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Effect of Twisted – Tape Tubulators on Heat Transfer and Flow Friction inside a Double Pipe Heat Exchanger

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Abstract

Computational fluid dynamics (CFD) has been employed for the Heat exchanger efficiency of a counter flow heat exchanger. The Heat exchanger efficiency has been assessed by considering the computed Nusselt number and flow friction characteristics in the double pipes heat exchanger equipped with two types twisted-tapes: (1) single clockwise direction and (2) alternate clockwise and counterclockwise direction. Cold and hot water are used as working fluids in shell and tube side, respectively. Hot and cold water inlet mass flow rates ranging are between 0.04 and 0.25 kg/s, and 0.166 kg/s, respectively. The inlet hot and cold water temperatures are 54 and 30 ℃, respectively. The results obtained from the tube with twisted-tapes insert are compared with plain tube. Nusselt number and friction factor obtained by CFD simulations were compared with correlations available in the literature. The numerical results were found in good agreement with the results reported in literature.

Keywords: *CFD, Twisted-tape, Double pipe Heat Exchanger, Heat exchanger efficiency*

NOMENCLATURE

A Area [m^2]
C_p Specific heat [J/kg·K]
d Diameter [m]
D_h Hydraulic diameter [m]
f Friction factor
h Heat transfer coefficient [$W/m^2 K$]
H Pitch length based on 180° [m]
k Thermal conductivity [W/m·K]
L Tube length [m]
m Mass flow rate [kg/s]
Nu Nusselt number
Pr Prandtl number
ΔP Pressure drop [N/m^2]
Q Heat transfer rate [W]
Re Reynolds number
U Overall heat transfer coefficient [$W/m^2 K$]
T Temperature [°C or K]
y Twist ratio
u Velocity [m/s]
V Volumetric flow rate [m^3/s]
W Width of twisted tape [m]
ν Kinematic viscosity [m^2/s]
ε Percentage of heat loss
η Heat transfer enhancement efficiency

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Subscripts

a	Annulus
avg	Average
c	Cold water
h	Hot water
i	Inner
lm	Logarithmic mean difference
1	Inlet
2	Outlet
o	Outer
p	Plain tube

1. INTRODUCTION

Heat exchangers are important engineering devices in many process industries since the efficiency and economy of the process largely depends on the performance of the heat exchangers. Therefore, high performance heat exchangers are very much required. Improvement in performance may result in reduction in size of heat exchanger. Alternatively high performance heat exchangers of a fixed size can give an increased heat transfer rate; it might also give a decrease in temperature difference between the process fluids enabling efficient utilization of thermodynamic availability.

Nowadays, twisted-tape inserts have widely been applied for enhancing the convective heat transfer in various industries, due to their effectiveness, low cost and easy setting up. Energy and material saving consideration, as well as economical, have led to the efforts to produce more efficient heat-exchanger equipment. Therefore, if the thermal energy is conserved, the economical handling of thermal energy through heat-exchanger will be possible

Liao and Xin [1] studied the heat transfer and friction characteristics for water, Ethylene glycol and ISO VG46 turbine oil flowing inside four tubes with three-dimensional internal extended surfaces and copper continuous or segmented twisted-tape inserts. It was found that a tube with three dimensional extended surface and twisted tape inserts was a better choice to enhance the convective heat transfer for the laminar tube side flow of highly viscous fluid. They expressed that the replacement of continuous twisted tape inserts with the segmented twisted tape inserts induced a greater decrease in the friction factor but comparatively small decrease in the Stanton number. The Stanton number is the ratio of heat transfer rate to the enthalpy difference and gives a measure of heat transfer coefficient.

Ray and Date [2] numerically predicted the heat transfer characteristics of laminar flow and heat transfer through a square duct with twisted tape insert. The heat transfer characteristics are predicted under axially and peripherally constant wall heat flux conditions. Relative thermo hydraulic performance of square and circular ducts, both fitted with twisted tapes of same twist ratio was also studied. The results showed significant improvement in heat transfer rate with square duct, particularly at higher Prandtl number and lower twist ratios.

