Heat Transfer and Pressure Drop Characteristics in a Circular Tube Fitted with Combined Twisted Tape and Helical Screw Tape Insert

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ABSTRACT
In present work, the performance characteristics of combined twisted tape and helical screw tape inserts as a passive heat transfer augmentation tools are investigated in a double tube cross flow heat exchanger. Water is taken as medium of heat transfer. Four different combinations of these tools were experimentally studied and average Nusselt number and friction factor were calculated with Reynolds number ranging from 12,000 to 24,000. Based on overall enhancement ratio, optimum combination of tools is proposed.

General Terms
A - surface area of test tube [m2]

CP -specific heat at constant pressure [J/kg K]

D- tube diameter [mm]

L- tube length [mm]

f -friction factor

h -convective heat transfer coefficient [W/m2 K]

k -thermal conductivity [W/m K]

Nu-Nusselt number

Q -heat transfer rate [W]

Re- Reynolds number

T -temperature [°C]

U -mean velocity in tube [m/s]

ρ -density [kg/m3]

m -mass flow rate[kg/s]

ave- average

b -bulk

c- cold

h- hot

i- inlet

o- outlet

p -plain tube

t - turbulator

w -water

wall –tube wall

Keywords
heat transfer augmentation; twisted tape; Pressure drop.

1. INTRODUCTION
Various heat transfer enhancement devices are used to improve heat transfer performance of heat exchangers. Now days a many thermal engineering researchers are in search of new heat transfer augmentation methods between surfaces and the surrounding fluid. Due to this fact, Bergles [1] classified the mechanisms of enhancing heat transfer as active or passive methods. Methods in which external power is needed to enhance heat transfer are named active methods. Vibration of the surface and stirring of the fluid are examples of active methods to enhance heat transfer. On the other hand methods which do not require external power are termed as the passive enhancement methods.

Many researchers have found that full-length twisted-tape inserts improve the heat transfer performance but at the same time increase the pressure drop. studied the heat transfer and pressure drop characteristics of laminar and turbulent flow in a smooth circular tube fitted with regularly spaced twisted-tape elements were studied by Saha [2,3] and reported less pressure drop. Twisted tape techniques have been used to augment heat transfer in double pipe heat exchanger. Saha et al. [4] have considered twisted tape element connected by thin circular rods. They observed that the pressure drop associated with the full-length twisted tape could be reduced without impairing the heat transfer augmentation rates in certain situation. Smith Eiamsa-ard et al. [5] conducted experiments on a concentric tube heat exchanger with air as a hot fluid and water as a cold fluid. Hot air passed through inner tube while the cold water was flown through the annulus. They reported A maximum percentage gain of 165% in heat transfer rate using the helical insert in comparison with the plain tube. Saha et al. [6] investigated the use of turbulences promoters with short length Twist tape, and regularly spaced Twist tape element. They achieved better thermodynamics performance with short length Twist tape, and regularly spaced Twist tape element instead of full-length Twist tape. Saha et al. [7] have considered different types of strips like longitudinal rectangular, square and crossed cross-section, full length and short length, as well as regularly spaced types. They found that short length strips perform better than full-length strips. Friction factor reduces by 8-58% and Nusselt number reduces by 2- 40% for short length strips. For regularly spaced strips elements, friction factor increases by 1-35% and Nusselt number increase by 15-75%.

Eiamsa-ard and Promvonge [8] experimentally investigated the enhancement of heat transfer in a concentric double tube heat exchanger fitted with loose fit helical screw tape with and without core rod in the Reynolds number range of 2000 to 12000 and Halit Bas, Veysel Ozceyhan [9] experimentally investigated flow friction and heat transfer behavior in a twisted tape swirl generator inserted tube in the range of Reynolds number from 5132 to 24,989 and air as a working fluid and reported a considerable increase on heat transfer and pressure drop when compared with those from the plain tube. In general, the twisted tape insert generate the swirling flow and stronger turbulence in tubes. This causes a thinner boundary layer and longer resident time of the flow leading to an increase in the heat transfer coefficient. However, an increase in pressure drop is the penalty of the twisted tape technique. The straight tape twisted in geometry form of helical tape with similar geometry of the screw tape, called the helical tape was introduced in a research study. The helical tape and the twisted-tape can create the swirling flow in the circular tube and both of them posses the different characteristics of flow. For the helical tape, the swirling flow goes in single way direction (a screw motion), while the twisted-tape shows the swirling flow in two ways direction simultaneously.

