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Applicability of double ribbed twisted tapes in heat transfer enhancement of tubular heat exchanger

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1. Introduction

The development of high-performance thermal systems has increased interest in heat transfer enhancement techniques. Heat transfer augmentation techniques refer to different method used to increase rate of heat transfer without affecting much the overall performance of the system. Heat exchangers are widely used in industry both for cooling and heating. Creation of turbulence with the help of twisted tape in the flow passage is one of the favorable passive heat transfer augmentation techniques due to their advantages of easy fabrication, operation as well as low maintenance. Heat transfer enhancement or augmentation techniques refer to the improvement of thermo hydraulic performance of heat exchangers. Among many techniques (both passive and active) investigated for augmentation of heat transfer rates inside circular tubes, a wide range of inserts have been utilized, particularly when turbulent flow is considered. A lot of methods are applied to increase thermal performance of heat transfer devices such as treated surfaces, rough surfaces, swirling flow devices, coiled tubes, and surface tension devices. Furthermore, as a heat exchanger becomes older, the resistance to heat transfer increases owing to fouling or scaling. These problems are more common for heat exchangers used in marine applications and in chemical industries. In some specific applications, such as heat exchangers dealing with fluids of low thermal conductivity (gases and oils) and desalination plants, there is a need to increase the heat transfer rate. The heat transfer rate can be improved by introducing a disturbance in the fluid flow (breaking the viscous and thermal boundary layers), but in the process pumping power may increase significantly and ultimately the pumping cost becomes high. Therefore, to achieve a desired heat transfer rate in an existing heat exchanger at an economic pumping power, several techniques have been proposed in recent years.

Inserts have been attracted lots of attention, though not regarding their effect on the characteristics of the employing fluid [8,14]. There are different types of inserts inside the tubes to increase the heat transfer to the working fluid, including fins, twisted tapes, porous discs, turbulators, perforated plates, and dimples, etc.

[15–19]. Twisted tapes have been widely employed inside the tubes to increase the heat transfer performance in the tube and have shown less effect on the pressure drop compared with other enhancement techniques such as fins [20–23]. In a tube integrated with twisted tape inserts, swirl flow is generated with higher axial fluid velocity along the tube, resulting in a higher heat transfer [24–27]. Furthermore, twisted tapes provide a mixing flow similar to a turbulator, which helps heat transfer enhancement [27–30]. Therefore, in this study, thermal performance of double pipe heat exchanger with or with twisting tape inserts with varying cut-out ratio has been done.

2. Past Studies

Heat transfer enhancement in different types of heat exchangers can lead to better heat exchanger performance and hence decrease the cost and size of the system [1–4]. Different techniques are used to enhance and improve the heat transfer such as fluted [4], different finned [5,6] and micro fined [7], louvered [8], wire brushes [9], coiled wires [10], and twisted-tape inserts. The inserts of twisted-tape in the pipes are widely and employed to enhance the heat transfer in heat exchangers. Using the CFD method can be informative in studying the flow behaviour of internal flows which are difficult to obtain through traditional experimental tests [11, 12]. Different studies have been carried out to achieve optimal design and the best heat transfer performance [13,14]. Eiamsa-ard et al. [15] published the results from a case study on the thermal performance assessment of a concentric tube heat exchanger with regularly-spaced twisted-tape inserts as swirl generators. The article also presents comparison against results obtained with full length twisted-tape inserts and the development of a mathematical model to simulate the swirling induced by the regularly-spaced twisted tape inserts in the concentric tube heat exchanger. They concluded that at similar conditions, full length twisted tapes gave higher heat transfer rate and thermal performance factor than the regularly-spaced inserts. In addition, they reported that the augmented heat transfer decreased with increasing the space ratio.

Tamna et al. [16] used V ribbed twisted-tapes to enhance the heat transfer within the heat exchanger. The air in the test flowed having the Reynolds number range (between 5300 and 24,000 using constant wall heat flux. Results noted that the pressure drop and heat transfer increased with higher Reynold numbers. They also report that the maximum pressure drop and heat transfer achieved from the twisted-tape type V-ribbed were at the highest relative rib heights.

