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An Experimental Study on The Performance of Double Pipe Heat Exchanger Using Twisted Tapes with Different Number of V-Cut

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ABSTRACT

In this experimental study, investigation has been done for the heat transfer and friction characteristics of a double pipe heat exchanger (DPHE) using twisted tape inserts with different number of V-cut at a constant depth. The study has been done to compare the effects of twisted tape inserts on heat transfer rate, Nusselt number, and friction factor when compared to a plain tube. Water was used as the testing fluid, and the Reynolds number range was between 5500 and 10000. Twisted tape inserts without V-cut, with single V-cut, with double V-cut and with triple V-cut were used to enhance heat transfer rate and also increasing the frictional resistance in the system.

The results of the study shows that the heat transfer characteristics of the DPHE were improved with the use of twisted tape inserts. Heat transfer rate enhanced by 26.66%, 57.14%, 89.28% and 139.26% compared to plain tube for Twisted tapes without V-cut, with single V-cut, with double V-cut and with triple v-cut respectively. However, it's important to note that along with the improved heat transfer, the frictional resistance in the system also increased. Friction factor enhanced by 9.97%, 39.88%, 59.83% and 79.77% with respect to plain tube for twisted tape without V-cut, with single V-cut, with double V-cut and with triple V-cut respectively. The experiments reveal that twisted tape is more beneficial at use at low Reynolds number. While comparing Performance evaluation criteria (PEC) with without V-cut twisted tape it is found that PEC enhanced by 18.10%, 33.0% and 56.19% for single V-cut, double V-cut and triple V-cut respectively.

Keywords: *Double Pipe Heat Exchanger, Twisted Tape, V-cut, Nusselt number, Friction Factor, Performance Evaluation Criteria*

Nomenclature:

Symbol	**Symbol name**	**Unit**
Q	Heat transfer rate	K
U	Overall heat transfer rate	W/ (m^2.K)
A	Heat transfer surface area	m^2
Dt	LMTD	K
Q_{act}	Actual heat transfer rate	W
Q_{max}	Maximum heat transfer rate	W
K	Thermal conductivity	W/m.K
p	Density of the fluid	k_g/m^3
V	Velocity of fluid	m/s
µ	Dynamic viscosity	N-s/m^2
P	Pitch of twisted tape	m
α	Thermal diffusivity	m^2/s
ν	Kinematic viscosity	m^2/s
L	Length of Twisted tape	m
T_{ho}	Outlet temperature of hot water	K
T_{hi}	Inlet temperature of hot water	K
T_h	Bulk temperature of hot water	K
T_{co}	Outlet temperature of cold water	K
T_{ci}	Inlet temperature of cold water	K
T_c	Bulk temperature of cold water	K
U_h	Mean velocity of hot water	m/s
V_h	Volume flow rate of hot water	Lit/hr
ρ_{in}	Density of hot water at inlet temperature	k_g/m^3
T_w	Tube wall temperature of inner tube	K
C_{ph}	Sp. heat capacity of hot water	J/(kg·K)

N	Kinematic viscosity of hot water	m^2/s
Δ_p	Pressure drop	N/m^2
Q_h	Heat transfer rate released by hot water	W
Q	Mean heat transfer rate	W
C_{min}	Minimum capacity of thermal energy	J/K
V_c	Volume flow rate of cold water	Lit/hr
ρ_h	Density of hot water at bulk temperature	k_g/m^3
C_{pc}	sp. heat capacity of cold water	kJ/kgK
K_h	Thermal conductivity of hot water	J/kg
h_i	Heat transfer coefficient	$W/(m^2K)$
Q_c	Heat transfer rate absorbed by cold water	W
δ	Deviation of heat transfer rates	J/ m^2s
ΔTA	Temperature difference between two streams at A	K
ΔTB	Temperature difference between two streams at B	K

1. Introduction:

Heat exchangers are widely used in a modern day. Condensers, evaporators, air coolers, chilling towers, radiators and oil coolers are commonly found examples of heat exchangers. Since using heat exchangers is a cost effective and design savvy method these are widely used in thermal power-plants, oil refineries, vehicle engines, ship engines rooms etc to transmit the heat between two fluids.