The aim of present work is to investigate the effect of helical and twisted tape insert tool separately and simultaneously on heat transfer and pressure drop in a circular tube.

2. EXPERIMENTAL SET UP

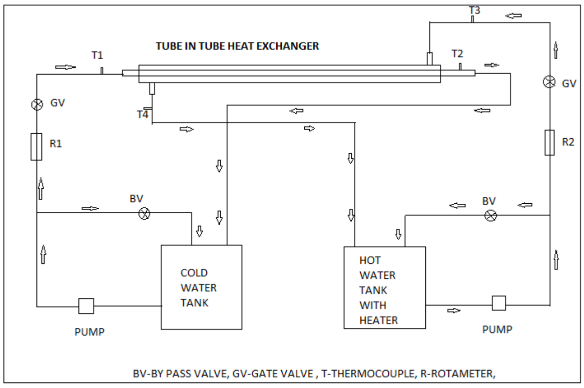

Fig.1 Experimental Set Up

Fig.2 (a) Helical Screw tape

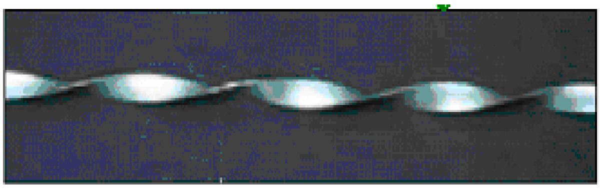

Fig.2 (b) Twisted tape

3. METHOD

Experiments were conducted in a double-pipe heat exchanger. The test water was flowing on the inner tube-side (copper tube, D=25 mm, L=2000 mm) and the heat transfer medium was passes, in counter-flow, through the annulus. Chilled water at constant flow rate of 0.482 kg/sec was used as the cooling medium in the cooler. The pressure drops across the test section were measured by using U-tube manometers. Two rotameters were provided to indicate the flow rate of the test liquid. The temperature in the test liquid storage tank was maintained constant at 25 °C. Fig.2 (a and b respectively) shows the helical screw-tape and twisted tape inserts made up of aluminum used in this test with the geometric dimensions of helical tape width (w) =19 mm, tube

wall clearance (c) =3 mm, core rod diameter (d) =11 mm, pitch length (S) =45 mm and tape thickness (t)= 6 mm. For twisted tape the width was 16 mm, tape thickness was 1.5 mm and tape pitch length was70 mm.

In the test run, four combinations of tools were used. 1) helical screw-tape in 1/3rd of tube length from beginning and twisted tape for remaining 2/3rd length. 2) Twisted tape for initial 1/3rd length, helical screw-tape in middle 1/3rd length and twisted tape for remaining 1/3rd length. 3) helical screw-tape in 1/3rd of tube length from beginning, twisted tape for middle 1/3rd length and helical screw tape for last 1/3rd length. 4) helical screw-tape in 2/3rd of tube length from beginning and twisted tape for last 1/3rd length.

In the experiments, water filled in a water tank was heated until the temperature reaches 65 °C. Then, this hot water was flowed into the inner tube of a double tube heat exchange through rotameters. When a constant temperature of 65 °C was reached for hot water at the inlet of heat exchanger, the cold water was allowed to enter the heat exchanger via a control valve. The cold water flow was maintained 0.482 kg/sec whereas the hot water flow rate was adjusted to maintain hot water Reynolds number between12,000 to 24,000. As steady state conditions were reached, temperatures of the inlet and outlet of the cold and the hot waters were recorded throughout the experiment and pressure drop was also measured by U tube manometer for the case of the plain tube and tube with inserts.