Suri et al. [17] conducted an experimental study on the effect of square wings in multiple square perforated twisted-tapes on fluid flow and heat transfer of heat exchanger tube. Their experimental study encompassed analysis of the Nusselt number and friction factor of circular tube heat exchanger fitted with multiple square perforated with square wing twisted-tape inserts under a ranger of Reynolds number from 5000 to 27,000. They reported that the maximum enhancement in Nusselt number and frictions factor as being 6.96 and 8.34 times of that of the plain circular tube, respectively.

3. Research Method

Twisted tape (TT) inserts are one of the most important passive heat transfer enhancement methods used in circular channels. It is a swirl flow device. When they are inserted in circular channels, swirl flow is imparted to the fluid. The enhancement in heat transfer is due to the agitation of fluid, increase in effective flow length and mixing induced by cross stream secondary flows. Twisted tapes are identified by a parameter called "Twist ratio". In this work, an attempt is made to analyze the performance of a modified double pipe heat exchanger by varying cut-out ratio.

Research Model

Fig. 2 shows a heat exchanger tube integrated with a novel double V-cut TT with uniform wall temperature. The geometrical parameters include the tube length (L), tube diameter (D),

tape width (w), twist pitch (y), tape thickness (δ), and V-cut dimensions (b, c) are listed in Table 3.1. Five cases corresponding to the heat exchanger tube equipped with TT without cut, V-cuts with b/c = 0.6, 0.8, 1 and 1.25 are selected in the present numerical simulations. All five cases maintained the same twist ratio y/w=3 and tape thickness of 1mm. Conventional PTT is used as the baseline case. Water is selected as the working fluid. The turbulent flow with Reynolds number (Re) ranging from 4000 to 12,000 is considered. The water flow at the tube inlet is considered uniform velocity and uniform temperature profiles.

In this work, the V-cut depth was increased from 3 to 6 mm while the V-cut width remained the same at 5 mm. In this way, the influence of cut ratio on the thermal performance of a twin pipe heat exchanger is tested and varied from 0.6 to 1.25.

CFD Modelling

A thermo and fluid-dynamics study of the different geometries was conducted through CFD simulations. The geometry of the turbulator was generated using ICEM software, faithfully reproducing the geometric characteristics of the problem. The complexity of the geometry prevented use of a hexahedral grid because of some volume intersections near the turbulator wall. A grid of tetrahedral type was therefore chosen for both fluids, with thickening of the grid near the pipe wall (the height of the centroid of the first cell of the wall is equal to 0.075 mm). The smaller grid dimensions near the turbulator wall were performed using tetrahedral volumes.

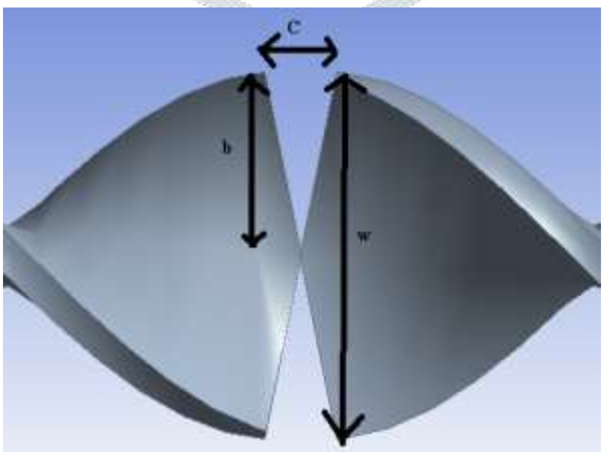


Fig. 2: Geometry parameters of the double V-cut TT

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

Boundary Conditions

Solid walls were modelled with the wall-type boundary condition. On the lateral surface of the pipe a constant heat flux is assigned, which determines a condition of the wall temperature variable along the axis of the pipe. In correspondence to the turbulator wall, however, an adiabatic condition was imposed because of its contact with the same temperature fluid on both faces. Boundary conditions are specified for each region of the computational domain. The internal regions that shared common faces did not require any boundary condition, it just assigned as a fluid. The flow is assumed incompressible, Newtonian, turbulent, and 3D-model. The velocity of water was used as the inlet boundary condition, while the pressure was specified as the outlet boundary condition. In the present study, velocity inlet and pressure outlet boundary conditions are selected for the computational domain. Pressure at the outlet of the pipe is atmospheric. Uniform flow rate of water with a temperature of 300 K is assumed to enter from the inlet of the tube and the tube wall temperature is assumed to be constant in axial and radial directions (Tw = 350).

