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Application of Double Ribbed Twisted Tapes in Heat Transfer Enhancement of Tubular Heat Exchanger

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Abstract- **Nowadays, heat exchangers with twisted-tape inserts have widely been applied for enhancing the convective heat transfer in various industries such as thermal power plants, chemical processing plants, air conditioning equipment, refrigerators, petrochemical, biomedical and food processing plants. In general, twisted tape insert introduces swirl into the bulk flow which consequently disrupts a thermal boundary layer on the tube surface. Recently, the use of twisted tape with cuts and holes becomes popular due to their thermal performance improvement in comparison with other types of twisted tape and several studies have been carried out on these types of modified twisted tape. This work aims to present a numerical model for heat transfer intensification in a heat exchanger tube equipped with novel V-cut twisted tape. The effects of different cut ratios (0.6<b/c<1.25) on the turbulent flow characteristics and thermal performance of the system will be investigated over the Reynolds number range from 4000 to 12000. All the simulation will be performed for fully developed turbulent flux in the Reynolds number range with uniform heat flux of 5000 W/m2.The numerical results of heat transfer (Nusselt number, Nu), pressure drop (friction factor, f) and enhancement Performance Factor in a tube with twisted tapes (V-Cut) were reported in the study.**

Keywords- **Plane tube, plane tube with twisted tape, V- cut twisted tape, Nusselt number, Reynolds number, Performance factor, pressure drop, Friction factor.**

I. INTRODUCTION

Nowadays, heat exchangers with twisted-tape inserts have widely been applied for enhancing the convective heat transfer in various industries such as thermal power plants, chemical processing plants, air conditioning equipment, refrigerators, petrochemical, biomedical and food processing plants.

In general, twisted tape insert introduces swirl into the bulk flow which consequently disrupts a thermal boundary layer on the tube surface.In recent days the twisted-tape inserts have been widely applied for enhancing the convective heat transfer in various industries, due to their effectiveness, low cost and easy set up.

Because it also creates the swirl flow which improves the fluid mixing and mix the bulk flow well. It is relatively low cost and low pressure drop with less fouling problems.

In general, using different ways to increase the surface area for heat transfer has contributed significantly in increasing the thermal performance of heat exchangers when compared with its counterparts without the surface optimization, but there is a downside in which the increase in pressure drop for the surface optimization and thus for maintaining the flow requires the use of recycling fluid pumps in a larger capacity than normal situation.

II. LITERATURE REVIEW

Azher et al. (2018) studied forced convection heat transfer through a horizontal pipe built-in with/withouttwisted tape-inserts is numerically studied under a uniform heat flux condition. Water is used as aworking fluid.

Sivakumar et al. (2018) investigate the friction factor characteristics and heat transfer characteristics of a concentrictube with triangular cut twisted tape (TCTT) insert with twist ratio Y is 5.4 and depth of triangular cut was 1.2 cm were studiedfor laminar flow.

Mahipal et al. (2018) deals with the use of swirlflow devices with different combinations as passive heat transfer augmentation technique. In this article, the twodifferent swirl flow devices used are namely twisted tape (TT) and wire coil (WC) turbulator. The present work deals withthe counter flow type condition of heat exchanger. Effect ofdifferent length combination of these two different turbulatortwisted tape and wire coil on the heat transfer, friction factorand pressure drop for Reynolds number ranges from 2000-10000, has studied in double pipe heat exchanger (singlepass).

Agrawal et al. (2018) Heat transfer enhancement technique refers to different methods used to increase rate of heat transfer withoutaffecting much overall

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performance of the system. These techniques are used in heat exchangers, some of the application of heat exchangers are in process industries, thermal power plant, air conditioning equipment, refrigerator, radar forspace vehicles, automobiles etc. In the past decades several studies on passive techniques of heat transfer enhancementhave been reported.

Bhattacharyya et al. (2017) Numerical investigation of heat transfer characteristics in a tube fitted with inserted twistedtape swirl generator is performed. The twisted tapes are separately inserted from the tubewall. The configuration parameters include the, entrance angle (α) and pitch (H).Investigations have been done in the range of $\alpha = 180^o$, 160^o and 140^o with Reynolds number varying between 100 to 20,000.

Maradiya et al. (2017) Heat transfer devices have been used for conversion and recovery of heat in many industrial and domestic applications. Over five decades, there has been concerted effort to develop design of heat exchanger thatcan result in reduction in energy requirement as well as material and other cost saving. Heat transfer enhancement techniques generally reduce the thermal resistance either by increasing the effective heattransfer surface area or by generating turbulence.

Mahdi et al. (2016) reported the use of variant twisted tapes fitted in a double pipe heat exchanger to improve the fluid mixing that leads to higher heat transfer rate with respect to that of the plain-twisted tape. Heat transfer, flow friction and thermal enhancement factor characteristics in a double pipe heat exchanger fitted with plain and variant twisted tapes using water as working fluid are investigated experimentally.

