# Heat Transfer Enhancement in a Circular Tube Fitted with V-cut Twisted Tape

**Duraid Majeed Muter**

*Middle Technical University, Technical Institute of Anbar, duraidmajeed@mtu.edu.iq*

Research aims to increase the effectiveness of heat transfer in a single-tube heat exchanger with a torsion ratio (y/w = 4 and 6). The ANSYS 15.0, FLUENT package is used to evaluate and simulate the flow field and heat transfer. A copper heat exchanger tube with a circular cross-section that was one meter long and had inner and outer diameters of 20 and 22 mm was among the mimicked works. To prevent heat loss, distilled water is forced through a fiberglass-coated tube in a laminar flow (Re = 1050-1850). According to the findings, using adhesive tape caused the heat transfer coefficient to rise significantly, by a factor of around (15–26%) greater than using a smooth tube. The ANSYS 15.0 package, FLUENT, is utilized to evaluate and do the flow field and heat transport simulation. There was good compatibility with a maximum of 13% when the thermal performance of plain and coiled tape input tubes were compared.

**Keywords:** Twisted ratio, V-cut twisted tape, heat transfer, friction factor, twist ratio.

## 1. Introduction

Thermal system is very important in engineering matters. There are several methods that have been improved to maximize heat exchange efficiency in order to deliver the best results. Common heat exchangers have used a variety of surface augmentation development strategies to boost the heat transfer rate efficiency. The development of the boundary layer is slowed down and the amount of turbulence that results in the formation of eddies and secondary flows are increased by the usage of enhanced surfaces. One of the subpar methods now employed to increase heat transmission is the employment of vortex flow devices. The fluid experiences a secondary vortex flow as a result. This effect is brought on by a variety of devices, including changing tube flow patterns, duct geometry changes, and tube insertion. Quite a bit of effort has lately been done on the development of heat exchangers to improve the coefficient of heat transfer within the heat pipes and increase the performance of heat transfer augmentation technologies.

Yadav [1], for the development of vortex flow, researchers presented the friction and heat transfer in a double U-tube heat exchanger through a graded strip that was half its length. It was discovered that using adhesive tape outperforms normal pipe by raising the transfer of heat coefficient by roughly 41%. It was discovered that the standard tube has (1.4–1.6) time’s greater thermal performance than half-length twisted tape. Naga et al. [2] employed twisted narrow-width strips in a horizontal tube with a circular cross section to speed up heat transfer. The air was the studying fluid, and the inner tube's diameter was 27.6 mm. Three different winding ratios of twisted strips were used in the experiments (4, 5, and 6). There are five distinct widths for each of these tapes (27 full widths, 23, 19, 15, 11 mm). The Reynolds number fell between 6005 and 14500.They noticed that as the y/w ratio falls, heat transmission rises. bodeus. [3] conducted a study to determine the water's ability to transfer heat from the turbulent flow side of the pipe. The tube has a 5.3 spiral stainless steel twisted strip attached to it, as well as a round section. In order to maintain a consistent heat flow condition, glass fibres are wrapped around nichrome wire that is surrounding the test section. On the tubes outside at the test segment, temperatures were recorded at five distinct locations. The temperature was measured using Type T thermocouples. The investigation covered a range of Reynolds values from 9700 to 20500. The twisted tube's heat flow ranges from 16 to 32 kW/m2, whereas the smooth tube's ranges from 11 to 20 kW/m2.

The throughput of the procurement band provided through the front is 2.8 to 5 times that of the smooth tube. Results have been compared

With Boelter. And Dittus error was -14% to 19%. Spiral bar with regular vacuum cut nareesh. [4] Perform blood flow transfusion. The Reynolds range used in the experiments ranged from 6,000 to 40,000. The helical angles of the three separate helical strips that were used were 60°, 45°, and 30°. The heat transfer rate is increased by inserting spiral strips, according to experiments, because of the turbulent flow that is created in the tube's circular part. It was deduced that the local heat transfer coefficients rise to extremely high levels along the spiral strip's lower face and subsequently fall as one moves away from it. Heat transport is not significantly impacted by the spiral's number of channels or spiral angle. According to the Reynolds number, the spiral strip improved heat transfer rate by no more than 30%. The efficiency of heat transport decreased as the Reynolds number increased.

Samy [5] Using Computational Fluid Dynamics (CFD) Modeling, one may model, simulate, and analyse a parabolic twisted ribbon inclusion (PCT) fixed in a round tube and its impact on heat transfer rate. For the simulation, Fluent-6.3.26, a commercial CFD programme, was employed. Laminar flow occurs in a conventional circular tube, which has a thermally constant flow. The simulation took into account three distinct twisted strips with torsion ratios of 3.93, 4.91, and 5.89 and depths of cut of 0.6, 2 and 2.5 cm m. It was found that as torsion ratios (y) and cutting depth decreased, in addition in the pipe fitted with the PCT, the factor of friction and Nusselt number increased. The Nusselt number and factor of friction changes are fewer than 9% and 7.5%, respectively, and are compatible with CFD anticipated findings for normal tube validation. [6] Carried out an experiment to investigate the thermal and characteristics of flow of tubes induced with various types of twisted strips. Throughout the study, three different torsion ratios were employed (4.33, 5.29, and 6.71). According to the experimental findings, smooth tubes with torsion ratios of 5.29 and 6.71 improved heat transfer by 20.9% and 15.4%, respectively, whereas those with torsion ratios of 5.29 and

6.71 improved heat transfer by 24.86%. They observe that due to the engine's smaller contact surface area, the factor of friction for a torsion ratio of 4.33 is greater than that for torsion ratios of 5.29 and 6.71. A maximum variation of 8.28 for the Nestle numbers and 8.16% for the factor of friction were used to build empirical relationships.