Lokanath and Misal [3] used the twisted tapes in shell and tube heat exchanger for different fluids. Their study revealed that twisted tapes of tighter twists were expected to give higher overall heat transfer coefficients.

Wang and Sunden [4] compared the performance of tube inserts including twisted tape and wire coil inserts for both laminar and turbulent flows and reported that twisted tape was more effective than those with wire coil inserts, if no pressure drop penalty was considered and also concluded that the shape of the insert was important for the enhancement and insert thickness does not change the performance trend.

Naphon [5] studied the heat transfer and pressure drop characteristics in a horizontal double pipe heat exchanger with twisted tape inserts at different pitch (H = 2.5 and 3cm) by varying the temperature and mass flow rates for both hot and cold water flows. It was observed that the heat transfer rate at lower twist ratio was higher than those from higher ones across the range of Reynolds number. This was because the turbulent intensity and the flow length obtained from lower twist ratio was higher than those at higher ones and also stated that the tube-side heat transfer coefficient at higher cold water mass flow rate was higher than that of the lower ones. This was because the heat transfer rate depends directly on the cooling capacity of cold water.

Eiamsa-ard et al. [6] an experimental study on the mean 'Nu'; 'f' and 'g' in a round tube with short-length TT insert. The full-length twisted tape is inserted into the tested tube at a single y = 4.0 while the short-length tapes mounted at the entry test section. The experimental result indicates that the presence of the tube with short-length twisted tape insert yields higher heat transfer rate.

Seemawute and Eiamsa-Ard [7] Visualization of flow characteristics induced by twisted tape consisting of alternate-axis (TA) has been comparatively investigated to that induced by typical twisted tape (TT). The visualization was carried out via a dye injection technique. The effects of twist ratios (y/W) on heat transfer and fluid friction were also extensively examined. The visualization results show that TA give better fluid mixing and thus higher heat transfer rate than TT, at similar conditions. In addition, swirl number and thus residence time of a fluid flow is promoted as tape twist ratio decreases, this visualization results is consistent with the superior heat transfer at smaller twist ratio.

This paper is proposed to study the heat transfer characteristics and pressure drop of the double pipes with and without twisted tapes insert. Therefore, it is expected that this kind of twisted tape might be capable of reducing the flow resistance and maintaining a high heat transfer rate as well. The heat transfer and pressure drop characteristics of the double pipes with and without twisted-tapes insert will be investigated through computational fluid dynamic simulation.

2. DATA REDUCTION EQUATIONS

The data reduction of the measured results is summarized as follows:
Heat transferred to the cold water in the test section Eq.(1)

$$Q_c = m_c C_{pc}\left(T_{c2} - T_{c1}\right) \tag{1}$$

Heat transferred from the hot water in the test section Eq.(2)

$$Q_h = m_h C_{ph}\left(T_{h1} - T_{h2}\right) \tag{2}$$

The percentage of heat loss between hot and cold water side in the present heat exchanger can be given:

$$\varepsilon = \frac{Q_h - Q_c}{Q_c} \times 100 \tag{3}$$

The average heat transfer rate Eq.(4) for hot and cold water side is taken for internal convective heat transfer coefficient calculation:

$$Q_{avg} = \frac{Q_h + Q_c}{2} \tag{4}$$

The surface area of the inner tube is calculated using the Eq.(5)

$$A_i = \pi d_i L \tag{5}$$

Logarithmic mean temperature difference

$$\Delta T_{lm} = \frac{(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})}{\ln\left(\frac{T_{h1} - T_{c2}}{(T_{h2} - T_{c1})}\right)} \tag{6}$$