Jedsadaratanachai et al. (2014) presents a numerical analysis of laminar fully developed periodic flow and heat transfer in aconstant temperature-surfaced circular tube with single twisted tape inserted. The twisted tape isintroduced and inserted in the middle of the tested tube. The effects of twisted ratios (y/W = 1, 2, 3, 4, 5and 6) are presented for Reynolds number (Re) values ranging from Re = 100 to 2000. The SIMPLEalgorithm and periodic condition are used in the current study.

III. RESEARCH METHODOLOGY

Recently, the use of TT with cuts and holes becomes popular due to their thermal performanceimprovement in comparison with other types of TT and several studies have been carried out onthese types of modified TT.

The main physical reasons for improved performance of these typesof TT can be presented as: (1) Strong swirl flow induced by TT (2) The secondary vortex flow generated near the cuts and holes which improves the turbulent intensity of the fluid flow and (3) Better fluid mixing between the tube walls and the core region. The above literature review shows that the heat transfer enhancement by using modified TT.

The schematic drawing of the present study is shown in Fig. 3.1a. Five types of twisted tapes (p-TT and V-cut) inserts inside a circularpipe with twisted ratios of 4.0 are performed as shown in Fig. 3.1. The length of the test pipe is 80 cm with an innerand outer diameter of 2.8 cm and 3.2 cm, respectively.

The twisted tape material is aluminum of full length, the thickness of 0.3 cm, the width of 2.5 cm, the width ratio (WR) equal to 0.34 and the depth ratio (DP) equal to 0.43. The tape width issmaller to that of the inner diameter of the pipe.

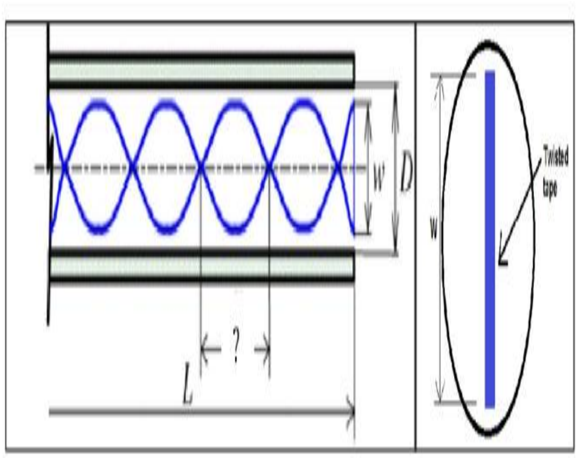
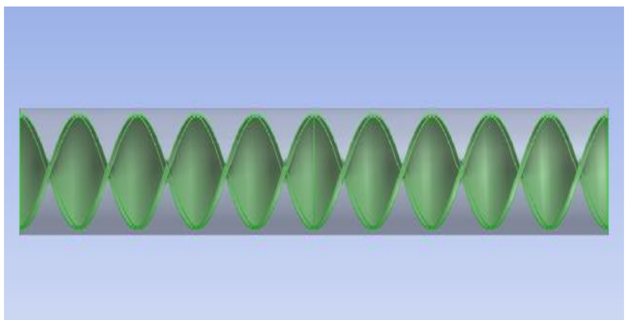
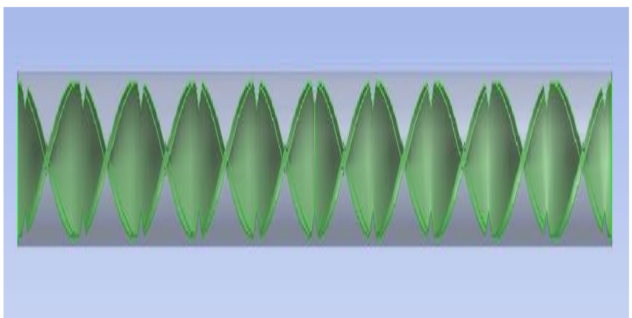


Fig 1.Schematic drawing of the present study.



(b) PTT.



(c) VTT with b/c = 0.6.