The most popular spiral coiled tube design parameters were examined by Osama [7]. A spiral tube heat exchanger with a 16 mm diameter had its effects when a coiled wire from a twisted bar was inserted. The Dean number lies between 800 and 3000. First, Coiled wire with various inserts measuring 16, 21, and 31 mm was used for the trials. Next, tests using various circular and square sections were conducted while the insert pitch stays at 16 mm. Finally, at a constant insert pitch of 15 mm, trials were conducted using square wires of varying thickness (2 & 3 mm). Distilled water was combined with Al2O3 and TiO2 nanoparticles, which had diameters of 90 nm and 31 nm, respectively. Volume concentrations of 0.09, 0.2, 0.3, and 0.4% were employed to present the heat transfer flow using Nano-fluids in the helical coil tubes. Distilled water was mixed with nanoparticles of Al2O3 and TiO2 that had corresponding sizes of 90 nm and 31 nm. Volume concentrations of 0.09, 0.2, 0.3, and 0.4% were employed for the aim of simulation of the heat transfer flow using Nano-fluids in the helical coil tubes. In a previous study [8], A helical screw tape was inserted into a circular, straight conduit and the thermal behavior of CuO/water and Al2O3/water Nano-fluids was compared. Three various tapes of helical screw were employed, with twisted ratios of (y=4, 3.44 and 2.78). A 0.2% volume concentration of the CuO/water and Al2O3/water Nano-fluids was utilized in the experiment. The largest increases in Nusselt number attributable to the use of water, Al2O3/water, additionally, CuO/water are, respectively, 157.24%, 167.84%, and 180.82% at y=2.78 when compared to a simple tube.

Experimental studies on the inserting tape effect and using Nano-fluid in a twin pipe heat exchanger were conducted by Maddah et al. [9]. The internal pipe, which is 5 mm thick and has an inner diameter of 8 mm. On the shell side, cold water was being used; in addition hot water was running through the inner tube. A 130 cm long, 5 mm wide and 1 mm thick tape is inserted. Aluminium sheet was utilized to make the twisting tape. The Nano-fluid, which has 0.02% of volume concentration and 30 nm of diameter, was created using titanium dioxide. Twisting tape has been found to raise the coefficient of heat transfer of Nano-fluid by 20 to 35 percent. Increases in operating temperature and mass flow rate will also result in the coefficient increasing. Additionally, an experiment demonstrated that using twisted tapes results in a larger friction factor and pressure decrease.

Masoud et al. [10] developed the factor of friction, Nusselt numbers, and thermal performance index of a tube using experimental and numerical techniques with three different types of developed strips (jagged, perforated, and notched), each having a constant pitch length and width of 16 mm. The CFD code FLUENT6.2 was used to implement the numerical portion of the simulation for a single twist ratio of 3.94. The findings showed that employing jagged inserts produced good thermal performance, maximum gains in Nusselt number and performance over traditional twisted tape of 32% and 33%, respectively.

## 2. Study Aims

Research aims to increase the effectiveness of heat transfer in a single-tube heat exchanger with a torsion ratio (y/w = 4 and 6) with the use of twisted rods by about 25% or more.

## 3. Study methodology

The ongoing employment aims to study the improvement of qualities of the heat transfer using a swirl flow device in a heating exchanger of single pipe under flow of laminar with constant heating flux circumstances, numerically, and both experimentally. A variety of experimental and computational techniques have been investigated to improve the quality of heat transfer procedure through a pipe fitted up with many sorts of inserts, based on the literature study mentioned above.

The process of designing heat exchangers is more challenging. It involves additional consideration of issues such as the performance of the equipment's long-term and economics, as well as estimates of factors of friction, efficiency, and rate of heat transfer. So, while utilizing any enhancement tools or techniques in the heat exchanger, the advantages of the enhanced coefficient of heat transfer and the more significant pumping cost should be balanced using: V-cut torsion bar (V-TT), (y = 6.0 and 8.0), and axially alternate twisted torsion bar with variable wrap ratio were employed to improve heat transmission in a horizontal and inclined heat exchanger tube. FLUENT PACKAGE 15.0 will be used for the numerical analysis. While Jaisankar et al [11], were utilizing twisting tape, various twisting ratios were used in solar water heaters. Friction's impact on heat improved heat transport and performance. They came upon the article, “Reliability of a Solar Water Heaters Using a Twist Rod.” Entries are 8–24% smaller in size and superior to those in standard mode. Munoz [12] studied heat transfer magnifying for the initial time utilizing internal spiral fins in a PTC absorbing tube. The temperature efficiency was determined to have increased by about 2%, although the cost rise was just 0.5%. Kim [13] conducted experimental and numerical analyses of the thermal efficiency of glass evacuation solar panels with various tube-containing forms. Choudhari [14] investigated the wire impact coil insertion on heat transfer & friction throughout the instance of a twin tube heating exchanger using various wire coil materials, including copper, aluminum, in addition stainless steel, as well as various rates of fluid mass flows.

## 4. Theoretical Analysis

For single-tube heat exchangers, some suppositions the rating of mass flow and properties of the fluid are taken into consideration in steady state situations. Kinetic and potential energy hardly vary at all. You can think of the water's specific heat as constant. Because it is modest, the conduction heat transfer mechanism has been ignored along the tube. Heat generation is minimal since the external surface of the tube is insulated. The phase of the flow inside the heating exchanger remains unchanged. A Process for Data Reduction Heat Transfer Rate The following factors affect how much electric power can be used to heat the tube's outer surface wall. Accordingly, the power can be determined by the value the current and voltage as equation (1):

Power=I*V (1)

Where I is the current in (A) and V is the voltage. The electrical power can be obtained according to equation (2).

Electric power = $Q_b = (T_{ho} - \dot{T}_{hı})\dot{m}_b C_p$ (2)

Thus, the electrical quantity can be calculated according to equation (3).

Inner Side Coefficient of Heat Transfer (hi)

$$Q_h = (\overline{T}_s - T_m)\bar{h}_i A_s \quad (3)$$

Where $\overline{T}_s$ and $T_m$ are calculated according to equation (4) and (5).

$$\overline{T}_s = (T_1 + T_2 + T_3)/3 \quad (4)$$

$$T_m = (T_i + T_o)/2 \quad (5)$$

Thus, the inner tube surface's average Nusselt number can be determined as follows:

$$\overline{Nu_ı} = (\overline{h_ı} \times d_i)/K_h \quad (6)$$

The heated tube's interior flow is laminar, and the equation is used to get the Reynolds number, which ranges from 1056 to 2002.

$$R_e = 4\dot{m}/\pi d_i \mu \quad (7)$$

Friction Factor

The following formula can be used to get the Darcy friction coefficient based on the experimental pressure drop. [11]:

$$f = 2\Delta P d_i/L\rho {U_m}^2 \quad (8)$$

In this study, the experimental setup is as presented in Figure 1. Figure 2 illustrates the specifics of a standard twisted tape and a V-cut twisted ratio inserts.