A double-pipe heat exchanger is a type of heat exchanger that consists of two concentric pipes, one inside the other. It is also known as a concentric tube heat exchanger or a tube-in-tube heat exchanger. The two pipes are typically made of different materials to facilitate efficient heat transfer between two fluids. To enhancement of the heat transfer rate using the twisted tape inserts are evaluated.

Sanjay Kumar Singh, Arvind Kumar (2021) [1] studied, a double pipe heat exchanger with incorporating a twisted tape with dimple inserts. In this study, a correlation has been established between the geometry of the dimples and the Reynolds number (Re). In all cases, the performance evaluation criteria decrease with an increase in Reynolds number (Re). This observation indicates that as the Reynolds number increases, the Nusselt number also increases. Indri Yaningsih, Takahiko Miyazaki, Agungtri Wijayanta, et al.(2018) [15] conducted an experimental study using V- cut twisted tape inserts. The results indicated that at low Reynolds numbers, better performance was observed, and as the Reynolds number increased, the thermos-hydraulic performance tended to decrease. The deviations in friction factor, Nusselt number, and thermal performance were within 3% each.

The objective of this work is to investigate the heat transfer and friction characteristics in a horizontal double pipe heat exchanger by employing twisted tape inserts without V- cut, with single V- cut, with double V- cut, with triple V- cut at angle of 45degrees and constant depth. The specific aim of the study includes evaluating the impact of no. of V- cut on heat transfer and frictional effects within the heat exchanger.

1. To examine how the no. of V- cut on twisted tape affects both the heat transfer rate and the frictional characteristics within the heat exchanger.

2. Comparing Nusselt number and friction factor results for a plain tube with twisted tapes we used.

3. Evaluating performance evaluation criterion (PEC).

Proposed Methodology:

In the experimental setup, the double pipe heat exchanger is used in counter flow arrangement with water as working fluid. The setup has mainly two circuits, hot water circuit and cold water circuit. Cold water circuit is open circuit and includes cold water reservoir with 200ltr capacity, 0.5HP centrifugal pump, rotameter with range of 50LPH to 200LPH and some flow valves.

The hot water circuit is the closed loop and it includes the 200 ltr hot water tank or boiler equipped with solid state relay with sensitivity of ±0.01ºC, stirrer 0f 25 ltr capacity euiped with moter and blades to mix the hot water to maintain same temperature, 0.5Hp centrifugal pump, rotameter of 50LPH to 200LPH range, thick layer of insulation is used on the pipes, ball type valve is used to regulate flow.

The testing section has outer pipe made up of galvanised iron and has length of 2500mm, inner diameter of 30mm and outer diameter 36mm. Inside pipe made up of copper and has the length of 2500mm, inner diameter 16mm, outer diameter 20mm. 6 T-type thermocouples on the surface of inner tube and 4 RTDs (resistance Temperature detector) were attached at inlet and outlet of both the hot and cold pipes with a data logger device from which all temperature data can be fetch into a pendrive. To measure the pressure drop of hot water, a U-tube manometer is used. The twisted tape is made up of aluminium and has 14mm width, 0.8mm thickness, 2500mm length and the constant pitch of 50mm. Four twisted tapes which includes without V-cut, with single V-cut, with double V-cut, with triple V-cut has been prepared for this experiment. The V-cut has 5mm depth and 45º angle.

The hot water tank (boiler) is brought to a steady state condition of 72ºc, and the hot water is directed to the stirrer to maintain a constant temperature. The hot water is then pumped from the hot water tank through a rotameter, which regulates the flow rate, and enters the inner tube of the heat exchanger. Simultaneously, cold water is pumped directly from the reservoir through another rotameter, maintaining a constant flow rate, into the outer pipe of the heat exchanger. The flow rate of the hot water is gradually increased in increments of 10 LPH (Liter per Hour) from 110 LPH to 200 LPH, while the flow rate of the cold water is kept constant at 50 LPH throughout the experiment. Six T-type thermocouples are installed on the surface of the pipes to measure the temperature at various points, providing regular temperature readings. Additionally, four RTDs are installed at both the inlet and outlet of the hot and cold water pipes to measure the temperature accurately. For the experiments involving twisted tape inserts, the tapes are carefully inserted into the inner tube where the hot water flows. The testing pipes are then wrapped with glass wool to minimize any heat loss. Data readings from the various temperature sensors and instruments are collected using a data logger, and the data is stored on an external pen drive. The U-tube manometer is used to measure the deviation in frictional losses occurring during the heat transfer process.