The over all heat transfer coefficient is calculated using the Eq.(7)

$$U = \frac{Q_{avg}}{A_i \Delta T_{lm}} \tag{7}$$

Annulus side heat transfer coefficient (h_a) is estimated using the correlation of Dittus -Boelter [9]:

$$Nu_a = \frac{h_a D_h}{k_c} = 0.023 \mathrm{Re}_a^{0.8} \mathrm{Pr}_c^{0.3} \tag{8}$$

where D_h is the hydraulic diameter, $D_h = D_i - d_o$

The inner tube side heat transfer coefficient (h_i) Eq.(9) is determined by neglecting the conduction thermal resistance of copper tube wall:

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_a} \tag{9}$$

The inner tube side Nusselt number

$$Nu_i = \frac{h_i D_i}{k_h} \tag{10}$$

The Reynolds Number

$$\mathrm{Re}_i = \frac{u_h \times d_i}{\nu_h} \tag{11}$$

Friction factor is related to pressure drop and it is calculated using the following Eq.(12) for a fully developed flow.

$$f = \frac{\Delta P}{\left(\frac{L}{d_i}\right) \times \left(\frac{\rho u^2}{2}\right)} \tag{12}$$

Blasius correlation [8]

$$f = 0.448\,\mathrm{Re}^{-0.275} \tag{13}$$

Heat transfer enhancement efficiency

$$\eta = \frac{Nu_T}{Nu_P} = \left[\frac{Nu_T}{Nu_P}\right] / \left[\frac{f_T}{f_P}\right]^{1/3} \tag{14}$$

3. CFD MODELING

Three-dimensional simulations of the turbulent fully develop flows of fluid in the double pipes heat exchanger were carried out using the commercial CFD software Solidworks Flow Simulation in order to predict the heat transfer and pressure drop for a plain tube and tube equipped with twisted – tapes type 1 and 2. The schematic diagram is shown in Figure 3.1 to understand the boundary conditions used in the present work. Double pipe exchanger consists of two concentric tubes in which hot water flows through the inner tube (d_i = 25 mm and L = 2000 mm) and cold water flows in counter flow through annulus (d_o = 54.5 mm and L = 2000 mm). The cold water has the inlet mass flow rate and temperature are 0.166 kg/s and 30°C. Inlet mass flow rate of hot water is varying between 0.008 to 0.117 kg/s and temperature inlet is 54°C. The summary of the details of the simulation setup are given in Tables 1.

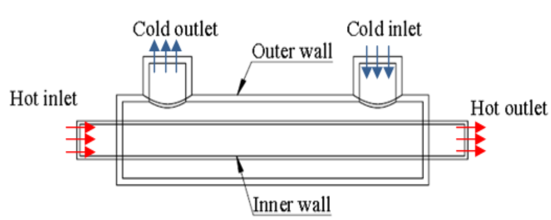


Figure 1. Schematic diagrams representing the boundary conditions.

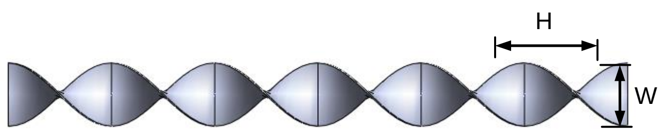
Table 1. Details of Twisted-tapes double pipe dimensions

Inner tube	
Inner diameter (d_i)	25.0 mm
Length	2000 mm
Material	Copper
Outer tube	
Inner diameter (d_o)	54.5 mm
Length	2000 mm
Material	Galvanized iron
Twisted - tapes	
Tape pitch length (H, 180°)	50.0 mm
Tape width (W)	23.5 mm
Tape thickness	1.5 mm
Twist ratio ($y = H/d_i$)	2
Material	Aluminum

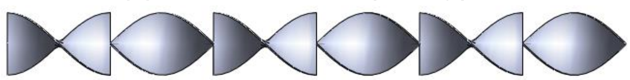
Figure 2 shows the twisted - tapes are used with twist ratios y = H/d_i = 2.0. Twisted tapes are made from aluminum strips of thickness 1.5 mm and width 23.5 mm. Each twisted - tape twists through an angle of 180°.

The twisted – tapes type 1 consists of a series of elements of clockwise twist arranged axially within a pipe, as depicted in Figure 2(a).