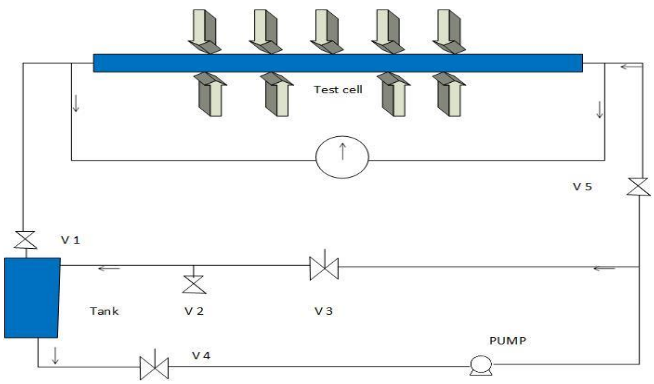



Figure.1 An experimental setup

Figure.2 standard twisted tape and a V-cut twisted ratio inserts

## 5. Numerical Simulation

We can examine complex processes using numerical simulations instead of costly prototype construction and labor-intensive experimental testing. Numerous engineering issues call for the simulation of the Navier-Stokes equation for complex fluid flows. To examine how fluid flows interact inside a tube that is plain with twisted tape inserts, mass conservation, energy, and equations of momentum are solved. In the sections that follow, numerical procedure will be expressed. The method of finite volume was utilized to answer the equations representing flow in motion for the system geometry simulations, which were performed using the commercial CFD solver Fluent 15.0. Laminar kinetic and laminar dissipation energy, as well as convection terms and energy, Using the second-order upwind method, they were discretized. The connection between the velocity and pressure fields for the current situations was resolved using the SIMPLE technique. [15-20]. In essence, the method for calculating pressure is gauss-correct. To find the best computing grid for which the data findings remain the same as the grid gets smaller, a grid independence test is conducted. In order to compare the two models results, it is appropriate to establish a grid with more cells. Grid-independent refers to the ability to overlook the truncation error in numerical simulation because calculational results vary so little with a denser or looser grid. The rationality of numerical findings and the truncation error are directly influenced by the independence of the grid. The estimated (2) million cell grid size offers adequate precision and resolution, and this grid size is used as the standard in all circumstances because grid refinement studies demonstrate that the average Nusselt number remains constant as the cell count rises. Figure (3) illustrates the grid independence test results for the TR=4 configuration (3) of V-cut twisted tape.

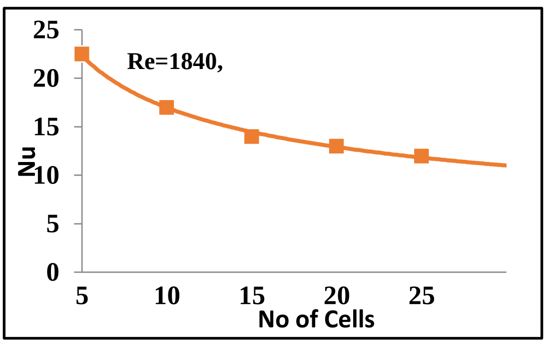



Figure. 3 The V-cut twisted tape grid independent solution test

5.1 Calculating Equations Defining Moving Fluids

The Navier-Stokes equations and the continuity equations are used to formulate differential equations that describe fluid flow. Enabling the energy conservation equation is necessary for flows that involve heat transfer processes. The mass conservation balance is applied to a fluid with a very small differential volume to produce the continuity equation. To characterise the flow in Cartesian coordinates, three equations are derived in the following style [19–20]:

$$\left(\frac{\partial W}{\partial Z}\right)+\left(\frac{\partial U}{\partial X}\right)+\left(\frac{\partial V}{\partial Y}\right)=0 \qquad (9)$$

Navier-Stokes Equations:

The equation of Z-Momentum can be described as:

$$\rho\left\{W\left(\frac{\partial W}{\partial Z}\right)+U\left(\frac{\partial W}{\partial X}\right)+V\left(\frac{\partial W}{\partial Y}\right)\right\}=$$

$$\mu\left[\left(\frac{\partial^2 W}{\partial Z^2}\right)+\left(\frac{\partial^2 W}{\partial X^2}\right)+\left(\frac{\partial^2 W}{\partial Y^2}\right)\right]-\left(\frac{\partial P}{\partial Z}\right) \qquad (10)$$

The equation of X-Momentum can be described as:-

$$\rho\left\{W\left(\frac{\partial U}{\partial Z}\right)+U\left(\frac{\partial U}{\partial X}\right)+V\left(\frac{\partial U}{\partial Y}\right)\right\}=\mu\left[\left(\frac{\partial^2 U}{\partial Z^2}\right)+\left(\frac{\partial^2 U}{\partial X^2}\right)+\left(\frac{\partial^2 U}{\partial Y^2}\right)\right]-\left(\frac{\partial P}{\partial X}\right) \qquad (11)$$

The equation of Y-Momentum can be described as:-

$$\rho\left\{W\left(\frac{\partial V}{\partial Z}\right)+U\left(\frac{\partial V}{\partial X}\right)+V\left(\frac{\partial V}{\partial Y}\right)\right\}=\mu\left[\left(\frac{\partial^2 V}{\partial Z^2}\right)+\left(\frac{\partial^2 V}{\partial X^2}\right)+\left(\frac{\partial^2 V}{\partial Y^2}\right)\right]-\left(\frac{\partial P}{\partial Y}\right) \qquad (12)$$