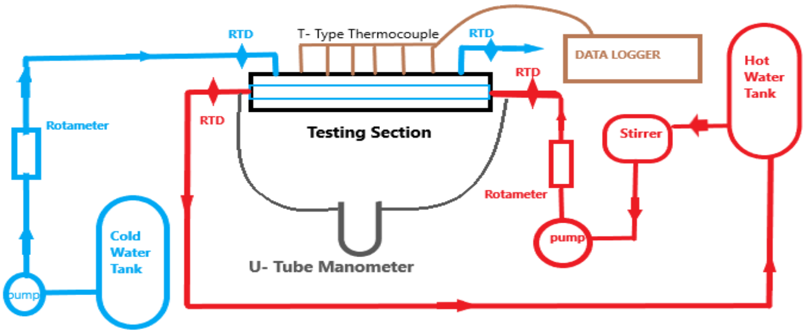


Fig. 1: Scematic Diagram of Double Pipe Heat Exchanger

Figure 2 : Twisted tape without V- cut

Figure 3 : Twisted tape with single V- cut

Figure 4 : Twisted Tape with Double V- cut

Figure 4 :Twisted Tape with Triple V- cut

Figure 6 : Experimental setup for DPHE in Heat Transfer Research Lab

Formulae used in calculations:

Bulk mean temperature of hot water , $Th = \frac{(Thi + Tho)}{2}$ (1)

Bulk mean temperature of cold water , $Tc = \frac{(Thi + Tho)}{2}$ (2)

Average temperature of wall $Tw = \frac{T_1+T_2+T_3+T_4+T_5+T_6}{6}$ (3)

Mean velocity of hot water, $Uh = \frac{(Vh * \rho in)}{\left(\frac{3.14D^2 \rho h}{4}\right)}$ (4)

Reynolds Number (For hot water), $Re = \frac{(Uh \; X \; D)}{v}$ (5)

Heat transfer rate absorve by cold water , $Q_c = \rho_c$ x V_c x C_{pc} $(T_{co} - T_{ci})$ (6)

Heat transfer rate released by hot water , $Q_h = \rho_h$ x V_h x C_{ph} $(T_{hi} - T_{ho})$ (7)

Mean value of heat transfer rate $Q = \frac{(Qh + Qc)}{2} = hi \times A \times (Th - Tw)$ (8)

Friction factor $f = \frac{\Delta p}{\left(\frac{\rho h U h^2}{2}\right)} \left(\frac{L}{D}\right)$ (9)

Nusselt number $Nu = \frac{(hi \times D)}{Kh}$ (10)

Performance Evaluation Criteria $PEC = \frac{\frac{Nu}{Nuo}}{\left(\frac{f}{f0}\right)^{0.33}}$ (11)

Validation of plain tube without inserts of twisted tape:

It suitable for this experimental study to validate their experimental setup using two specific correlations: Gnielinski correlation (Eq.12) for the Nusselt number and Filonenko correlation (Eq. 13) for the friction factor. For the Nusselt number, the maximum deviation between the experimental values and the predictions of the Gnielinski correlation was found to be ±9.48%. This indicates that the experimental values generally align well with the values predicted by the Gnielinski correlation, with deviations within an acceptable range. Similarly, for the friction factor, the maximum deviation between the experimental values and the predictions of the Filonenko correlation was found to be ±6.88%. This suggests that the experimental values of the friction factor are in good agreement with the values estimated by the Filonenko correlation, with deviations falling within an acceptable range.