The twisted – tapes type 2 consists of a series of elements of alternating clockwise and counterclockwise twist arranged axially within a pipe so that the leading edge of an element is at right angles to the trailing edge of the previous element, as illustrated in Figure 2(b).



(a) The twisted – tapes Type 1

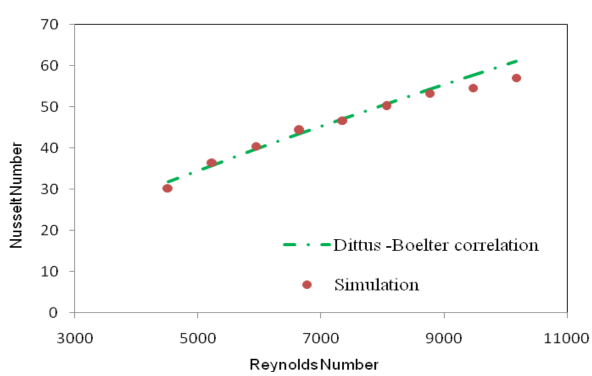


(b) The twisted – tapes Type 2

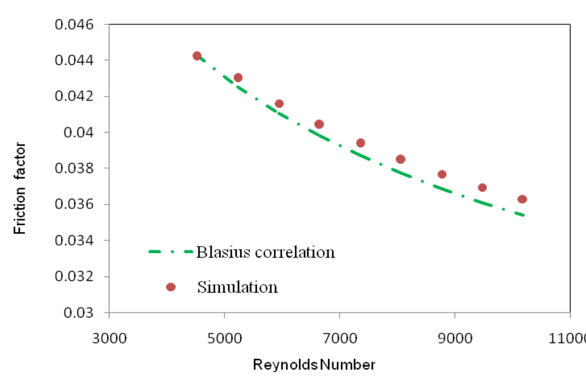
Figure 2. The twisted tape geometries.

4. RESULTS AND DISCUSSION

Firstly, the results obtained from simulation on heat transfer rate and pressure drop characteristics in the plain tube are verified in terms of Nusselt number and Friction factor under turbulent flow regime. The Nusselt number and friction factor obtained from simulation are compared with those from the proposed correlations by Dittus-Boelter and Blasius [8] as depicted in Figure 1(a) and (b), respectively.



(a)



(b)

Figure 3. Verification of the plain tube : (a) Nusselt number and (b) friction factor.

Fig. 3(a) and (b) show the comparison of Nusselt number and friction factor of the plain tube obtain from the simulation results with those from the proposed correlations. The data from the simulation are in agreement with Dittus-Boelter's Nusselt number and Blasius's friction factor correlations [9] with the discrepancy of less than 1.97%, 1.55%, respectively.

