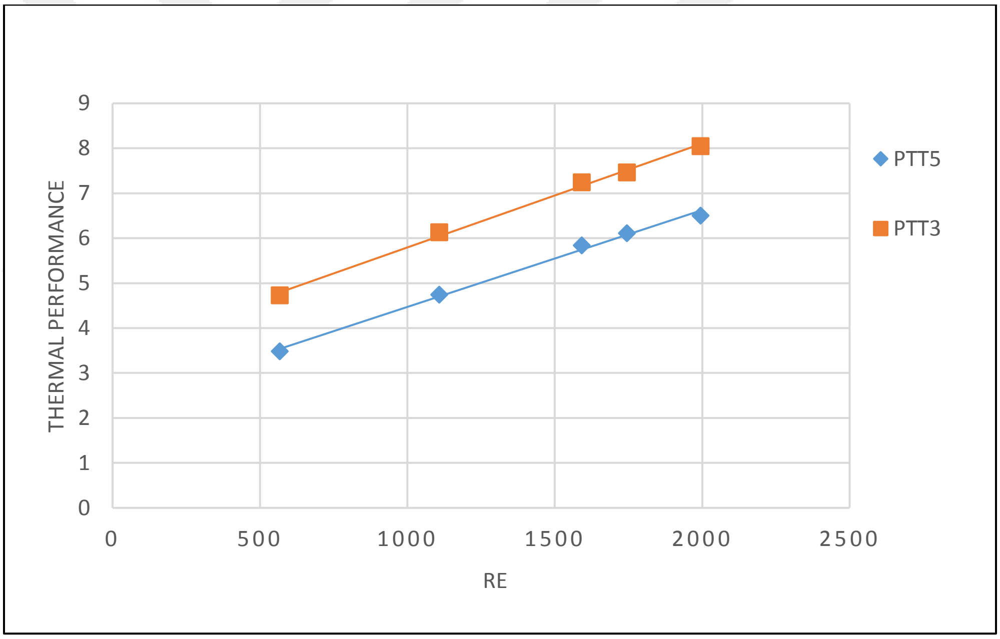


Figure 4.28: Thermal performance for (PTT) at different twist ratio with Reynolds number.

4.5.3 Thermal Performance Factor (η) for Semicircular Cut Twisted Tape (SCTT)

Figure 4.29 present the variation of the thermal performance factor (η) with Reynolds number (Re) for Semicircular twisted tape (SCTT) with various twist ratio(y=3.0, 5.0). It is noticed that the value (η) increase with the increase in (Re) for the same reason that explained in the previous section. The decreasing of twist ratio

(y) from y= 5.0 to y=3.0 also caused a considerable enhancement in heat transfer and thermal performance due to the combined effect of increase in swirl intensity and the generating of local vortices caused by semicircular cut.

The value of (η) of (SCTT5) varies from 3.6 to 7.0 at the Reynolds number variation from 566 to 1994 respectively while the value of (η) of (SCTT3) varies from 4.77 to 8.4 at the same range of (Re).

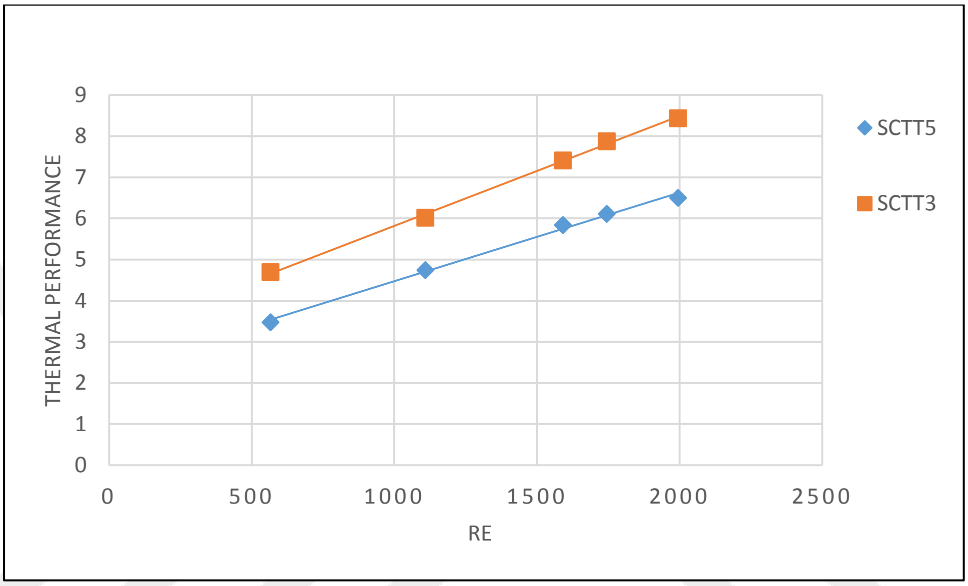


Figure 4.29: Thermal performance for (SCTT) at different twist ratio with Reynolds number.