From above equations, energy Equation can be determined as:-

$$\left\{(\rho C_p)\left(W\left(\frac{\partial T_{nf}}{\partial Z}\right)+U\left(\frac{\partial T_{nf}}{\partial X}\right)+V\left(\frac{\partial T_{nf}}{\partial Y}\right)\right)\right\}=k\left[\left(\frac{\partial^2 T_{nf}}{\partial Z^2}\right)+\left(\frac{\partial^2 T_{nf}}{\partial X^2}\right)+\left(\frac{\partial^2 T_{nf}}{\partial Y^2}\right)\right] \qquad (13)$$

## 6. Results and Discussion

Experimental Test Rig Validation to validate the results of the studies, we looked at the friction factor and heat transmission for smooth tubes. The commonly utilized empiric of Shah's formula is displayed in Figure 4 together with the Nusselt Number values for the present test vs. (Z/D) (4).

$$\mathrm{Nu}\ (x)=1.953\left(\sqrt[3]{\mathrm{Re.Pr.}\frac{D}{X}}\right) \qquad (14)$$

$$\mathrm{Re.Pr.}\frac{D}{X}\geq 33.3 \qquad (15)$$

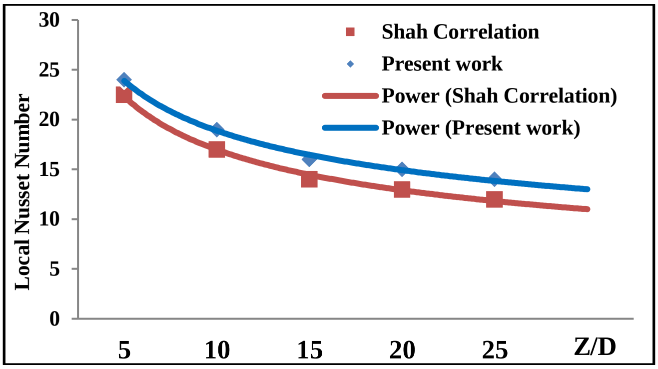



Figure.4 A comparison of the current project and the Shah correlation at Re = 1130, $q^n$=4450 W/$m^2$

The experimental results and Shah's equation have a high agreement, with a maximum variance of (13%). The friction factor's compliance with the published Hagen-Poiseuille equation is depicted in Figure 5 with a maximum variation of 7.6%.

The following equation show the computation of the factor of the friction:-

$$f = 64/Re \qquad (16)$$

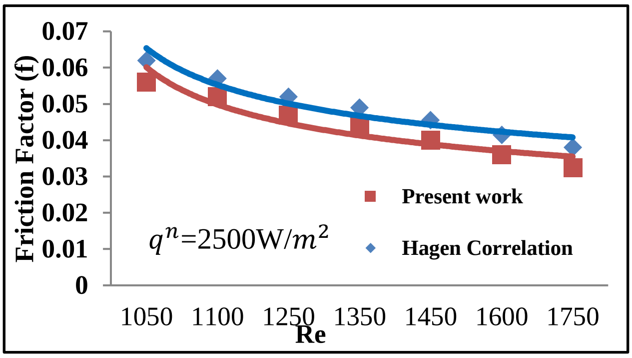



Figure. 5 A comparison of the current project and the Hagen correlation at $q^n$=2500 W/$m^2$

6.1 Examination of Experimental Results

Flow-Thermal Effect in inclined addition to Horizontal Tubes: Effect of the Tape Insert The method for converting experimental results into regional values of the factor of the heat transfer in the horizontal tube is shown in Figure 6. This conversion yielded regional values for the Nusselt number. The Nusselt number value is highest in the thermal appearance area of this figure and gradually declines for the various types of twisting tape and the plain tubes. Because the twisting bar produces turbulence in fluid flow and reduces the layer of thermal boundary thickness, the Nusselt number rises when it is present under the same conditions. The curve's shape demonstrates that as flow approaches the tube's end, the boundary layer's growing influence influences a reduction in heat transmission. Figures 7 and 8 show, respectively, the relationship between the Nusselt and the Reynolds numbers for a smooth tube in comparison to a tube with two distinct types of inscribed strips. For the majority of shock absorber varieties by lowering the twisting ratio value and raising the Reynolds value, the Nusselt number rises.

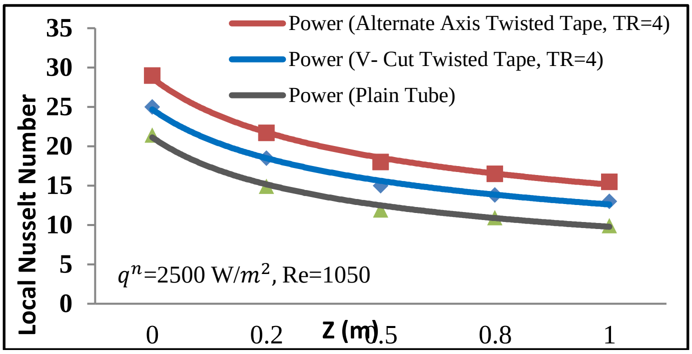



Figure. 6 The differences in local Nusselt numbers along the tubes for the two types of twiste tape and plain tubes

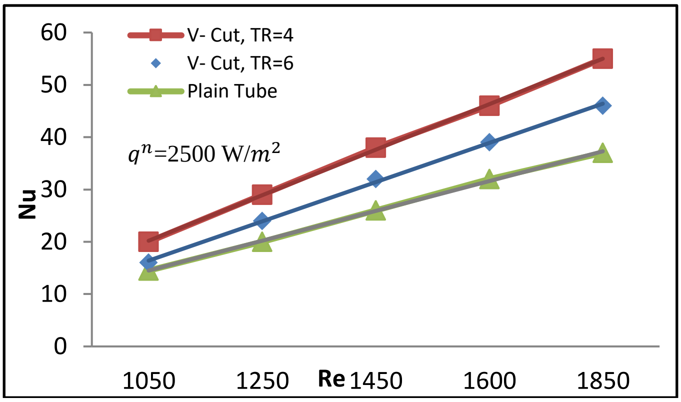



Figure. 7 Nusselt number for V-cut twist tape and the effects of Re and twisted ratio