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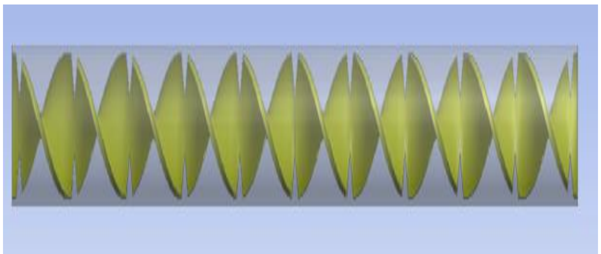
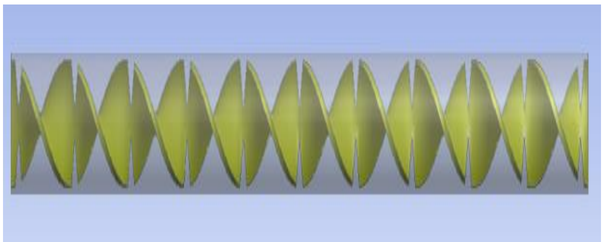
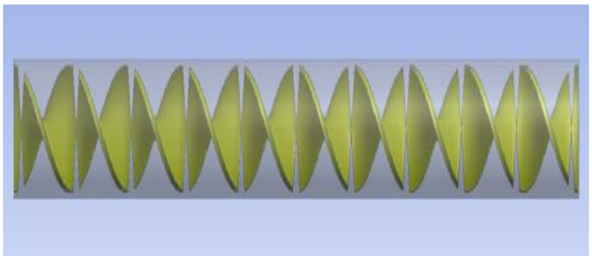


(d) VTT with b/c = 0.8.



(e) VTT with b/c = 1.



(f) VTT with b/c = 1.25

Fig 2. PTT and different VTT cut inserts with different cut ratio.

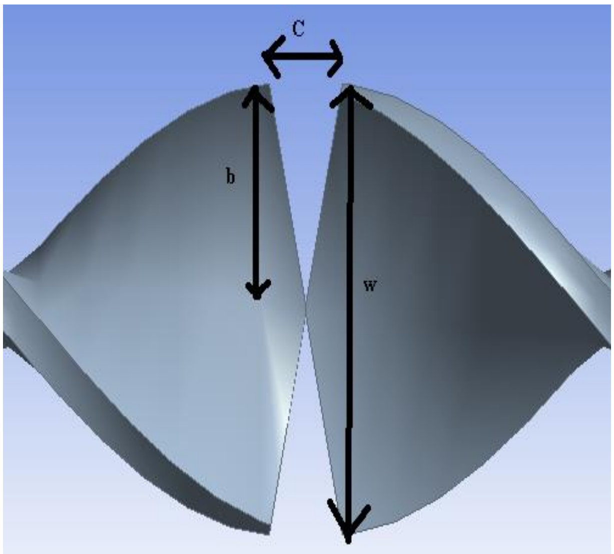


Fig 3. Geometry parameters of the double V-cut TT.

Table 1. Parameters of model.

V-cut depth (mm)	b	3, 4, 5, 6
V-cut width (mm)	c	5
Cut ratio	b/c	0.6, 0.8, 1, 1.25

In this work, V-cut depth has been changed from 3 to 6 mm keeping V-cut width 5 mm constant. Thereby, cut ratio is evaluated and varied from 0.6 to 1.25 to know the effect of cut ratio on thermal performance of double pipe heat exchanger.

IV. CFD MODELLING

The steady-state fluid flow characteristic in the three-dimensional computational domain can be described using the following governing incompressible fluid flow equations.

Continuity equation:

$$\frac{\partial u_i}{\partial x_i} = 0$$

Momentum balance without gravity force:

$$\rho_{u_i}\frac{\partial u_i}{\partial x_i} = -\frac{\partial P}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j}$$

Energy equation:

$$\rho C_p \frac{\partial (u_i T)}{\partial x_i} = \frac{\partial}{\partial x}\left(\lambda_{eff}\frac{\partial T}{\partial x_i}\right)$$

In conservative form, the partial differential equations for the RNG k−ε model are

Turbulent kinetic equation:

$$\rho u_j \frac{\partial k}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\mu_{eff}\alpha_k \frac{\partial k}{\partial x_j}\right] + \tau_{ij}\frac{\partial u_i}{\partial x_j} - \rho\varepsilon + G_K + G_b$$

Turbulent kinetic dissipation equation

$$\rho u_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\mu_{eff}\alpha_\varepsilon \frac{\partial \epsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\partial \varepsilon}{\partial x_j} + C_{1\varepsilon}\frac{\varepsilon}{K}(G_K + C_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{K}$$

The above Reynolds Averaged Navier-Stokes (RANS) turbulence models offer the most economic approach for computing complex turbulent industrial flows.

Generally, the Navier-Stokes equations describe the motion of the turbulentflow. However, it is too costly and time-consuming to solve these equations for complexflow problems [26].

Alternatively, two methods have been suggested in the past: (i) Large Eddy Simulation (LES) where the large energy containing eddies are simulateddirectly while the small eddies are accounted for by averaging. The separation of largeand small eddies requires following, (ii) Reynolds averaging (RANS) where all eddiesare

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accounted for by Reynolds stresses obtained by averaging the Navier-Stokes equations (time averaging for statistically steady flows, ensemble averaging for unsteady flows).

