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Effect of Wavy (Corrugated) Twisted Tape Inserts on Heat Transfer in a double Pipe Heat Exchanger

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Abstract

In the present work heat transfer and friction factor properties were experimentally investigated by using copper wavy (corrugated) twisted tape inserts. The turbulent flow was created by inserting the wavy twisted tape inserts into the inner tube of heat exchanger creating high rate of turbulence in pipe, which results in increasing heat transfer enhancement and pressure drop. The tape consists of the corrugations and the twisting with various twist ratios (TR=10.7, 8.5, 7.1). The length and width of insert was 1 meter and 14 mm respectively. The outer tube of heat exchanger is made up of mild steel with outside diameter 0.0198 m & 0.0142 m inside diameter and the inner tube is made up of copper with 0.038 m outside diameter and 0.032 m inside diameter. The length of pipe in pipe heat exchanger is 1.4 m. The bulk mean temperatures at various positions are used for different flow rate of water. From the obtained results the new Correlations for Nusselt number and friction factor are developed for twisted tape inserts. The Reynolds number is varied from 5000 to 17000. The results of varying twists in wavy twisted tape inserts with different pitches have been compared with the values for the smooth tube. It showed that the highest heat transfer rate was achieved for the wavy twisted tape with twist ration 7.1. The Nusselt number value increased by 172 % and friction factor value increased by 32.11% as compared to the smooth tube values.

Keywords - Heat transfer, heat exchanger, wavy twisted tape, turbulent, pressure drop, friction factor,

Introduction

In heat exchanger, the enthalpy is transferred between two or more fluids, at different temperatures. The use of heat exchangers are in various industrial processes for heating and cooling applications such as air conditioning and refrigeration systems, heat recovery processes, food and dairy processes, chemical process plants etc. The major challenge in designing a heat exchanger is to make the equipment more compact and achieve a high heat transfer rate using minimum pumping power. Techniques for heat transfer augmentation are relevant to several engineering applications. In recent years, the high cost of energy and material has resulted in an increased effort aimed at producing more efficient heat exchange equipment. Sometimes there is a need for miniaturization of a heat exchanger in specific applications, such as space application, through an augmentation of heat transfer. 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 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 thereby breaking the viscous and thermal boundary layer. However, 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 and are discussed under the classification section. The heat transfer enhancement techniques are performed in widespread applications. Those methods are, for instance, the insertion of twisted strips and tapes, the insertion of coil wire and helical wire coil and the mounting of turbulent decaying swirl flow devices in several heat exchangers. The results of those studies have been shown that although heat transfer efficiencies are improved, the flow frictions are also considerably increased. In this report the various wavy twisted tapes are used for heat transfer enhancement having various twist ratios. The strips are expected to induce a rapid mixing and a high turbulent and longitudinal vortex flow like a delta wing, of course, resulting in an excellent rate of heat transfer in the tube.