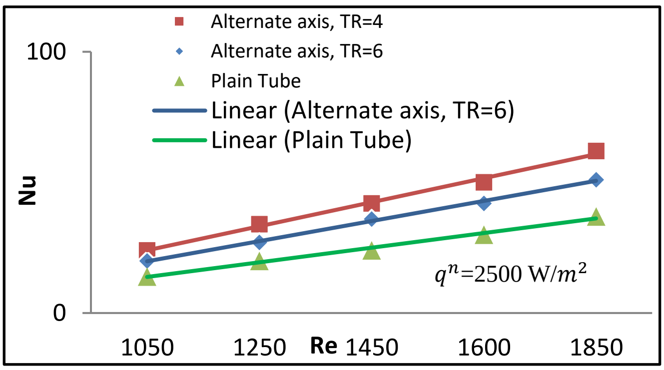



Figure. 8 Nusselt number for Alternate axis and the effects of Re and twist ratio

Information from an experiment conducted in a horizontal tube with normal convection is then used to evaluate the results of the experiment of an inclined tube with a V-cut convoluted bar. Figure 9 shows the differences between a V-cut convoluted tube with torsional ratios (y = 4, 6) and a normal tube at the inlet for testing by comparing the Nusselt and Reynolds numbers for each. With this statistic as a reference, it is clear that the Reynolds number goes up as the average of Nusselt numbers goes down. Also, when a lower curvature ratio is used, the average Nusselt number is higher than when a larger curvature ratio is used. This occurs because the higher eddy flow at the tube wall reduces the boundary layer thickness at the lower torsion ratio. At the twisted ratios of y = 4 and 6, respectively, the Nusselt values for the V-cut insert of the twist strip are 1.6 & 1.4 times larger compared to the compared tubes.

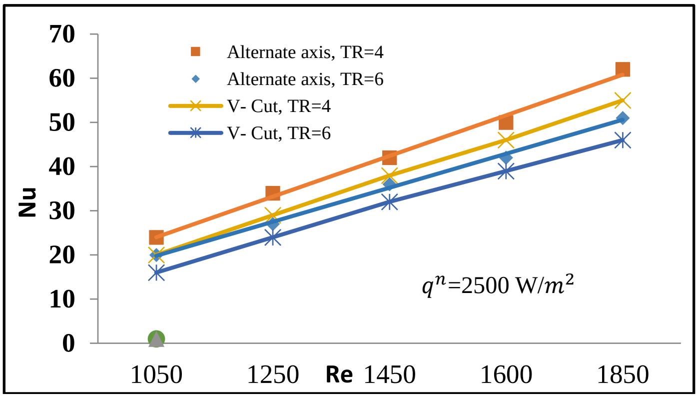



Figure. 9. The effects of Re and twisted ratio on alternate axis V-cut twist tape are represented by the Nusselt number

Figures 10 & 11 illustrate the correlation between the reynolds number and the coefficient of friction for the smooth tube by examining the Effect of Hydrodynamics in inclined and Horizontal Tubes. This is in comparison to the twisted tape inserts in two different varieties in horizontal tubes. For the majority of twist ratio types, the Reynolds number and twist ratio often increase together with the coefficient of friction. The lowest twist ratio results in the highest factor of friction value. Figure 12 illustrates that the factor of friction drops with increasing Reynolds number and is greater for twist ratios of 4 than for those of 6. This is because the V-cut twist ratio produces a larger swirl flow at lower twists. The results demonstrated that, in comparison to the plain tube, the factors of friction for the V-cut inserted with twisting ratios of y=4 & 6 are, correspondingly,1.3&1.1 times greater. This figure depicts that an inclined tube has a larger factor of friction than a horizontal pipe. Increasing tube inclinations often results in more skin friction, which accelerates the flow near the wall. In general, we advise against using the inclined tube in practical applications.

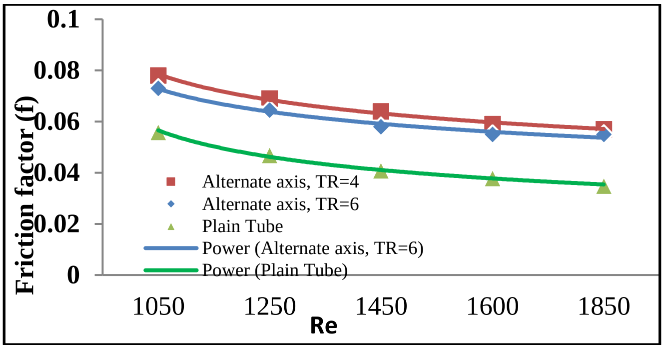



Figure.10 Reynolds number, twist,& factor of friction for distilled and twist for Alternate axis twisted tape

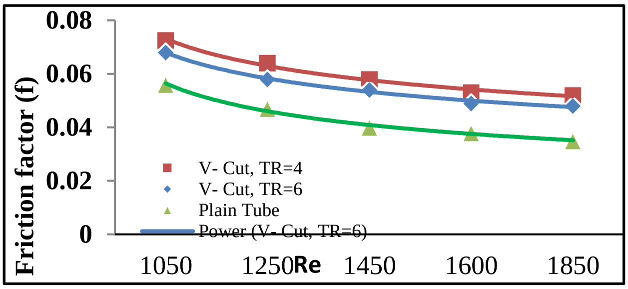



Figure. 11 Friction factor for distilled water with Reynolds number water and V-cut twist tape

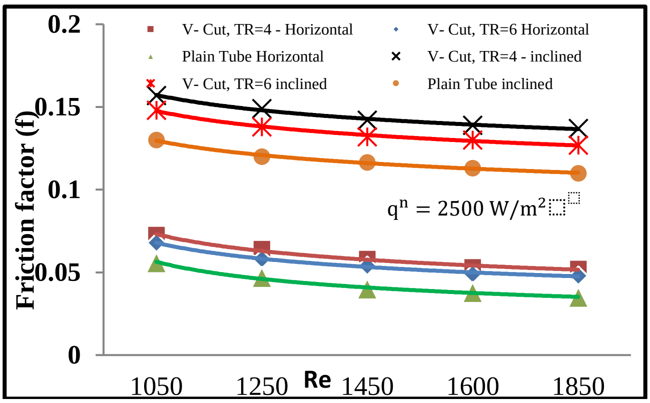



Figure. 12 (Re) and twisted ratio effects on (f) for V-cut twist tape (TR = 4, 6)