1. Boundary Conditions:
The inlet andoutlet conditions used in the calculation are periodic boundary conditions. The up stream temperature is 301.15 K, and the temperature of the tube wall is 343.15 K.

No slip conditions are imposed on the tube wall and the surfaces of the twisted tape. The convergence criterion is that all the norms of the residuals for the continuity, momentum, and energy equations should be less than 10^{-6}.

2. Meshing of Domain:
In this study, a general curve linear coordinate grid generation system based on body–fitted coordinates was used to discrete the computational domain into a finite number of control volumes. The geometries of the problems are carefully constructed.

All cases were modelled and meshed with the ANSYS 16. FLUENT also comes with the CFD program that allows the user to exercise the complete flexibility to accommodate the compatible complex geometries.

The refinement and generation of the grid system is important to predict the heat transfer in complex geometries. In other words, density and distribution of the grid lines play a pivotal role to generate accuracy. Due to the strong interaction of mean flow and turbulence, the numerical results for turbulent flows tend to be more dependent on grid optimisation than those for laminar flows [11].

3. Data Processing:
FLUENT evaluates the Nusselt number as follows:
The outlet air temperature $T_{out}$was calculated as a mass average temperature atthe outlet position of the calculation domain.

$$T_{out} = \frac{\int T\rho\vec{u}.d\vec{A}}{\int \rho\vec{u}.d\vec{A}} = \frac{\sum_{i=1}^{n} T_i \rho_i \vec{u}_i .\vec{A}_i}{\sum_{i=1}^{n} \rho_i \vec{u}_i \vec{A}_i}$$

The dimensionless number for air-side heat transfer in the finned-tube bank wasdefined and calculated depending on the Reynolds number and geometric parameters.

For many cases the Nusselt number and Stanton number are used toexpress the heat transfer coefficient and the characteristic length is not the same.

In here the Nu number was used as

$$Nu = \frac{hd}{k_a}$$

The static pressure at the inlet and outlet of the computational domain wereevaluated as

$$p_{in,out} = \frac{\int p d\bar{A}}{\int d\bar{A}} = \frac{\sum_{i=1}^{n} p_i \bar{A}_i}{\sum_{i=1}^{n} \bar{A}_i}$$

$$\mathbf{Q = m\ Cp\ (T_{out} - T_{in})}$$

Where,
m = mass flow rate
Cp = Specific heat
Tout = Temperature at outlet
Tin = Temperature at intlet

Heat transfer coefficient is calculated by

$$\mathbf{h} = \frac{\mathbf{Q}}{\mathbf{T_{W-T_B}}}$$

Where,
Tw = Wall temperature
Tb = mean temperature = (Tout + Tin)/2

Friction factor is calculated by

$$\mathbf{f} = \frac{\Delta \mathbf{P}}{(\rho \mathbf{u}^2/2)(\mathbf{L}/\mathbf{D})}$$

Where
f = friction factor
ΔP = Pressure drop
L = Length of pipe (m)
D = Internal dia. (m)
ρ = Density of water (Kg/$m^{3)}$
u = Velocity of water (m/s)

Performance factor η

$$\eta = \frac{\mathbf{N_{ptt}/\ Npt}}{\left(\frac{\mathbf{f_{ptt}}}{\mathbf{f_{pt}}}\right)^{0.33}}$$

V. RESULTS AND DISCUSSION

The numerical results of heat transfer (Nusselt number, Nu), pressure drop (friction factor, f) and enhancement performancefactor in a tube with twisted tapes (P-TT) and (V-Cut) are reported in the present section. The effects of cut-out ratio with (V-Cut) twisted of the tapes in a turbulent region of Reynolds number has been analysed.