Experimental Set-Up

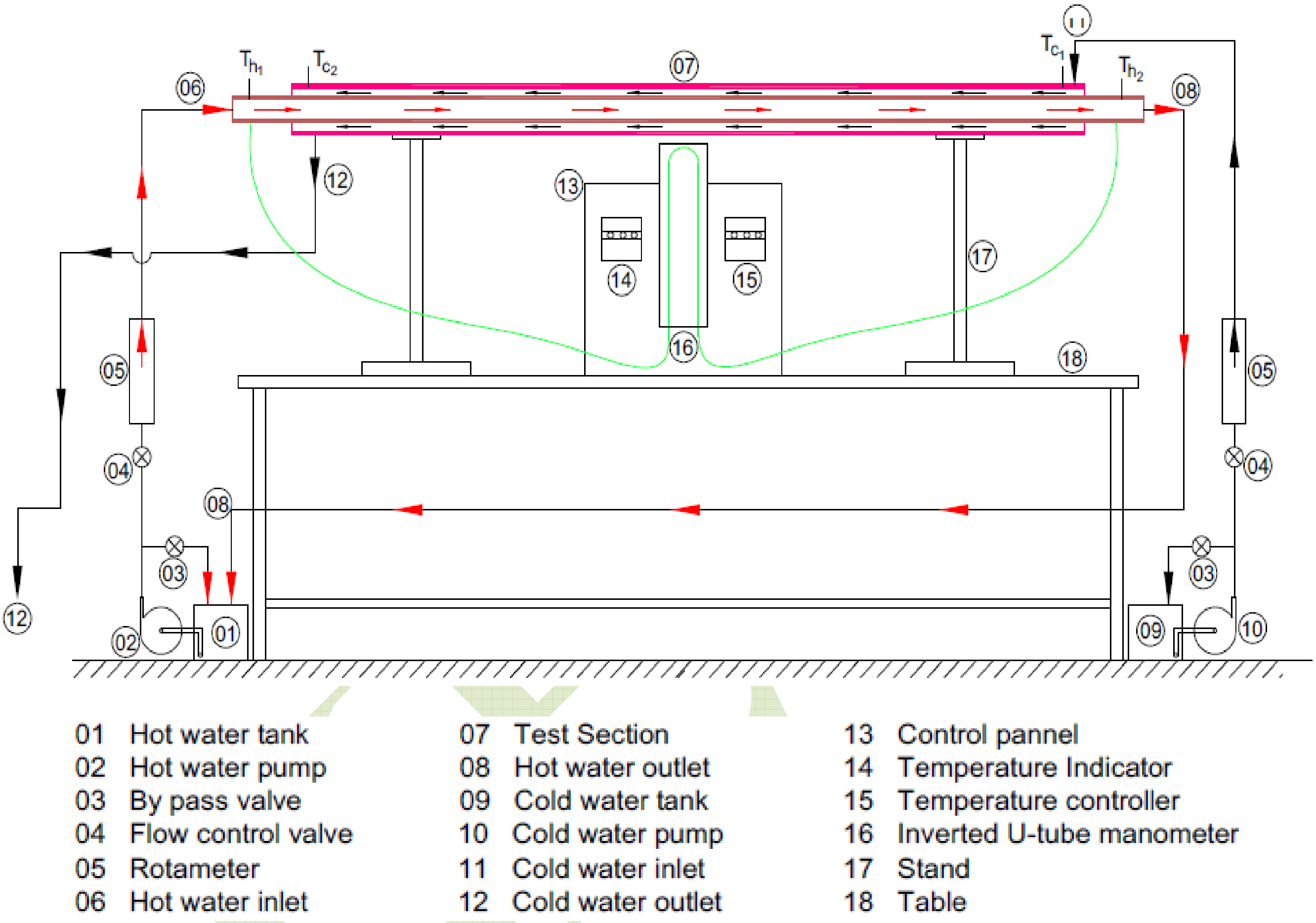

Fig. 1 The schematic diagram of experimentation

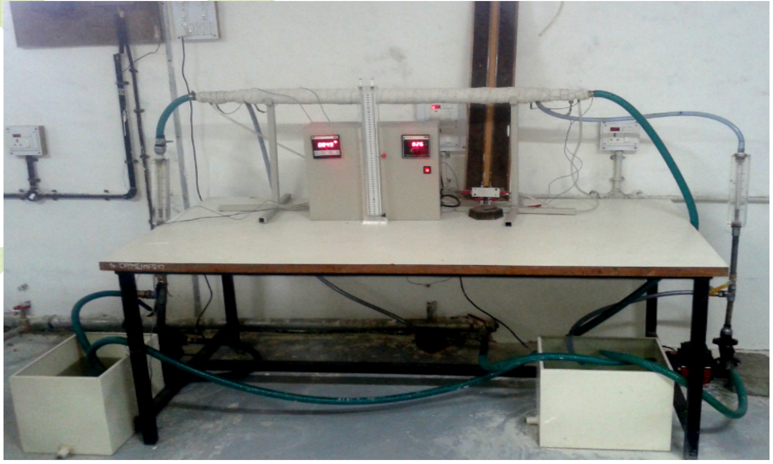

Fig. 2 Actual photograph of experimentation

The experimental set up and the various measuring devices were shown in figure. It consisted of tube in tube type heat exchanger. The material of inside tube was of Copper and outside tube was of Mild Steel. The thermocouples were used to measure the inlet and outlet temperature of cold and hot water. Here four thermocouples were used; two at the inlet and two at the outlet of hot and cold water respectively. Rota meters were used to measure the flow rate at inlet of cold and hot water. Two centrifugal pumps were used to circulate the cold and hot water. Two tanks were used for storing the hot water and cold water. Electric heater was attached to the hot water tank having capacity of 1500 watt. Inverted U-tube manometer was used to measure the pressure difference between inlet and outlet of test section of hot fluid the velocity of flow through inserted tube was measured by using current meter. The control valves and bypass valves were provided at inlet of both the rota meters.

Procedure