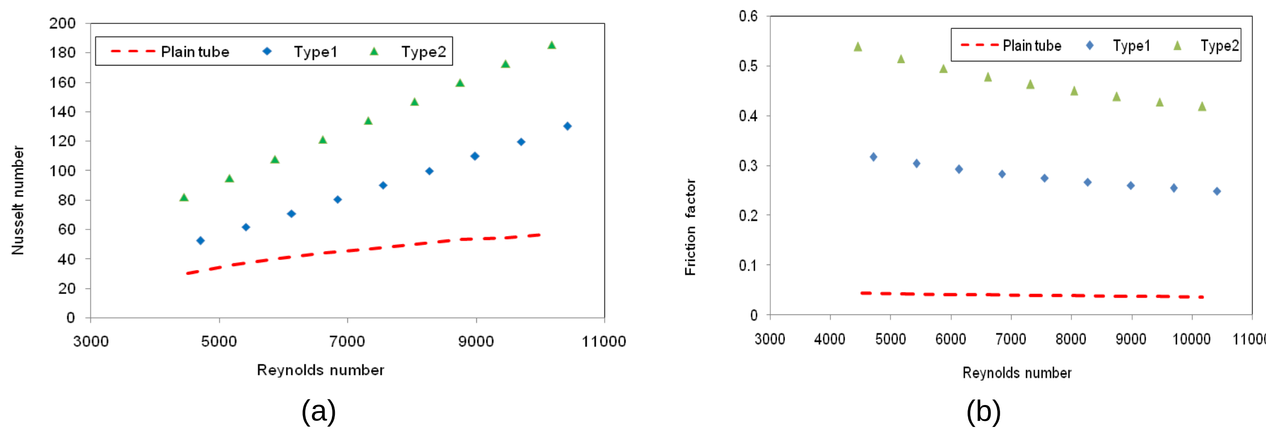


Figure 4. The variation of (a) Nusselt number and (b) Friction factor with Reynolds number.

The heat transfer rate of twist-tapes type 1 and 2 insert in terms of Nusselt number is shown in Fig. 4(a). The variation of Nusselt number and friction factor with hot water Reynolds number for tubes fitted with various inserts are given in Fig. 4(a) and (b), it's can be seen that Nusselt number increases and friction factor decreases with increasing hot water Reynolds number. This effect can be explained by reduction in the flow cross-sectional area, an increase in turbulence intensity and an increase in tangential flow established by inserts. Apparently, Nusselt number and friction factor in the tube equipped with type 2 are higher than those in the plain tube and the tube with twist-tapes type 1.

Heat transfer enhancement efficiency or thermal performance factor is one of the key parameters in the design of heat exchangers. In order to appraise the heat transfer augmentation performance of the two different perforated twist-tapes insert with plain tube [9]. Heat transfer enhancement efficiency calculated using Eq. (14). Fig. 6 shows the variation of heat transfer enhancement efficiency with Reynolds number in the tube equipped with twist-tapes type 1 and 2. It is observed that the increases of Reynolds number, Heat transfer enhancement efficiencies increased continuously. The twist-tapes type 2 is higher thermal enhancement factor than that of twist-tapes type 1. It means that enhancement effect is reasonable in the point of energy savings.

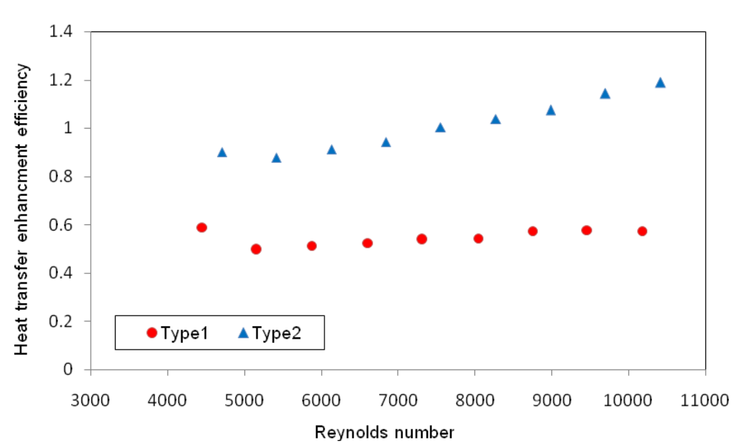


Figure 5. The variation of heat transfer enhancement efficiency with Reynolds number.

4. CONCLUSION

The CFD analysis is carried out to investigate the flow friction and Heat transfer chracteristics in a circular tube fitted with different twist-tapes using Solidworks Flow Simulation software. Two types twisted-tapes are (1) single clockwise direction and (2) alternate clockwise and counterclockwise direction. Cold and hot water are used as working fluids in shell and tube side, respectively. Hot and cold water inlet mass flow rates ranging are between 0.04 and 0.25 kg/s, and 0.166 kg/s, respectively. The inlet hot and cold water temperatures are 54 and 30 °C, respectively. The results obtained from the tube with twisted-tapes insert are compared with plain tube. Nusselt number and friction factor obtained by CFD simulations were compared with correlations available in the literature. Nusselt number increases and friction factor decreases with increasing hot water Reynolds number. The increases of Reynolds number, Heat transfer enhancement efficiencies increased continuously.The numerical results were found in good agreement with the results of correlations reported in literature.

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