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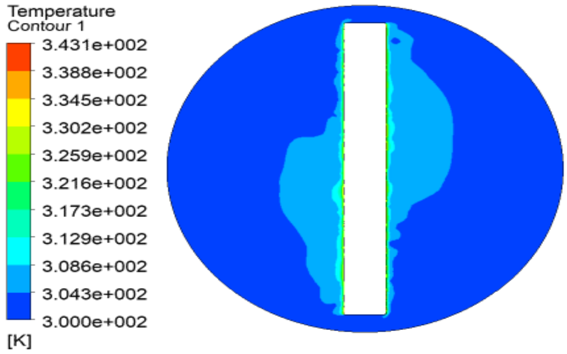
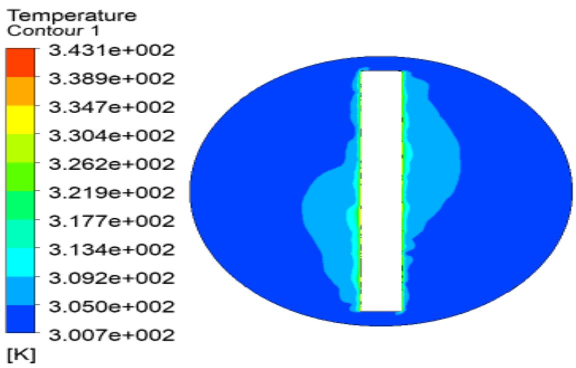
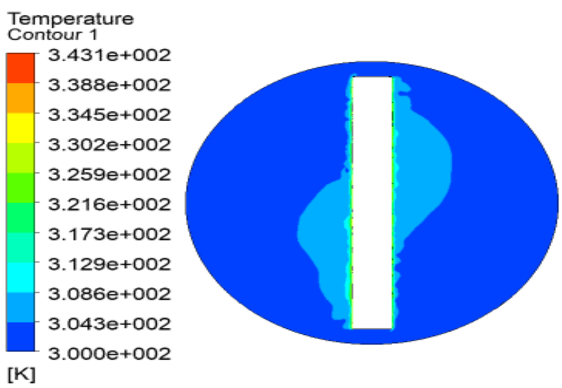


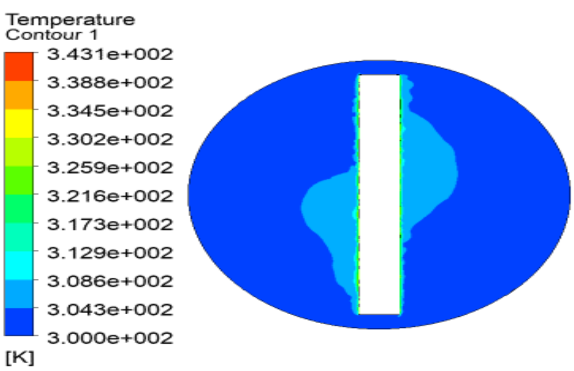
(a) Re = 4000



(b) Re = 6000



(c) Re = 8000



(d) Re = 10000

Fig 4. Temperature contours for P-TT twisted tape at different Reynolds numbers.

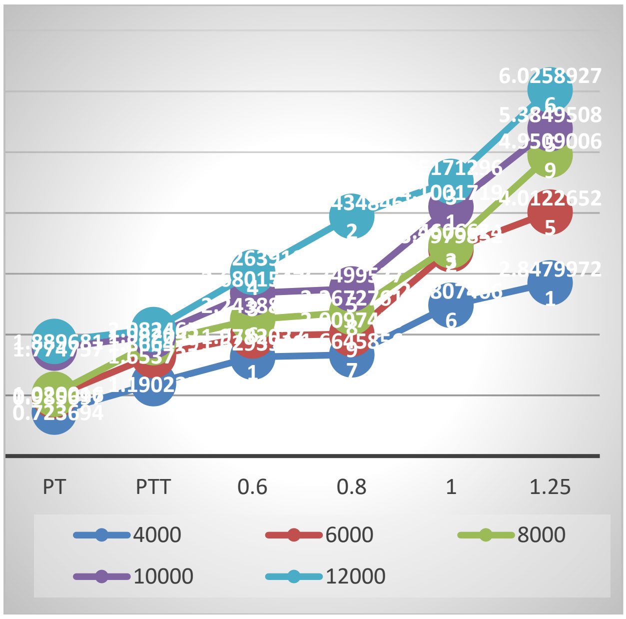


Fig 5. Variations of Nusselt number against Reynolds numbers for different double V-cut ratios.

Figure 5 shows the Variations of Nusselt number against Reynolds numbers for different double V-cut ratios. In this graph x axis shows the Reynolds number and y axis shows the Nusselt number. It can be seen, the Nusselt number increase when Reynolds number increase in plain tube and tube with PTT insert and cut ratio is increase when Reynolds number increase.

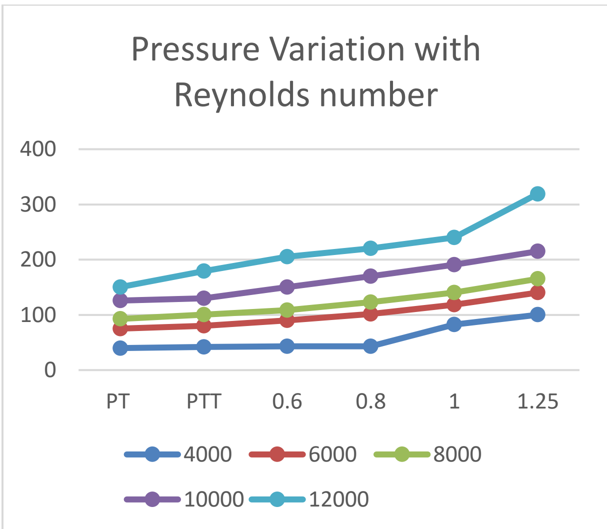


Fig 6. Variations of pressure drop against Reynolds numbers for different double V-cut ratios.