4. DATA REDUCTION

The average Nusselt number and the friction factor re based on the inner diameter of the test tube.Heat absorbed by the cold water in the annulus can be written by

$$Qc = m_c c_{pw} (T_{co} - T_{ci})$$
(1)

The heat supplied from the hot water, can be determined using

$$Q_h = m_h c_{ph} (T_{hi} - T_{ho})$$
(2)

The heat supplied by the hot fluid into the test tube is found to be 3–8% higher than the heat absorbed by the cold fluid for thermal equilibrium test due to convection and radiation heat losses from the test section to surroundings [4]. Thus, the average value of heat transfer rate supplied and absorbed by both fluids is taken for internal convective heat transfer coefficient calculation.

$$Q_{avg} = \frac{(Q_c + Q_h)}{2} = hA(T_b - T_{wall})$$
(3)

Where

$$T_b = \frac{T_{ho} + T_{hi}}{2}$$
(4)

and

$$T_{wall} = \frac{\sum T_{wall}}{5}$$

(5)

where is the local wall temperature evaluated at the outer wall surface of the test tube. The average wall temperature is calculated from 5 points of surface temperatures of the test tube. The average heat transfer coefficient, h and the average Nusselt number, Nu are estimated as follows:

$$h = Q_{avg}/A(T_b - T_{wall})$$

(6)

$$N_u = {hD}/{k}$$

(7)

Friction factor, can be written as [10]:

$$f = \frac{\Delta P}{\left(\frac{L}{D}\right)\left(\rho\frac{U^2}{2}\right)}$$

(8)

In which is mean velocity in the tube. All properties of the water are taken at the overall bulk water temperature. The overall enhancement ratio is defined as the ratio of the heat transfer enhancement ratio to the friction ratio at the same pressure drop and can be written as [10]:

$$\frac{N_{ut}}{N_{up}} \Big/ \left(\frac{f_t}{f_p}\right)^{\frac{1}{3}}$$

(9)

5. VERIFICATION OF SETUP

The test setup was checked by conducting experiments for a plain tube. The experimental Nusselt number and friction factor were compared with the those obtained from the correlations of Dittus–Boelter for the Nusselt number and Pettukhov equation for the friction factor. Comparison shows that results of the present work reasonably agree well within ±15% with friction factor correlation of Pettukhov and with Nusselt number correlations of Dittus-Boelter (Fig.3 and 4)

Fig.5 shows the variation of Nusselt number with Reynolds number for the four combinations. It was observed that the Nusselt number combination 4 is maximum among all combinations. This can be the result of maximum swirling motion and increased residence time in initial 2/3rd length due to helical screw tape. For other combinations this effect goes on reducing which results in lower heat transfer rate.

Fig.6 shows the variation in the friction factor with Reynolds number. It is seen that the pressure drop is maximum for combination 4. Comination 4 consists of helical screw tape for initial 2/3rd length which results in higher abstcles in the flow.

All other combinations have only 1/3rd length insertion of helical screw tape. This results in lower pressure drop. Thus friction factor is low.