In the experiment, initially the water tank was filled with cold water and maintained its temperature up to 80 ^{0}C by using water heater. Then, this hot water was flowed through the rota meter by opening the flow control valve with help of hot water pump and through the inner pipe of heat exchanger. The cold water from the cold water tank was allowed to enter the heat exchanger through rota meter by flow control valve & cold water pump. Adjust the flow rate of cold water at 100 LPH and made it constant during whole experiment. The flow rate of hot water was adjusted at 300 LPH and kept it constant. When the steady state was reached, the temperatures of the inlet and outlet of the cold and the hot waters were recorded and pressure drop across the test tube was measured for plain tube without inserts. Thereafter repeat same procedure with wavy twisted tapes having twist ratio (TR=10.7, 8.5, 7.1) for various flow rates of hot water like 400, 500, 600, 700, 800, 850, 900 & 950 LPH. The figure 3 shows the terminology of wavy twisted tape and figure 4, 5, 6 shows the wavy tape inserts with twist ratio 10.7, 8.5, 7.1 respectively.

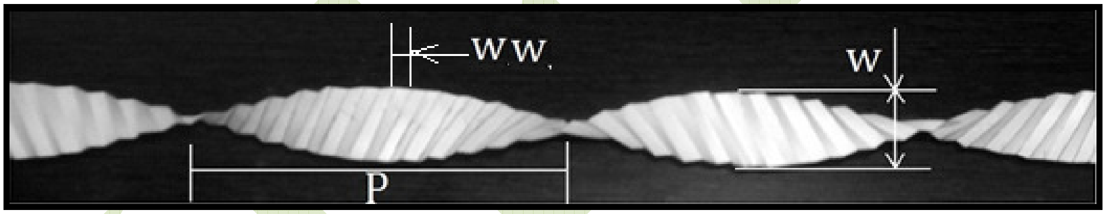

Fig. 3 Terminology of twisted tape

Fig. 4 Wavy corrugated twisted tape with TR – 10.7

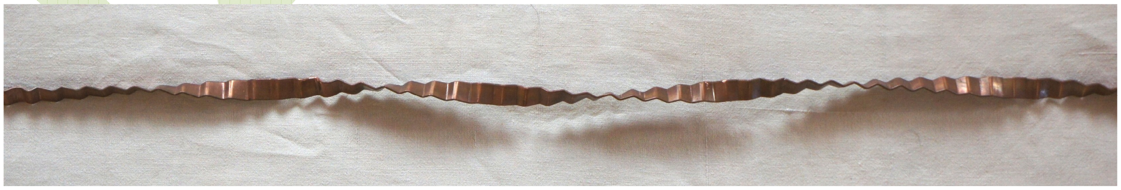

Fig. 5 Wavy corrugated twisted tape with TR – 8.5

Fig. 6 Wavy corrugated twisted tape with TR – 7.1

Specifications of inserts:

1. Material = Copper
2. Width of twisted tape (W) = 14 mm
3. Twist ratio (TR) = 10.7, 8.5, 7.1.
4. Length of insert = 1000 mm
5. Thickness of inserts = 2 mm
6. Wave-width (WW) = 10 mm
7. Depth of wave = 10 mm

Sample Calculations

The Properties of hot water and cold water are calculated at their bulk mean temperature,

$$T_{bh} = \frac{T_{h1} + T_{h2}}{2} \quad (1)$$

$$T_{bc} = \frac{T_{c1} + T_{c2}}{2} \quad (2)$$

T_{bh} and T_{bc} are bulk mean temperature of hot & cold water. T_{h1} & T_{h2} and T_{c1} & T_{c2} are inlet and outlet temperature of hot & cold water respectively.

Hot water heat transfer rate,

$$Q_h = m_h \times C_{ph} \times (T_{h1}-T_{h2}) \quad (3)$$

Cold water heat transfer rate,

$$Q_c = m_c \times C_{pc} \times (T_{c2}-T_{c1}) \quad (4)$$

m_h & m_c are the mass flow rate of hot and cold waters. C_p is the specific heat coefficient of water. $(T_{h1}-T_{h2})$ and $(T_{c2}-T_{c1})$ are the present temperature difference between inlet and outlet cold water and temperature difference of inlet and outlet hot water, respectively.

An average heat transfer rate between hot and cold waters and the convection heat transfer between copper surface and hot fluid flow, can be written as,

$$Q_{avg.} = \frac{Q_h + Q_C}{2} \quad (5)$$

$$Q_{avg.} = U \times As \times \Delta Tm \quad (6)$$

$$\Delta T_m = \frac{(\Delta T_1 - \Delta T_2)}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \quad (7)$$

$$\Delta T_1 = T_{h1} - T_{c2}$$

$$\Delta T_2 = T_{h2} - T_{c1}$$

As , U & ΔTm is the surface area of tube, overall heat transfer coefficient & Logarithmic mean temperature difference respectively.

Nusselt Number of cold water flowing through the annular space is given by,

$$Nu_o = 0.023(R_{eo})^{0.8} (P_r)^{0.3} \tag{8}$$

$$Re_o = \frac{\rho U_o D_h}{\mu} \tag{9}$$

$D_h = D_i - d_o$

Continuity equation, $mc = \rho A_o U_o$

Heat transfer coefficient (h_0) of cold water flowing through the annular space is given by,

$$Nu_o = \frac{h_o D_h}{K} \tag{10}$$

$$h_o = \frac{Nu_o K}{D_h}$$

Heat transfer coefficient of hot water (h_i),

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o} \tag{11}$$

Nusselt Number (Experimental) of hot water flowing through the tube,

$$Nu_i = \frac{h_i d_i}{K} \tag{12}$$

Theoretical Nusselt Number of hot water flowing through the tube is given by (Dittus Boelter equation).

$$Nu_i = 0.023(R_{ei})^{0.8} (P_r)^{0.3} \tag{13}$$

Experimental Friction Factor is calculated by,

$$\Delta P = \rho g h$$

$$\Delta P = \frac{fL\rho U_i^2}{2d_i}$$

$$f = \frac{2gd_i h}{LU_i^2} \tag{14}$$

Theoretical Friction Factor f can be written as,

$$f = 0.0055 \times \left(1 + \left(50 + \left(\frac{10^6}{\text{Re}_i}\right)\right)^{0.33}\right) \tag{15}$$

Result and discussion

After the experimental study, the Nusselt numbers and friction factors were calculated for plain tube and tube with wavy tape inserts. These results were compared with the correlation of Dittus and Boelter for Nusselt number &

John Nikuradse for friction factor. Figure 7a.shows the graph of Nusselt number Vs Reynolds number for plain tube. It is found that there is linear behavior of Nusselt number along Reynolds number. Nusselt number is a function of Reynolds number. Figure 7b.shows the graph of friction factor Vs Reynolds number for plain tube. The friction factor is inversely proportional with Reynolds number.