4.5.4 Thermal Performance Factor (η) for U-cut Twisted Tape (UCTT)

Figure 4.30 show the variation of the thermal performance factor (η) with Reynolds number (Re) for U-cut twisted tape (UCTT) with twist ratios (y=3.0, 5.0). The value of (η) shows increase with the increase in (Re) due to the fit of insert in the plain tube, which introduce more turbulence in the flow. Reducing twist ratio (y) from y= 5.0 to y=3.0 gave a considerable enhancement in heat transfer and thermal performance due to the combined effect of increase in swirl intensity and the generating of local vortices caused by u-cut modification in the normal twisted tape. The value of (η) of (UCTT5) varies from 3.7 to 7.1 at the Reynolds number variation from 566 to 1994 respectively while the value of (η) of (UCTT3) varies from 4.8to 8.44 at the same range of (Re).

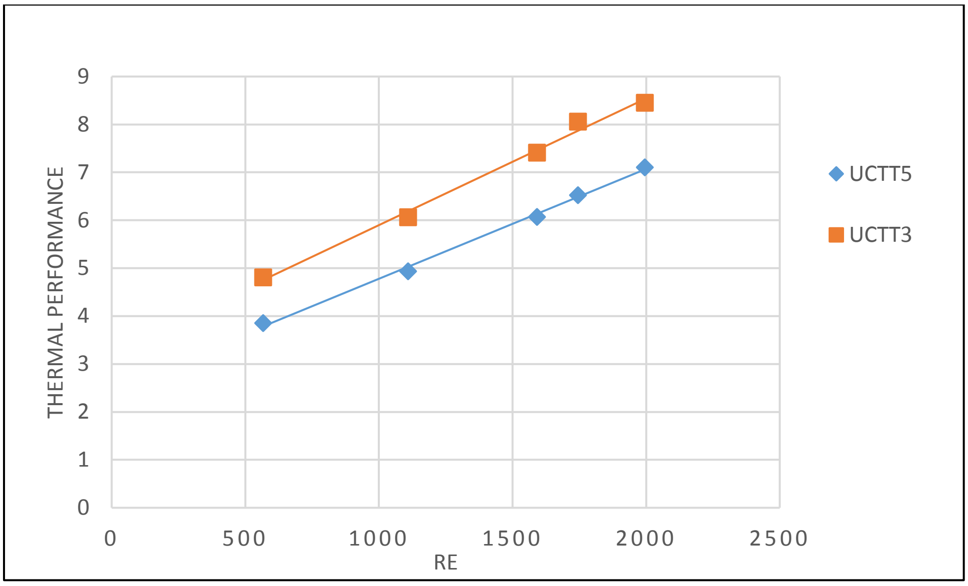


Figure 4.30: Thermal performance for (UCTT) at different twist ratio with Reynolds number.

4.5.5 Thermal Performance Factor for V-cut Twisted Tape (VCTT)

Figure 4.31 show the thermal performance factor (η) variation with Reynolds number(Re) for V-cut twisted tape (VCTT) with twist ratios(y=3.0, 5.0). The thermal performance factor shows the highest increase with the increase in Reynolds number comparing with the other performance previous twisted tape due to the effect of equipped the (VCTT) insert in the plain tube, which introduce more turbulence in the flow. Reducing twist ratio (y) from y= 5.0 to y=3.0 gave a considerable enhancement in heat transfer and thermal performance due to the combined effect of increase in swirl intensity and the generating of local vortices caused by v-cut modification in the normal twisted tape which yielded the higher performance. The value of (η) of (VCTT5) varies from 3.73 to 7.31 at the Reynolds number variation from 566 to 1994 respectively while the value of (η) of (VCTT3) varies from 5.0 to 8.65 at the same range of (Re).