Gnielinski correlatio

$$Nu_f = \frac{(f/8)(\mathrm{Re}-1000)\mathrm{Pr}_f}{\left\{1+12.7(f/8)^{0.5}\mathrm{Pr}^{0.66}-1\right\}\left\{1+(d/L)^{0.66}\right\}C_1} \quad (12)$$

$$for\ liquid,\ C_1 = \frac{\mathrm{Pr}_f}{\mathrm{Pr}_w} = 0.01;\ if\ \frac{\mathrm{Pr}_f}{\mathrm{Pr}_w} = 0.05\ to\ 20$$

Filonenko correlation

$$f = (1.82 \ln \mathrm{Re} - 1.64)^{-2} \quad (13)$$

Experimental Study of Heat Transfer and Friction Factor in Double Pipe Heat Exchanger :

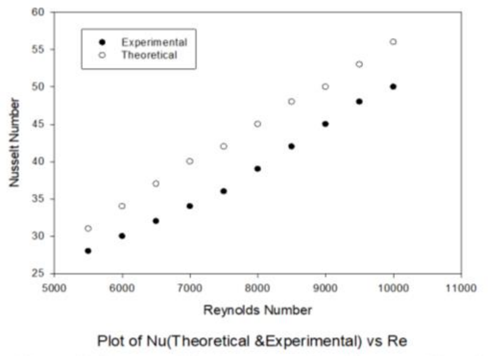


Figure 7: Setup validation comparison between Nusselt number and Gnielinski Nusselt number.

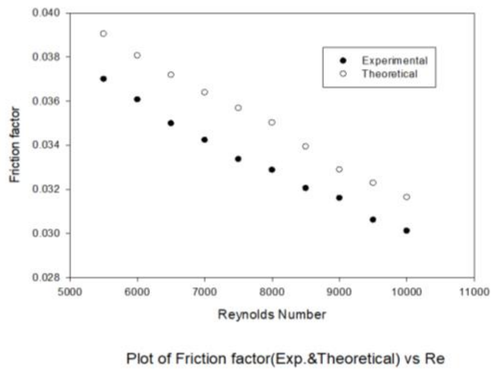


Figure 8: Setup validation comparison between friction factor and filonenko friction factor.

Comprehensive assessment of axial and radial V- cut twisted tape:

In this section, how the thermo-hydraulic performance of a DPHE is affected by vortices caused by number of V- cut made on twisted tape in axial direction are discussed. At a constant depth of 5 mm with V- cut angle of $45^0$the experiments were carried out with four different twisted tapes namely without V- cut, single V- cut, double V- cut and triple V- cut.

Effect of number of V- cut on heat transfer:

Variation of Nu with Re is shown in Fig. 8 and it can be observed that due to turbulence (joint effect of swirl and vortex flow) Nu increases with increasing *Re* for all cases. Besides, the heat transfer rate also depends on number of V- cut. Heat transfer rate enhanced up to 26.66% for twisted tape (without V- cut) with respect to plain tube which is only due to the swirl generated by the twisted tape. In case of V- cut made on twisted tape in axial direction, heat transfer rate enhanced by 57.14%, 89.28% and 139.26% w.r.t plain tube for single V- cut, double V- cut and triple V- cut respectively. The enhancement in heat transfer rate recorded here is due to both swirl flow as well as vortex flow which is generated by V- cut. While comparing heat transfer rate with without V- cut twisted tape the heat transfer rate enhanced by 25.71%, 51.42% and 91.43% for single V- cut, double V- cut and triple V- cut respectively. This enhancement in heat transfer rate is only due to the vortex flow generated by the V- cut. Effect of number of V- cut on heat transfer can be obtained by comparing double and triple V- cut with single V- cut. While comparing heat transfer rate with single V- cut it is found that there is increment of 20.45% and 52.27% for double V- cut and triple V- cut respectively. This enhancement is due to increase in number of V- cut. It reveals that heat transfer rate is directly proportional to number of V- cut.