Figure 6shows the Variations of pressure drop against Reynolds numbers for different double V-cut ratios. In this graph x axis shows the Reynolds number and y axis shows the Pressure drop. It can be seen, the Pressure drop increase when Reynolds number increase in plain tube and tube with PTT insert and cut ratio is increase when Reynolds number increase.

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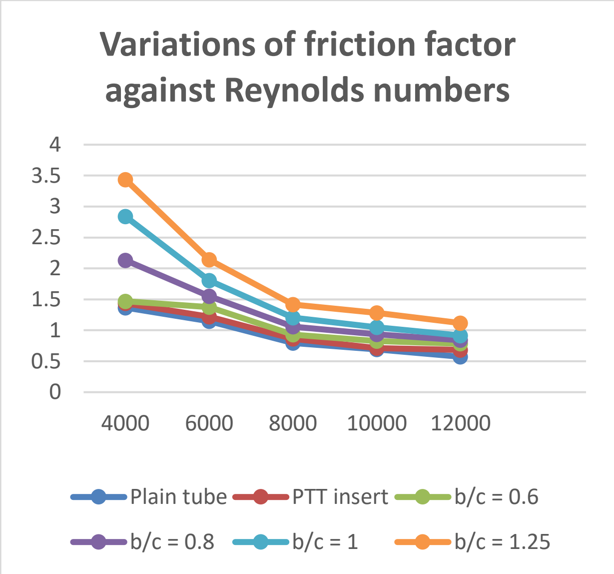

Fig 7. Variations of friction factor against Reynolds numbers for different double V-cut ratios.

Figure 7 shows the Friction factor vs Reynolds number for different double V-cut ratios. Friction factor (μ) is defined as the ratio between the force required to move a section of pipe and the vertical contact force applied by the pipe on the seabed. In this graph x axis shows the Reynolds number and y axis shows the friction factor. It can be seen in graph the pressure drop is decrease when the Reynolds number is increase in plain tube and tube with PTT insert.

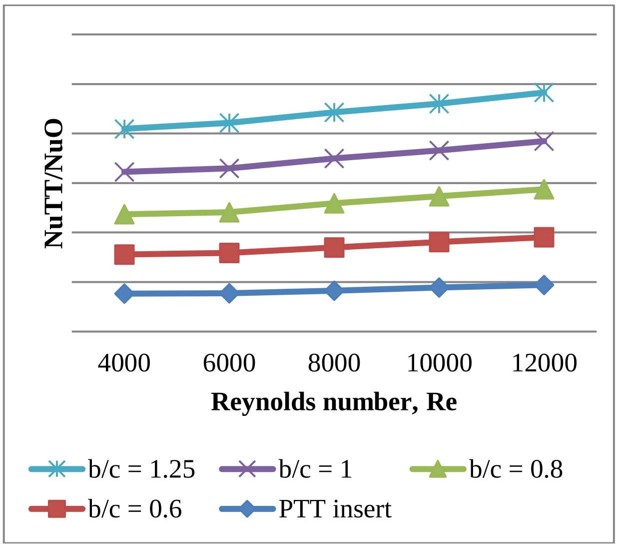

Fig. 8: Variations of overall enhancement ratio against Reynolds numbers for different double V-cut ratios.

Figure 8 Variations of overall enhancement ratio against Reynolds numbers for different double V-cut ratios. There are several different advantages and limitations for all heat transfer improvement mechanisms. They differ in geometrical arrangement and structure complexity while operating under various thermal and flow conditions. The enhanced heat transfer obtained by forced convection is always accompanied by an increase in the pressure drop. Therefore, in order to determine the net final gain and to promote a higher heat transfer rate (as represented by insert twisted tape) and consequently increased the heat duty of the heat exchanger.

This Fig. shows Variations of overall enhancement ratio against Reynolds numbers for different double V-cut ratios. Generally, the overall enhancement ratio enhances by increasing the Reynolds number increasing.