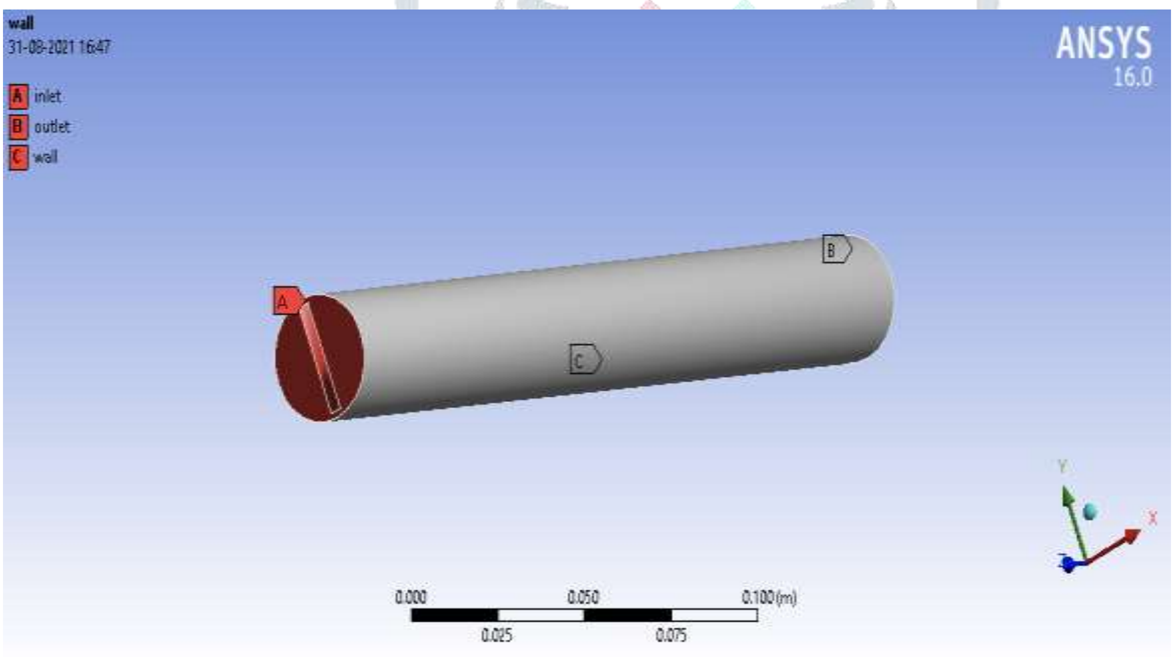
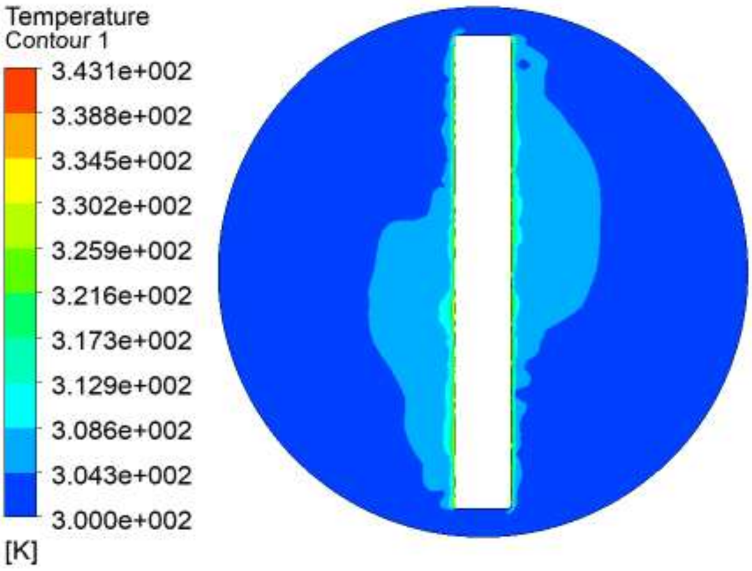