## 6.2 Influence Of Heat Flux In A Horizontal Tube

The Nusselt number of a simple tube varies with flux heat applied. It should be attended that the increase in the rate of heat transfer for plain tubes is roughly equivalent and proportional to variations in the heat flux quantity between (2500 and 12261 W/m2). The average temperature of the bulk fluid as well as the average wall temperature increasingly diverge as the heat flux rises. Additionally, the studying fluid's physical properties are immediately and continuously altered by the heat flow. As a result, in the case of a smooth tube, raising the heat flow while keeping the Reynolds number values constant has no discernible impact. Correlations for horizontal tubes Empirical relationships between both the factor of friction and the Nusselt number were computed depending on the experiment's findings. To accomplish this, several regression analysis is utilized.

6.3 Nusselt Number Correlations

Equations (5-3) and (5-4) show the expected correlations for alternate axis twisted tapes and V-cut tapes in terms of the average Nusselt number. These equations are shown that the fitted values for alternate axis twisted tapes and V-cut tapes are within± 3% and ±4% of the experimental data.

$$\text{Nusselt No}(\text{V} - \text{cut insert}) = 2.61 \times \text{y}^{-0.05} \times \text{Re}^{0.19} \times \text{Pr}^{0.83} \tag{17}$$

$$\text{Nusselt No}\ \ (\text{Alternate axis insert}) = 9.58\ \times \text{y}^{-0.011} \times \text{Re}^{0.43}\ \times \text{Pr}^{0.79} \tag{18}$$

The formulas for V-cut and alternative axis twist tapes, correspondingly, represent the fitted values of the friction factor. The largest variations for cassettes with a V-cut and an alternate axis added, respectively, are 6% and 7.2%, and the experimental results and the statistical evidence are in strong agreement.

$$\text{friction factor}\ (\text{V} - \text{cut insert}) = 42.4\ \times \text{y}^{-0.1} \times \text{Re}^{-0.95} \tag{19}$$

$$\text{friction factor}\ (\text{Alternate axis insert}) = 35.4\ \times \text{y}^{-0.18} \times \text{Re}^{-0.94} \tag{20}$$

Examination of Numerical Results are exhibited in a horizontal tube to demonstrate the characteristics of heat transfer and the flow of the single-phase finite volume technique model employed in the commercial CFD software programme, ANSYS-Workbench 15.0. Pre-processing, solution, and post-processing are the three main steps in the ANSYS Workbench's simulation analysis procedure. The entire basic procedure for ANSYS Workbench simulation evaluation, includes each step of the simulation analysis to address the appropriate functional demands. using V-cut and Alternate axis, Figures 13 and 14 illustrate the average Nusselt and Reynolds numbers for several types of twist tapes, respectively. The results demonstrate that, in the presence of Reynolds number and twisted ratio, the Nusselt number behaves in a manner consistent with the experimental result. The ratio of heat transfer via convection (α) to heat transfer by conduction alone (λ/L) is measured by the unstellt number. Relationships involving convective heat transport are typically stated in terms of Nusselt number as a function of Prandtl Number and Reynolds Number.

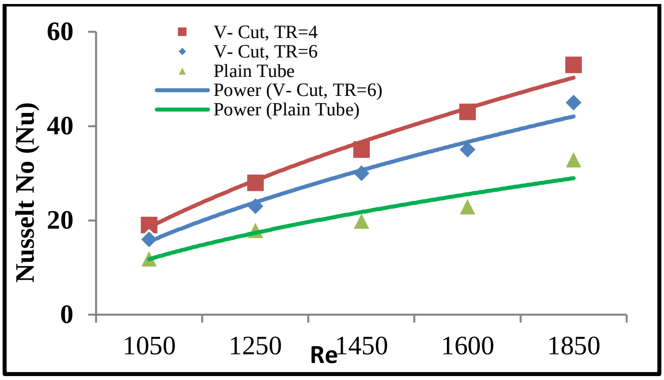



Figure. 13. Results of calculations using V-cut twist tape and comparing the average Nusselt numbers to the Reynold numbers for distilled water in a tube at $q^n$= 2500 W/m$^2$

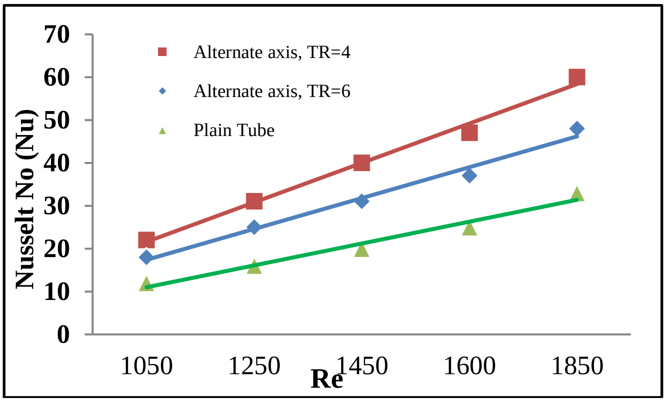



Figure. 14. Results of calculations using alternate axis twist tape and comparing the average Nusselt numbers to the Reynold numbers for distilled water in a tube at $q^n$= 2500 W/m$^2$

To study Velocity Vectors in an Inclined and Horizontal Tube, Figures 15 and 16 depict the velocity vector V-cut and alternative axis twisted tapes are placed along the horizontal tube at section (Z=50 cm) , respectively. There is a secondary flow that is created, as well as rotating movement along the tube, which will improve the tube's ability to transmit heat. Additionally, when the twist ratio decreases, this secondary flow will grow.