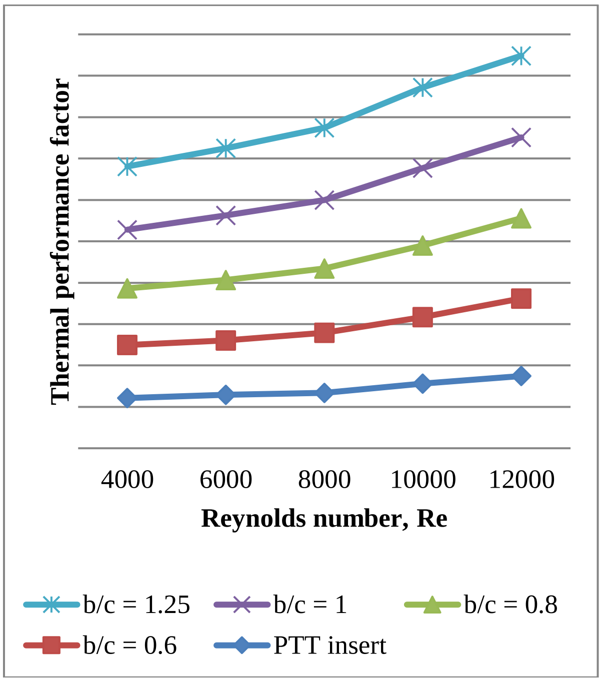

Fig 9. Variations of thermal performance factor against Reynolds numbers for different double V-cut ratios.

Figure 9 Variations of thermal performance factor against Reynolds numbers for different double V-cut ratios. In this graph x axis show the Reynolds number and y axis shows the thermal performance. It can be shown that, the thermal performance factor increase by increasing Reynolds number. In addition, the maximum thermal performance factor for PTT insert and VTT insert.

VI. CONCLUSION

The characteristics of heat transfer and friction factor for different twisted tapes (V-cut) and (P-TT) inserted inside a horizontalpipe, with twisted ratios (TR=4.0) have been studied numerically.

Accordingly, the following conclusions are drawn:
The use of twisted tape increases the heat transfer enhancement. The (V-cut) twisted tape presents a better heat transfer enhancement than that of the (P-TT) with all values of twisted ratio. The values of Nusselt number and friction factor values for the tube with square-cut twisted

tapes (STT) are noticeably higher than that of plain tube and also tube equipped with plain twisted tapes (PTT).

The rates of heat transfer are always higher for the pipe supplied with twisted tapes as compared with the plain pipe, and this occurs due to the strong vortex flow that produced by twisted tapes. Results show that the rate of heat transfer with the twisted ratio (TR=4.0) is higher.

The friction factor which obtained from the pipe with twisted tape inserts is significantly higher than that of the plain pipe. Moreover, the utility of lower twisted ratio leads to higher tangential contact among the surface of the pipe and swirling flow.

The maximum enhancement in the heat transfer under the model flow conditions is found when Nusselt number ratio is equal to 193.48 which occur in the (V-cut) twisted tape with the twisted ratio (TR=4.0) for Reynolds number of around 12000.

The maximum thermal performance factor is 1.974 for (V-cut) twisted tape with the twisted ratio (TR=4.0) at Reynolds number (12000). The thermal performance factor for STT is better than SCTT and PTT.

Over the range of Reynolds number considered, the thermal enhancement factors for all the cases are more than unity indicates that the effect of heat transfer enhancement due to the enhancing tool is more dominant than the effect of rising friction factor and vice-versa with the SCTT, STT and PTT.