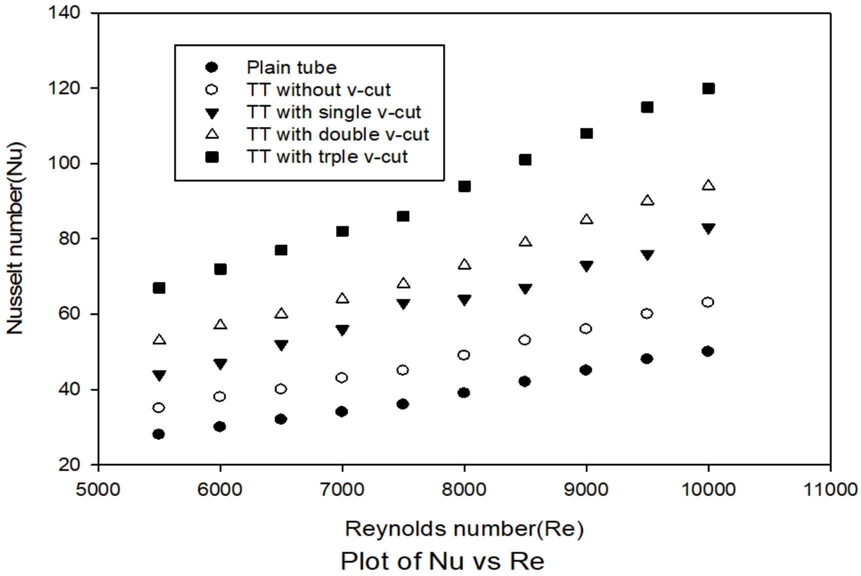


Fig. 9: Plots of *Nu* vs. *Re* values for all configurations

Effect of number of V- cut on friction factor:

Fig. 9 shows the variation of friction factor with Reynolds number and for all cases it is revealed that the friction factor decreases with increase in Reynolds number. Besides, the friction factor is directly related to turbulence which implies that like Nu, with increase in turbulence the f also increases. Friction factor increases up to 9.97% for twisted tape (without V- cut) with respect to plain tube which is only due to the turbulence generated by the twisted tape. In case of V- cut made on twisted tape friction factor enhanced by 39.88%, 59.83% and 79.77% w.r.t plain tube for single V- cut, double V- cut and triple V- cut respectively. The increment in friction factor recorded here is due to both swirl flow as well as vortex flow which is generated by V- cut. While comparing friction factor with without V- cut twisted tape it is found that the friction factor enhanced by 27.27%, 45.46% and 63.67% for single V- cut, double V- cut and triple V- cut respectively. This enhancement in friction factor is only due to the vortex flow generated by the V- cut. Effect of number of V- cut on friction factor can be determined by comparing double and triple V- cut with single V- cut. While comparing friction factor with single V- cut it is found that there is increment of 14.28% and 29.37% for double V- cut and triple V- cut respectively. This increment in friction factor is due to increase in number of V- cut. It shows that friction factor is directly related with number of V- cut made on twisted tape.

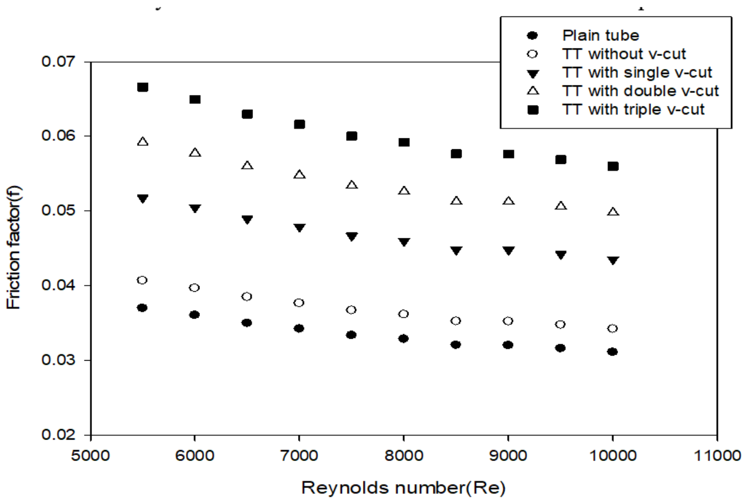
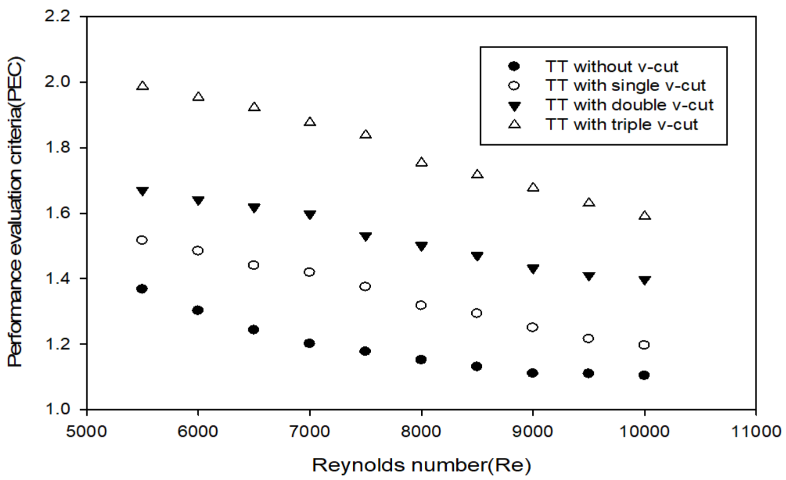