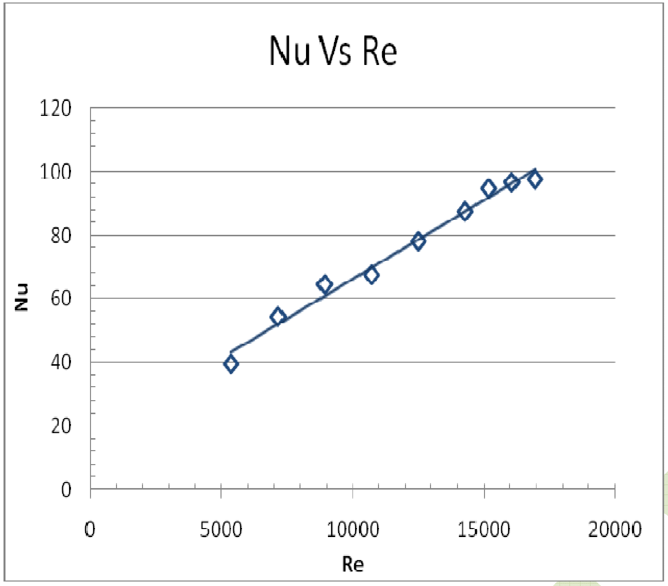

Fig. 7a Nusselt number Vs Reynolds number

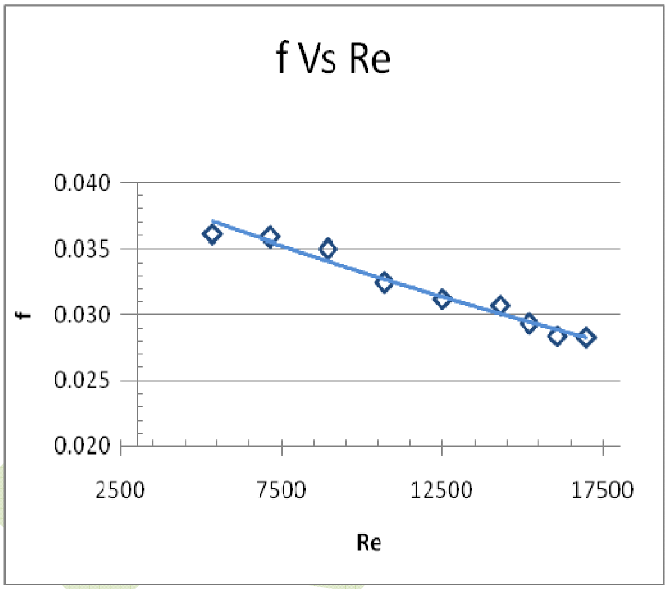

Fig. 7b Friction factor Vs Reynolds number

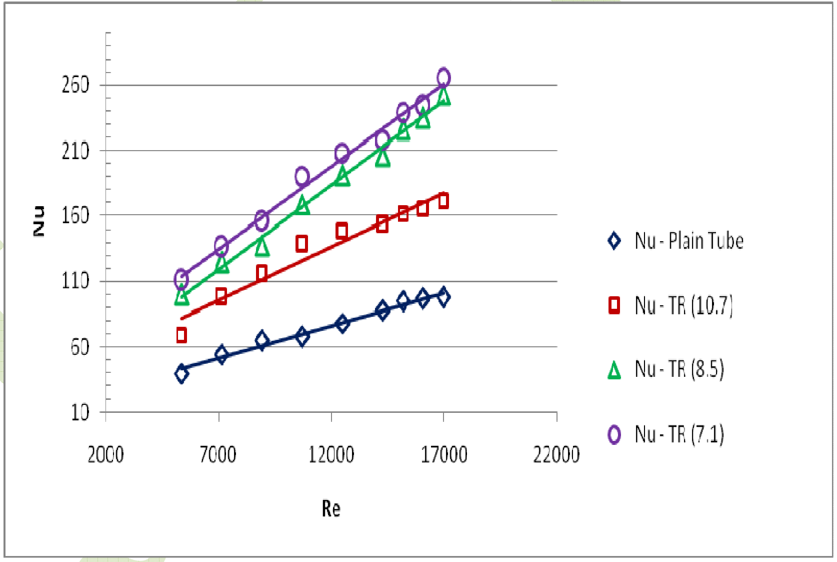

Fig. 8 Nusselt number Vs Reynolds number for TR=10.7, 8.5, 7.1

Figure 8 shows the variation of Nusselt number with Reynolds number at various twist ratios (TR=10.7, 8.5, 7.1). This figure concludes that the Nusselt number increases with increase in Reynolds number. Therefore heat transfer rate is more with higher Reynolds number. Here Nusselt number is more for the twisted tape with lesser twist ratio (TR – 7.1) for particular Reynolds number compared with other twisted tapes. So highest heat transfer rate was obtained for lesser twist ratio.

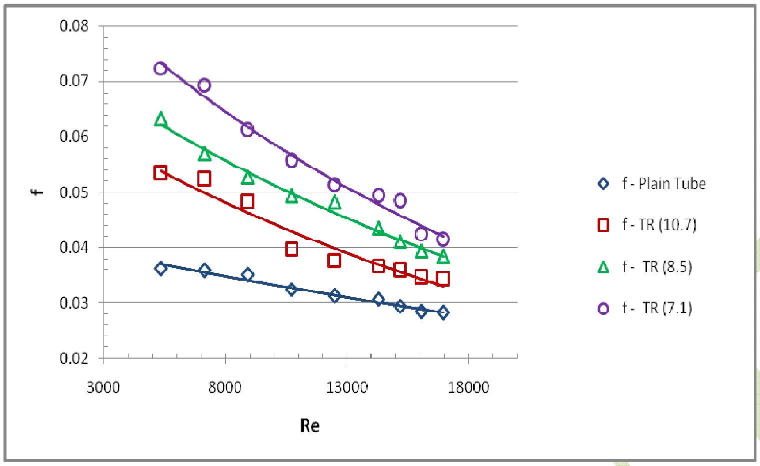

Fig. 9 Friction Factor Vs Reynolds number for TR=10.7, 8.5, 7.1

Figure 9 shows the variation of friction factor with Reynolds number. It was found that the friction factor become greater as the twist ratio decreased. The value of friction factor is more for the wavy twisted tape insert having twist ratio 7.1 as compared with other inserts. The friction factors for the case of the insert having twist ratio 7.1, 8.5 & 10.7 were 2.00, 1.47 and 0.147 times over the plain tube respectively.

Conclusions

By using wavy (corrugated) twisted tape inserts the highest heat transfer rate was achieved for twist ration 7.1. In comparison with plain tube all wavy twisted tape inserts would significantly enhance the heat transfer rate. The more twist increased the heat transfer and decreased the friction factor. From this experimental study the results can be concluded as follows,

1) For Reynold number range 5000 to 17000, the Nusselt number for wavy twisted tape insert with twist ratio 10.7, 8.5 and 7.1 was found to be 75.75 %, 157 % and 172 % respectively.
2) The Friction factor is increased approximately by 9.4 %, 22.44 % and 32.11 % with twist ratio 10.7, 8.5 and 7.1 respectively.

Nomenclatures

As	Lateral surface area of tube, m^2	Re	Reynolds number
Cp	Specific heat, J/Kg K	V	Mean velocity of water
f	Friction factor	L	Length of inner tube
h	Heat transfer coefficient, W/m^2K	ν	Kinematic viscosity of water
k	Thermal conductivity, W/mK	ρ	Density of water
Nu	Nusselt number	Pr	Prandle number
ΔP	Prassure drop		

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