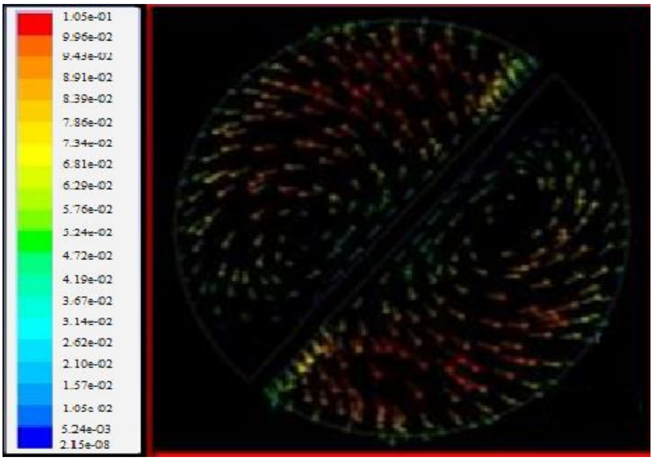



Figure. 15 V-cut twist tape location through the test section with (TR=4, Re=2001) velocity vector

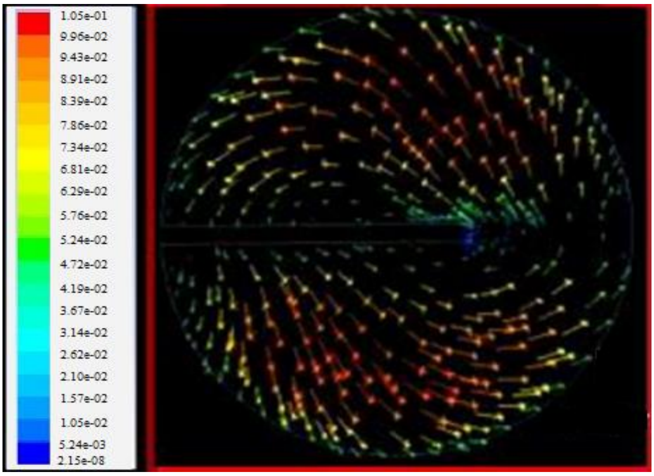
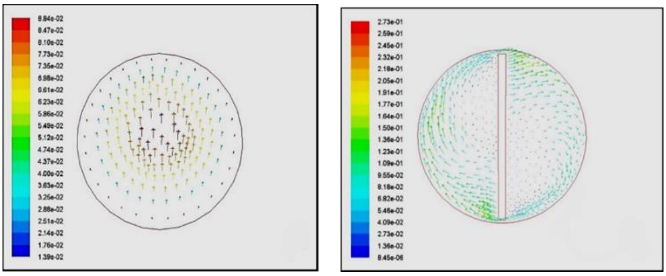



Figure. 16 Alternate axis twisting tape location through the test section at (TR=4, Re= 2001) velocity vector

The inner tube velocity vector for inclined tubes with plain tubes and tubes with end parts that feature V-cut tape inserts is illustrated in Figures 17 and 18. The secondary flow in the secondary flow field is obviously moving more swiftly with compare to the secondary flow in the plain tube. It has occurred as a result of the enhanced swirling motion.



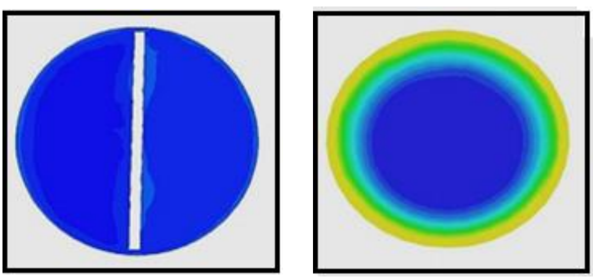
(a) (b)

Figure. 17 Velocity vector at location of inclined plain tube and tube fitted at ($q^{n}$=2500 $W/m^2$, Re=2001) for (a) Plain tube (b) V-cut twisted tape

Figure 19 for horizontal tubes illustrates the temperature contours for plain tube, V-cut tube, at several locations along the test section of (Z=50cm), alternative axis twisted tape, respectively. When switching from one type of twisted tape to another, or from a plain tube to one the temperature increases until it reaches the tube's centre with twisted tape inserts.

Figure. 19 Temperature contours in (K) for plain tubes, V-cut tubes, and alternate axis tape with (TR = 4) and (Re = 2002) at places along the test section with a (Z= 50 cm) are shown

With a V-cut insert and a PLAIN tube, Figure 20 depicts the temperature contours for an inclined tube at (Z=50cm). The gradients temperature along tube's portions is shown in following figures. It can be observed, the secondary flow field's rotating motion of the particles causes the temperature field created by the tube with twisted tape inserts to be more uniform than the temperature field created by the plain tube.



(a) (b)

Figure. 20 Temperature contours at the test section center at ($q^{n}$=2500 $W/m^2$, Re=2001) for (a) V-cut twisted tape (b) Inclined plain tube

## 7. Conclusions

Experimental and numerical research has been done on the thermal-hydraulic properties of two different types of twisted tape (V-cut twisted tape, Alternate axis) installed in horizontal and inclined tube heat exchangers with (y = 4 and 6). The factor of friction and Nusselt number factor, in addition to the experimental data for the plain tube, have been validated using the anticipated empirical relationships. According to this study's findings, the lower twist ratio (y = 4) had the maximum heat transfer enhancement value at roughly 12.6%; the highest variance was 12% and 6.6% for the lower twist ratio. Due to the primary swirl flow's larger disturbance, the experimental data for Nusselt and the factor of friction have been utilized to create an empirical correlation with maximum error ranges of 4% and 6%, respectively. The alternate axis insert improves heat transfer performance more than the V-cut insert; the inclined tube increased the friction factor in all cases when the Nusselt number was lower (by about 9%) than the horizontal tube. Twisted tape performed more thermally effectively than the smooth tube in the current study. This is due to both the main swirl flow and the efficient secondary flow.

We suggest the following to comprehend how fluid behaves in situations different than those in the tests above:

(1) Inclination Angles

- For the system to operate at its best, test the channel's inclination.
- For a variety of inclination angles, adjust the tilt angle for the channel.

(2) Used Fluids

- Examining the effects of Nano-fluids and tabulators on other base fluids, such as glycol and oil.
- Instead of using distilled water, examine the magnetic Nano-fluid’s flow and heat transfer properties.