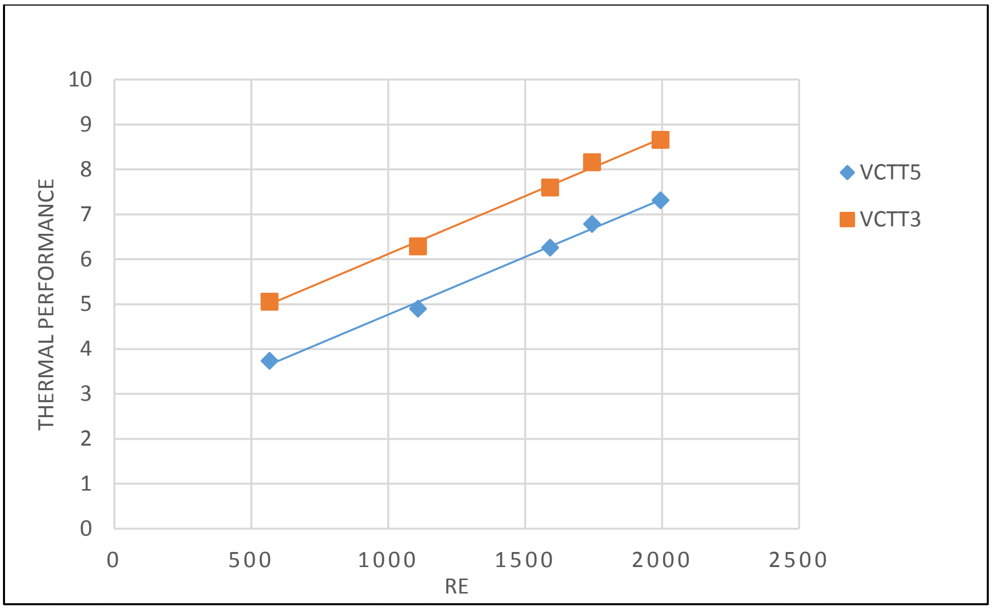


Figure 4.31: Thermal performance for (VCTT) at different twist ratio with Re.

4.5.6 Comparison the Thermal Performance Factor for Various Twisted Tapes

Figure 4.32 shows a comparison thermal performance factor (η) variation with Reynolds number (Re) for all twisted tapes that studied in present work. From this figure, It is indicated that the highest value of (η) was 8.65 which obtained from V-cut twisted tape with twist ratio of y=3.0 (VCTT3) at (Re) of 1994. U-cut twisted tape of 3.0-twisted ratio (UCTT3) yielded lower thermal performance than (VCTT3) with (η) of 8.44 at the same Reynolds number while it higher than the thermal performance of (SCTT3) which produced (η) of 8.4.

The lowest thermal performance at twist ratio of 3.0 produced by (PTT3) with thermal performance (η) of 8.04, while Typical twisted tape (TTT3) yielded higher thermal performance with (η) of 8.24 at the same condition and twist ratio. The other results of thermal performance factor of twist ratio y=5.0 was 6.5, 6.7, 7.0, 7.1 and 7.31 for PTT5, TTT5, SCTT5, UCTT5 and VCTT5 respectively.