Fig. 3: Boundary condition used

4. Results and Discussion

Analysis With Twist Tape Insert



(a) Re = 4000

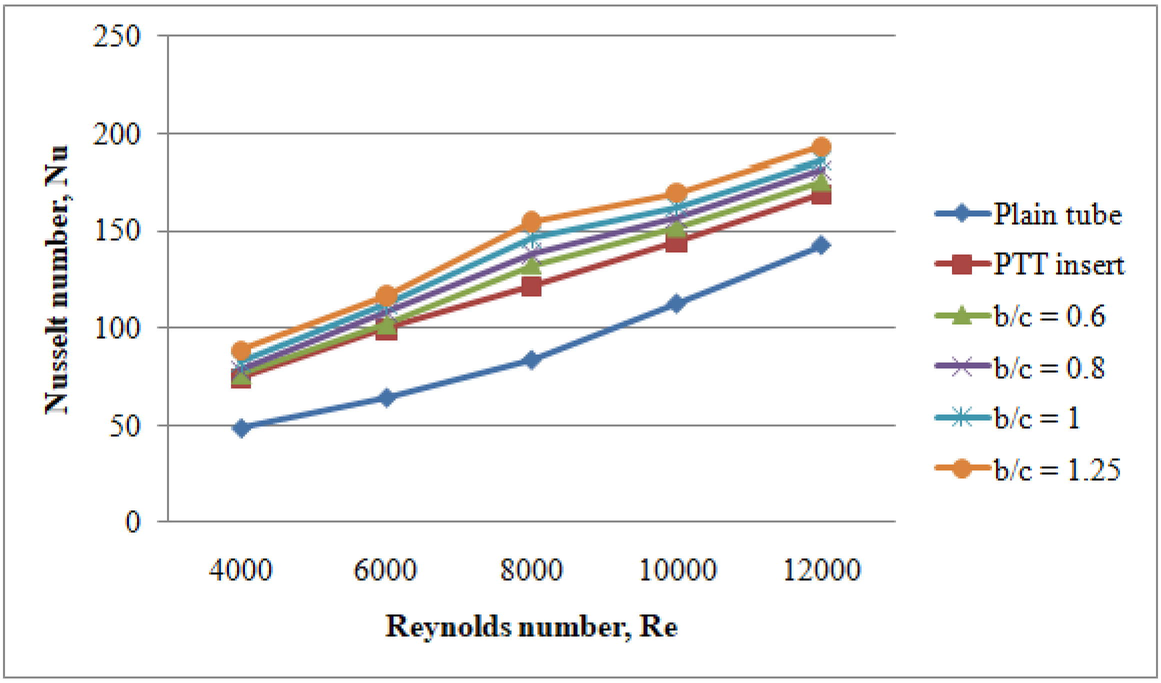


Fig. 4: Variations of Nusselt number against Reynolds numbers for different double V-cut ratios

Variation of Nusselt number with Reynolds number in the tube fitted with TT, the tube fitted with PTT and also the plain tube are presented in Fig. 5.10. It is observed that for all cases, the Nusselt number increases with the increasing Reynolds number. As expected, VTT heat transfer rates are higher than those from the plain tube fitted without twisted tape and other v-cut ratio. The lower twist ratio (PTT) heat transfer rate [4, 7] is higher than those from higher ones (*1.25*) due to increase in turbulent intensity and flow length across the range of Reynolds number.

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.

Fig. 5 illustrates the comparison between the two types of twisted tapes (P-TT), (V-cut) employed in the current work with v-cut ratios, respectively. It can be shown that, the thermal performance factor increases by increasing Reynolds number. In addition, the maximum thermal performance factor for (V-cut) twisted tape and (P-TT) plain twisted tape is 1.92 respectively, at twisted v-cut ratio of 1.25. For a given Reynolds number and heat flux, the (V-cut) twisted tape, with the v-cut ratio of 1.25 have a significant effect on the thermal performance factor.