REFERENCES

[1] Azher M. Abed, Hasan Sh. Majdi, Zainab Hussein, Doaa Fadhil, Ammar Abdulkadhim (2018), Numerical Analysis of Flow and Heat Transfer Enhancement In A Horizontal Pipe With P-TT And V-Cut Twisted Tape, Case Studies In Thermal Engineering,Vol 12, Pp 749–758.
[2] Pawan A. Sawarkar, Pramod R. Pachghare (2013), Experimental Analysis Of Augmentation In Heat Transfer Coefficient Using Twisted Tape With Semi-Circular Cut Insert, International Journal Of Science And Research, Volume 4 Issue 4, Pp 1174-1179.
[3] S. Liu, M. Sakr (2013), A Comprehensive Review On Passive Heat Transfer Enhancements In Pipe Exchangers, Renewable And Sustainable Energy Reviews, Vol 19, Pp 64–81.
[4] Mazen M. Abu-Khader (2012), Plate Heat Exchangers: Recent Advances, Renewable And Sustainable Energy Reviews, Vol 16, Pp 1883– 1891
[5] M.A. Akhavan-Behabadi, Ravi Kumar, A. Mohammadpour, M. Jamali-Asthiani (2009), Effect Of Twisted Tape Insert On Heat Transfer And Pressure Drop In Horizontal Evaporators For The Flow Of R-134a, International Journal Of Refrigeration Vol 32, Pp 922-930.
[6] Halit Bas, Veysel Ozceyhan (2012), Heat Transfer Enhancement In A Tube With Twisted Tape Inserts Placed Separately From The Tube Wall, Experimental Thermal And Fluid Science, Vol 41, Pp 51–58.
[7] Suvanjan Bhattacharyyaa, Himadri Chattopadhyay, Ayan Haldar (2017), Design Of Twisted Tape Turbulator At Different Entrance Angle For Heat Transfer Enhancement In A Solar Heater, Beni-Suef University Journal Of Basic And Applied Sciences,Pp 1-24.
[8] Smith Eiamsa-Ard, Chinaruk Thianpong, Petpices Eiamsa-Ard, Pongjet Promvonge (2009), Convective Heat Transfer In A Circular Tube With Short-Length Twisted Tape Insert, International Communications In Heat And Mass Transfer,Vol 36, Pp 365–371.
[9] Jian Guo, Aiwu Fan, Xiaoyu Zhang, Wei Liu (2011), A Numerical Study On Heat Transfer And Friction Factor Characteristics Of Laminar Flow In A Circular Tube Fitted With Center-Cleared Twisted Tape, International Journal Of Thermal Sciences, Vol 50, Pp 1263-1270.
[10] V. Hejazi, M.A. Akhavan-Behabadi, A. Afshari (2010), Experimental Investigation Of Twisted Tape Inserts Performance On Condensation Heat Transfer Enhancement And Pressure Drop, International Communications In Heat And Mass Transfer,Vol 37, Pp 1376–1387.
[11] Qasim S. Mahdi, Ali Abdulridha Hussein (2016), Enhancement Of Heat Transfer In Shell And Tube Heat Exchanger With Tabulator And Nanofluid, International Journal Of Mechanical Engineering And Technology, Volume 7, Issue 3, Pp.125–138.
[12] Mr. Mahipal, A. Parmar (2018), Numerical Analysis For Effect Of Different Length Combination Of Turbulators On Heat Transfer And Pressure Drop In Double Pipe Heat Exchnager, International Research Journal Of Engineering And Technology, Volume: 05 Issue: 12,Pp 1557-1566.
[13] Withada Jedsadaratanachai, Amnart Boonloi (2014), Effect Of Twisted Ratio On Flow Structure, Heat Transfer And Thermal Improvement In A Circular Tube With Single Twisted Tape, Journal Of Mathematics And Statistics, Vol 10 (1), Pp 80-91.
[14] Raj M. Manglik, Arthur E. Bergles (2002), Swirl Flow Heat Transfer And Pressure Drop With Twisted-Tape Inserts, Advances In Heat Transfer, Vol. 36,Pp 1-184
[15] Chirag Maradiya, Jeetendra Vadher, Ramesh Agarwal (2017), The Heat Transfer Enhancement Techniques And Their Thermal Performance Factor, Beni-Suef University Journal Of Basic And Applied Sciences,Vol 45, Pp 1-21.
[16] Taye Stephen Mogaji, Fabio Toshio Kanizawa, Enio Pedone Bandarra Filho, Gherhardt Ribatski (2013), Experimental Study Of The Effect Of Twisted-Tape Inserts On Flow Boiling Heat Transfer Enhancement

And Pressure Drop Penalty, International Journal Of Refrigeraion,Vol 36, Pp 504-515.

[17] P. Murugesan, K. Mayilsamy, S. Suresh, P.S.S. Srinivasan (2011), Heat Transfer And Pressure Drop Characteristics In A Circular Tube Fitted With And Without V-Cut Twisted Tape Insert, International Communications In Heat And Mass Transfer,Vol 38, Pp 329–334.

[18] S. Ray, A.W. Date (2003), Friction And Heat Transfer Characteristics Of Flow Through Square Duct With Twisted Tape Insert, International Journal Of Heat And Mass Transfer,Vol 46, Pp 889–902.

[19] Dharmesh A. Agrawal, Aswin M. Saigopal, Shritisha Yerpude, Junaid G. Khan (2018), Review On Heat Transfer Enhancement Technique Using Twisted Tape In Laminar And Turbulent Flow In A Circular Duct, International Journal Of Advance Engineering And Research Development, Volume 5, Issue 01,Pp 180- 187.

[20] P.K. Sarma, P.S. Kishoreb, V. Dharma Raoc, T. Subrahmanyam (2005), A Combined Approach To Predict Friction Coefficients And Convective Heat Transfer Characteristics In A Tube With Twisted Tape Inserts For A Wide Range Of Re And Pr, International Journal Of Thermal Sciences, Vol 44, Pp 393–398.

[21] Lieke Wang, Bengt Sundcn (2002), Performance Comparison of Some Tube Inserts Int. Comm. Heat Mass Transfer, Vol. 29, and No. I, Pp. 45-56.

[22] Yangjun Wang, Meiling Hou A, Xianhe Den, Li Li, Cheng Huang, Haiying Huang, Gangfeng Zhang, Changhong Chen, Weijun Huang (2011), Configuration Optimization Of Regularly Spaced Short-Length Twisted Tape In A Circular Tube To Enhance Turbulent Heat Transfer Using CFD Modeling, Applied Thermal Engineering,Vol 31, Pp 1141-1149.