Fig.10: Plots of *f* vs. Re for all geometries of the twisted tape

Effect of number of V- cut on Performance evaluation criteria (PEC):

Performance evaluation criteria is one of the parameters which helps to decide the utility of inserts and it is defined as the ratio of ratio of Nu to ratio f as mentioned in Equation section. Fig. 10 depicts the higher value of PEC at low Reynolds number and it decreases with increase in Reynolds number for each of insert's types as well as for plain tube. The experiments reveal that twisted tape is more beneficial at use at low Reynolds number. While comparing PEC with without V- cut twisted tape it is found that PEC enhanced by 18.10%, 33.0% and 56.19% for single V- cut, double V- cut and triple V- cut respectively. Effect of number of V- cut on PEC can be determined by comparing double and triple V- cut with single V- cut. While comparing PEC with single V- cut it is found that there is increment of 12.61% and 32.25% for double V- cut and triple V- cut respectively.



Plot of PEC vs Re

Fig. 11: Plots of PEC vs. Re for various arrangements

Conclusion :

In this experimental study it is observed that how the thermo-hydraulic performance of a DPHE is affected by vortices caused by number of V- cut made on twisted tape in axial direction are discussed. At a constant depth of 5 mm with V- cut angle of 45^0 the experiments were carried out with four different twisted tapes namely without V- cut, single V- cut, double V- cut and triple V- cut. After the calculation of both the heat transfer enhancement and friction factor's effect were studied. The following conclusions after the analysis can be drawn:

1. Nusselt number increases with increase in Reynolds number for every cases, it means Nusselt number is directly related with turbulence whe but friction factor decreases with increase in Reynolds number for every cases, it means friction factor dominates more in laminar flow than the turbulent flow.

2. heat transfer rate enhances as the number of V-cut increases.

3. Nu increases with increasing *Re* for all cases. Besides, the heat transfer rate also depends on number of V- cut. Heat transfer rate enhanced up to 26.66% for twisted tape (without V- cut) with respect to plain tube which is only due to the swirl generated by the twisted tape. In case of V- cut made on twisted

tape in axial direction, heat transfer rate enhanced by 57.14%, 89.28% and 139.26% w.r.t plain tube for single V- cut, double V- cut and triple V- cut respectively. The enhancement in heat transfer rate recorded here is due to both swirl flow as well as vortex flow which is generated by V- cut.

4. The friction factor decreases with increase in Reynolds number. Besides, the friction factor is directly related to turbulence which implies that like Nu, with increase in turbulence the f also increases. Friction factor increases up to 9.97% for twisted tape (without V- cut) with respect to plain tube which is only due to the turbulence generated by the twisted tape. In case of V- cut made on twisted tape friction factor enhanced by 39.88%, 59.83% and 79.77% w.r.t plain tube for single V- cut, double V- cut and triple V- cut respectively. The increment in friction factor recorded here is due to both swirl flow as well as vortex flow which is generated by V- cut.

5. While comparing PEC with without V- cut twisted tape it is found that PEC enhanced by 18.10%, 33.0% and 56.19% for single V- cut, double V- cut and triple V- cut respectively. It shows that using the triple V- cut twisted tape more beneficial.

Future Scope:

This experimental research and analysis featuring DPHE permits us of possibilities to investigate and research with twisted tape with single V- cut, double V- cut, triple V- cut are enlighten for future research:

- To develop the correlations for the effect of using twised tape with different number of V- cut on DPHE.
- Experimental study of the effect of using twised tape with different number of V- cut on DPHE while using nano fluid.
- Experimental study of the effect of using twised tape with different number of U-cut on DPHE.

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