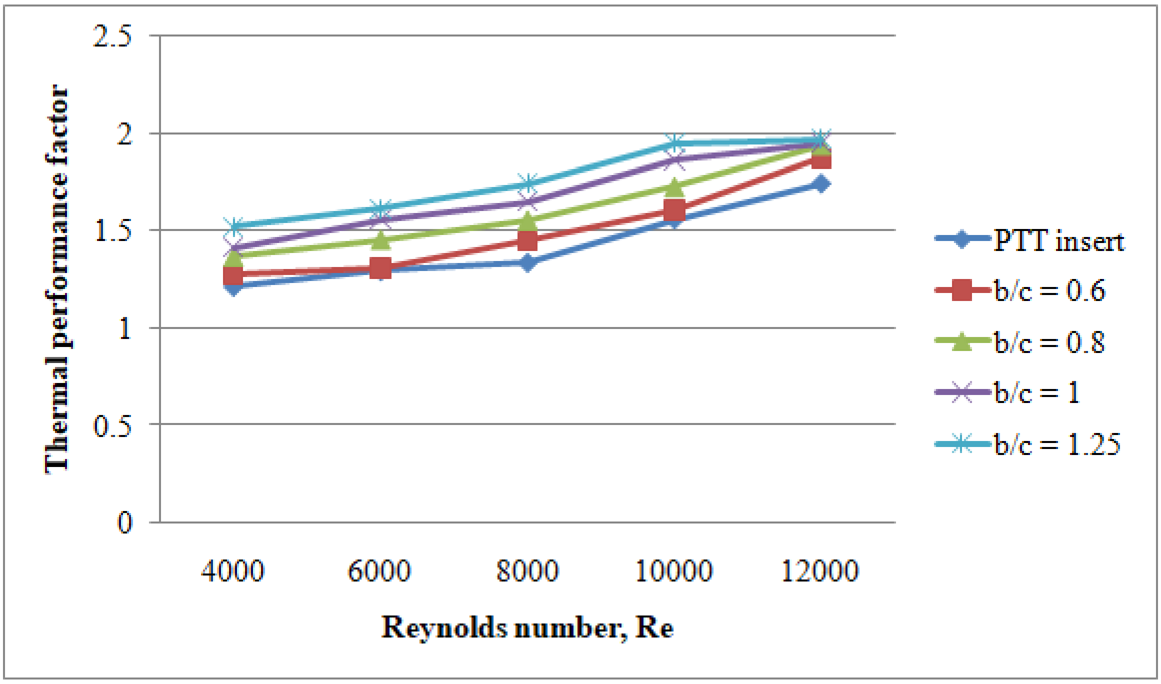


Fig. 5: Variations of thermal performance factor against Reynolds numbers for different double V-cut ratios

5. Conclusion

The characteristics of heat transfer and friction factor for different twisted tapes (V-cut) and (P-TT) inserted inside a horizontal pipe, with v-cut ratios have been studied numerically. Accordingly, the following conclusions are drawn:

1. 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.
2. 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 v-cut ratio (1.25) is higher than that of the twisted ratio (0.6).
3. The friction factor which obtained from the pipe with twisted tape inserts is significantly higher than that of the plain pipe.

4. Moreover, the utility of lower twisted ratio leads to higher tangential contact among the surface of the pipe and swirling flow.
5. The maximum enhancement in the heat transfer under the model flow conditions is found when Nusselt number ratio is equal to 1.962 which occur in the (V-cut) twisted tape with the v-cut ratio (1.25) for Reynolds number of around 12000.
6. The maximum thermal performance factor is 1.974 for (V-cut) twisted tape with the twisted ratio (1.25) at Reynolds number (12000).
7. The twisted tape inserts resulted in swirling of the flow and transverse mixing in the area around the inserts.
8. The pressure drop through the pipe-with-inserts was more than double the pressure drop through the same pipe without the inserts.
9. The profile of the dynamic pressure, temperature, velocity flow, and static temperature were non-uniform at the center of the pipe compared to the smooth pipe. Furthermore, the dynamic pressure became more non-uniform as the twisted-tape dimensions increased.
10. With regard to temperature, the twisted tape inserts induced a significant effect on the profile of static temperature especially near the twisted-tape boundaries and with the wider twisted-tape inserts, the effect on the static temperature in the core was more pronounced.

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