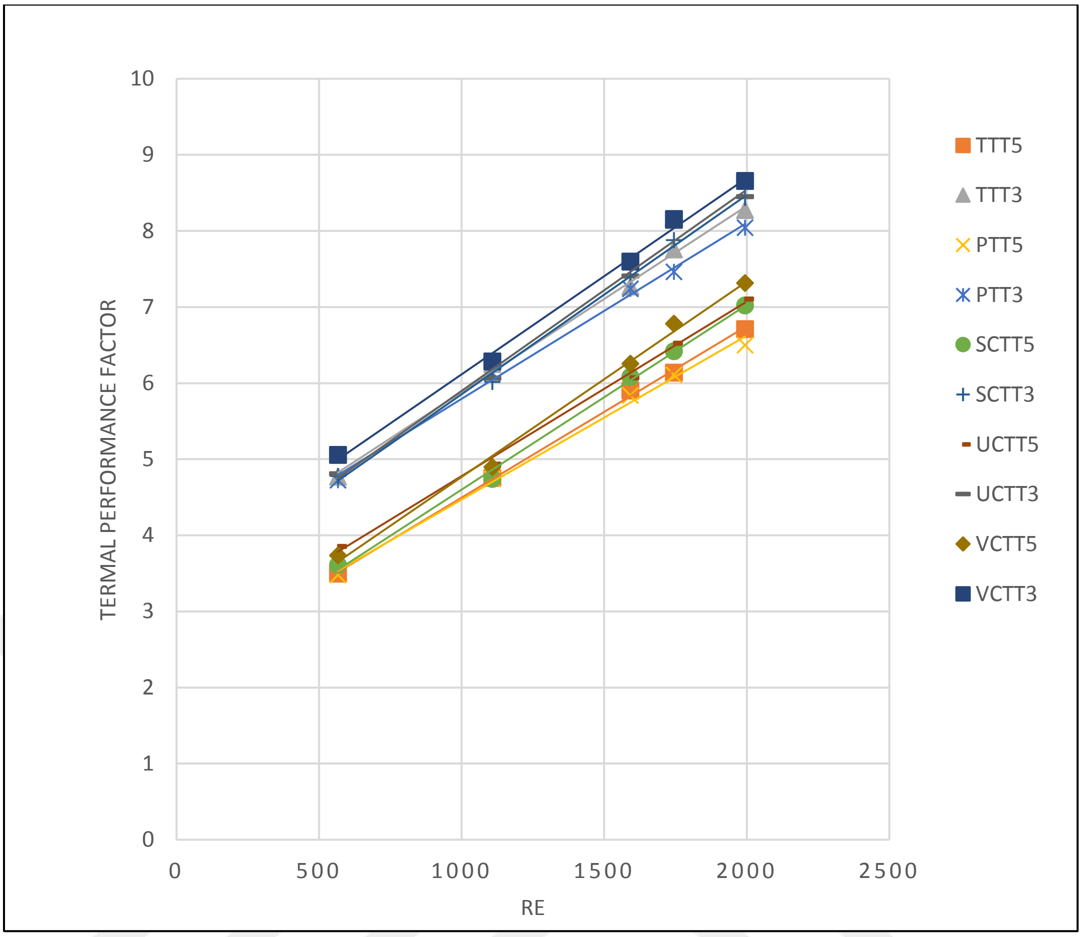


Figure 4.32: Comparison the Thermal performance for different twisted tapes and twist ratios with the variation of Re.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

An experimental investigation to evaluate the heat transfer and pressure drop characteristics for five variant twisted tapes (TTT,SCTT,UCTT,VCTT,PTT) equipped in plain tube with tow twist ratios (y=5.0,3.0) have been implemented. The experiments carried out under laminar flow regime with Reynolds number (Re) varies from 566 to 1994. The main findings that obtained from the present experimental work can be drown as the following:

5.1 Heat Transfer

1. The use of various categories of twisted tape inserts that mentioned above in plain tube yielded a considerably increase in heat transfer (Nu) comparing to the tube without insert.
2. Decreasing the twist ratio for the variant types (VCTT, UCTT, SCTT, TTT and PTT) produced higher Nusselt number (Nu).
3. VCTT with twist ratio of 3.0 yielded the highest increase in Nusselt number (Nu) with value of 68.63 with an enhancement of 195% comparing to the plain tube while the lowest enhancement produced by PTT with twist ratio of 5.0 with (Nu) of 48.75 and 105% comparing to the plain tube.

5.2 Pressure Drop

1. The friction losses associated by VCTT is higher than the losses of other types with friction factor of 0.574 and it is 5.667 times higher than the plain tube at (Re) of 566.
2. The friction factor decrease with the increase of twist ratio for all cases presented in this work.

3. Minimum friction losses yielded by PTT5 with friction factor of 0.162 at Reynolds number (Re) of 1994 over the range investigated.

5.3 Thermal Performance Factor

1. In this study, the higher thermal performance (η) obtained by (VCTT3) and it is 8.65 at Reynolds number of 1994, while (UCTT3), (SCTT3), (TTT3) and (PTT3) yielded 8.44, 8.4, 8.24and 8.04 respectively at the same conditions.
2. Decreasing twist ratio from y=5.0 to y= 3.0 caused a good enhancement in thermal performance (η).
3. Increasing the Reynolds number produced increase in thermal performance (η).

5.4 Future Work

Some suggestions for future work are listed below:

1. Studying the effect of other twisted tapes modification for example, alternative axis, W-cut twisted tape or another turbulators type such as coil wire insert, helical screw insert on heat transfer enhancement and friction losses through plain tube.
2. Studying the effect of changing the type of twisted tape material such as (stainless steel or aluminum).
3. The influence of variant twisted tapes on heat transfer augmentation in refrigeration system can also be studied.
4. By utilizing the same twist group, heat transfer enhancement for another type of fluids such as (air, oil) can be studied.

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