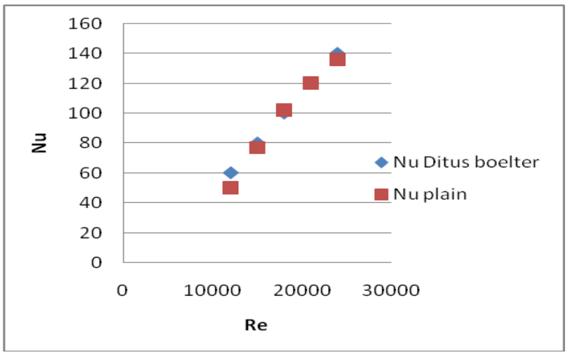

Fig.3 Verification of Nu with Re

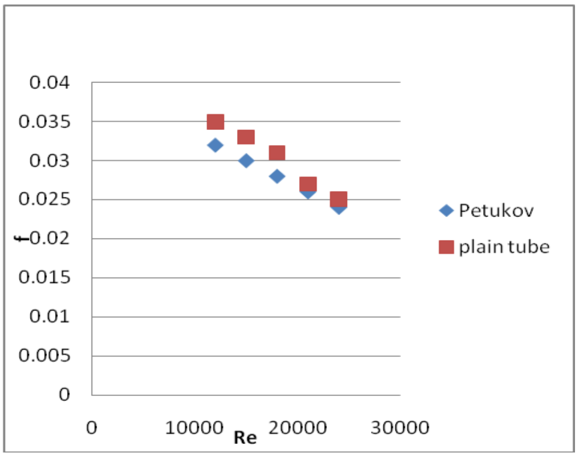

Fig.4 Verification of f with Re

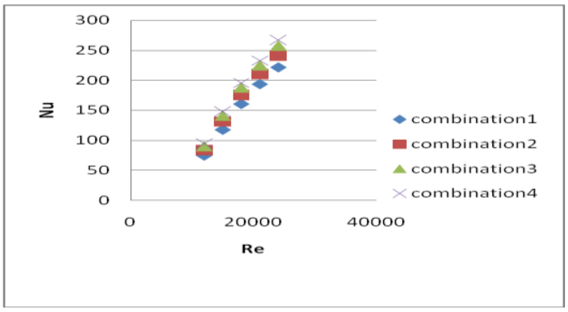

Fig.5 Variation of Nusselt number with Re

Fig.7 shows the variation of overall enhancement ratio with Reynold number. enhancement ratio was found to be maximum for combination 1. For this combination as swirling motion is initialized earlier , heat transfer effectiveness increases. At the same time, pressure drop is minimum due twisted tape insert in last 2/3rd length.

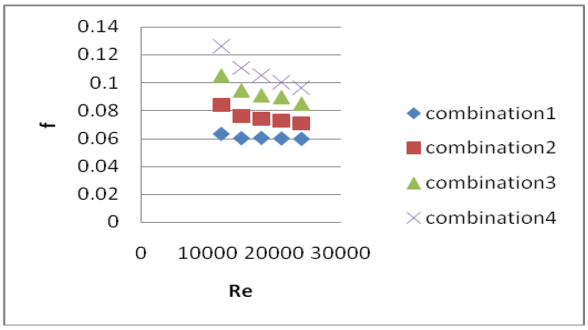

Fig.6 Variation of friction factor with Re

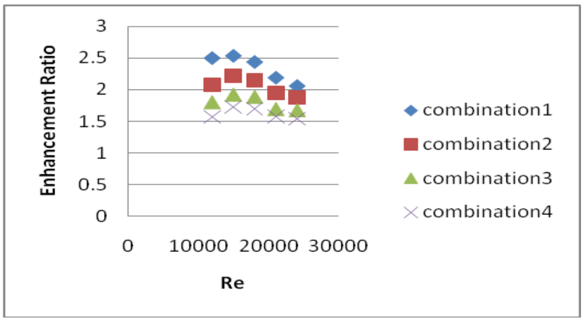

Fig.7. Variation of Enhancement ratio with Re

6. CONCLUSION

Heat transfer and pressure drop characteristics for different combinations of two passive tools are experimentally investgated. Experimental results show that the heat transfer and pressure drop increases with higher Reynolds number for all the combinations propsed in the study. However, the overall enhancement ratio increases as the length of twisted tape insertion increases in the combinaion and found to be maximum at the combiantion where helical screw tape is inserted in initial 1/3rd length of tube and twisted tape in remaining 2/3 length. Thus this combination was found to be optimum among all combinatons under consideration.

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