(3) Twisted Tapes

- Combining twisted tape with porous medium.
- Change the twisted tape's composition to something else, like (aluminum and stainless steel).

(4) Other Conditions

- Conduct the test under conditions of steady wall temperature
- Examining the effects of a two-phase method on flow and heat transmission

## References

1. Yadav, A. S., (2009), “Effect of Half Length Twisted-Tape Turbulators on Heat Transfer and Pressure Drop Characteristics inside a Double Pipe U Bend Heat Exchanger.” Jordan

Journal of Mechanical and Industrial Engineering, vol. 3, no. 1, pp. 17-22.

2. Sarada, S. Naga., A. V. Sita Rama Raju., K. Kalyani Radha and L. Shyam Sunder., (2010), "Enhancement of heat transfer using varying width twisted tape inserts." International Journal of Engineering, Science and Technology, vol. 2, no. 6, 107-118.
3. Salam, Bodius., Sumana Biswas., Shuvra Saha and Muhammad Mostafa K. Bhuiya., (2013), "Heat Transfer Enhancement in a Tube Using Twisted Tape Insert." Procedia Engineering, vol. 56, pp. 96-103.
4. Salam, Bodius., Sumana Biswas., Shuvra Saha and Muhammad Mostafa K. Bhuiya., (2012), "Heat Transfer Analysis of Helical Strip Insert with Regularly Spaced Cut Sections Placed Inside a Circular Pipe." International Journal of Modern Engineering Research, vol. 2, no. 5, pp. 3711-3716.
5. Salman, Sami D., Abdul Amir H. Kadhum., Mohd S. Takriff and Abu Bakar Mohamad., (2013), "CFD Analysis of Heat Transfer and Friction Factor Characteristics in a Circular Tube fitted with Parabolic-Cut Twisted Tape Inserts." International Journal of Engineering, Science and Technology vol. 7, no. 7, pp. 69-76.
6. Selvam, Swaminathan, Pr, Thiyagarajan and Suresh Sivan., (2014), "Experimental Studies on Effect of Bonding the Twisted Tape with Pins to The Inner Surface of The Circular Tube." Thermal Science vol. 18, no. 4, pp. 1273-1283.
7. Osama, M. J., (2014), "Parametric Investigation of Heat Transfer Enhancement in Helical Coil Tube by Using Vortex Generators (Coil Wire inserts) and Nanofluids, M.Sc. thesis Al–Mustansiriya University", Mechanical Engineering Department, Baghdad, Iraq.
8. Suresh, S., K. P. Venkitaraj., P.r. Selvakuma and M. Chandrasekar., (2012), "A Comparison of Thermal Characteristics of Al2O3/Water and Cuo/Water Nanofluids in Transition Flow Through a Straight Circular Duct Fitted with Helical Screw Tape Inserts." Experimental Thermal and Fluid Science vol. 39, pp. 37-44.
9. Maddah, Heydar., Reza Aghayari., Morshed Farokhi., Shabnam Jahanizadeh and Khatere Ashtary., (2014), "Effect of TwistedTape Turbulators and Nanofluid on Heat Transfer in a Double Pipe Heat Exchanger." Journal of Engineering.
10. Rahimia , Masoud., Sayed Reza Shabaniana and Ammar Abdulaziz Alsairafi., (2009), "Experimental and CFD Studies on Heat Transfer and Friction Factor Characteristics of a Tube Equipped with Modified Twisted Tape Inserts." Chemical Engineering and Processing vol. 48, pp. 762-770.
11. Rahimia, Masoud., T. K. Radhakrishnan and K. N. Sheeba., (2009), "Experimental Studies on Heat Transfer and Friction Factor Characteristics of Forced Circulation Solar Water Heater System Fitted with Helical Twisted Tapes." Solar Energy vol. 83, no.11, pp. 1943-1952.
12. Javier, Munoz and Alberto Abanades., (2011), "Analysis of Internal Helically Finned Tubes for Parabolic Trough Design By CFD Tools." Applied Energy vol. 88, no.11, pp. 4139-4149.
13. Kim, Yong and Taebeom Seo., (2007), "Experimental Studies on Effect of Bonding the Twisted Tape with Pins to The Inner Surface of The Circular Tube." Renewable Energy vol. 32, no. 5, pp. 772-795.
14. Choudhari, Shashank S and Taji S. G., (2007), "Experimental Studies on Effect of Coil Wire Insert on Heat Transfer Enhancement and Friction Factor of Double Pipe Heat Exchanger." International Journal of Computational Engineering Research vol. 3, no. 5, pp. 772-795.
15. Versteeg, H. K., and Malalasekera., (1995), "An Introduction to Computational Fluid Dynamics-The Finite Volume Method", Supplement to Advances in Heat Transfer, Academic Press. Longman group Ltd.
16. Shah, R. K. and A. L. London., (1978), "Laminar Flow Forced Convection in Ducts", Supplement to Advances in Heat Transfer, Academic Press.
17. Yaningsih, Indri., Tri Istanto and Agung Tri Wijayanta., (2016), "Experimental Study of Heat Transfer Enhancement in a Concentric Double Pipe Heat Exchanger with Different Axial

Pitch Ratio of Perforated Twisted Tape Inserts." AIP Conference Proceedings vol. 1717.

18. Suresh, S., K. P. Venkitaraj, P.r. Selvakuma and M. Chandrasekar., (2016), "Applications of Nanotechnology to Improve The Performance of Solar Collectors—Recent Advances and Overview." Renewable and Sustainable Energy Reviews vol. 62, pp. 767-792.
19. Cancan, Zhang., Wang Dingbiao., Kun Ren and Yong Han., (2016), "A Comparative Review of Self-Rotating and Stationary Twisted Tape Inserts in Heat Exchanger" Renewable and Sustainable Energy Reviews vol. 53, pp. 433-449.
20. Nakhchi, M. E and J. A. Esfahani., (2019), "Numerical Investigation of Rectangular-cut Twisted Tape Insert on Performance Improvement of Heat Exchangers." International Journal of Thermal Sciences vol. 138, no. 5, pp. 75-83.