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Experimental Investigation of Heat Transfer Enhancement in Circular Tube Using Twisted Tape Inserts

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Abstract: Experimental investigation of heat transfer and friction factor characteristics in a double pipe heat exchanger fitted with typical twisted tape elements, were studied. The inner and outer diameters of the inner tube are 19.9 and 22.2 mm, respectively. Cold and hot water were used as working fluids in inner and outer side of heat exchanger. The twisted tapes were made of aluminum strip with thickness of (0.8) mm and the length of (1) m. They were inserted in the test tube section in full-length twisted tape at different twisted ratios (5, 4.5, 4 and 3.5). The results, obtained from the tube with twisted tape insert, were compared with those without twisted tape. The experiment result showed that the improvement for heat transfer rate ranging from (50.54% to 52.22%) at twisted tape 5, (52.42% to 55.15 %) at twisted tape 4.5 and (52.41% to 56.98%) at twisted tape 3.5, for plain tube with twisted tape tubes with respect to plain tube without twisted tape.

Keywords: Twisted Tape Inserts, Heat Transfer Enhancement, Friction Factor, Laminar, Pressure Drop

1. Introduction

A heat exchanger is a device that is used to transfer heat between two or more fluids that are at different temperatures. Heat exchangers are essential elements in a wide range of systems, including the human body, automobiles, computers, power plants, and comfort heating/cooling equipment [1]. Generally one of wide utilized sort of heat exchanger is the double pipe heat exchanger, the enhancement of heat transfer rate which is the principle target of this work [2].

Energy and material saving considerations have enhanced an expansion of desired efforts at producing most efficient heat exchange equipment through the increment of heat transfer. As the efforts to get more efficient heat transfer equipment continue, an increasing number of augmented technique and surface are being created commercially. These techniques of enhancement can be categorized under; passive and active techniques, in addition to a hybrid technique which includes two or more from each of passive and active technique. [3]

The present work deals with finding the effect of change twisted ratio in heat transfer in the heat exchanger with different mass flow rate and comparing those results with plain tube without twisted tape tube.

Smith et al. [4] performed an experimental examinations in the heat transfer and friction factor in horizontal tube with and without twisted tape in classic twisted tape with twisted ratio, y=6.0 and 8.0. Water is used as working fluid. The results showed that heat transfer coefficient and friction factor increased with decreasing the twisted ratio. The maximum enhancement of Nusselt numbers is 179 % in plain tube for twisted ratio 6.

Ranjit and Amit [5] thorough an experimental study of heat transfer augmentation using twisted tape and twisted angles. Five twisted angles ($y=\infty$, y=2.915, y=3.612, y=4.105 & y=5.07) and three twisted tapes (y=2.149, y=3.127 & y=4.705) are used in the study. These result show that the heat transfer coefficient for twisted angles could contrast from (1.16 - 2.89) times the plain tube value but The friction factor is improved by (4 - 9.6) times the plain tube values. For twisted tapes The coefficient of heat transfer is varied from (1.28 - 2.48) times increment of the FF is between 3.19 to 9.1 times the plain tube value.

Murugesan et al. [6] studied experimentally the heat transfer and friction factor and thermal performance characteristics of turbulent flow ($6500 \leq Re \geq 12{,}500$) in heat exchanger in a tube which is fitted with a full length twisted tape with a trapezoidal cut and constant wall heat flux condition. The results showed that there was a significant increase in heat transfer coefficient and friction factor for tape with the trapezoidal cut "up to 3.68 and 4.25 times when are compared with the plain tube", individually.

Mohammed [7] investigated the high-temperature transfer and pressure drop in Eccentric Converging-Diverging Tube with twisted tape inserts. Experiments have been conducted with tape inserts of three different twisted ratio. The experimental information for the plain tube and (ECDT) without inserts are compared with (ECDT) with twisted tape insert. The results display that the Nusselt number for the (ECDT) 52% to 280% is higher than plain tube and pressure drop found 6.8 times the plain tube.

Bodius et al. [8] performed an experimental study of heat transfer increment for turbulent flow in a plain tube fitted with rectangular-cut twisted tape insert. The Reynolds numbers varies in the range of 10000-19000. The heat varies from 14 to 22 kW/m^2 for plain tube, and 23 to 40 kW/m^2 for tube with insert. At similar Reynolds numbers and Nusselt numbers in tube with rectangular-cut twisted tape The heat transfer has been enhanced from 2.3 times to 2.9 times in the cost of the increment of friction factors by 1.4 to 1.8 times in comparison with plain tube.

Sami et al. [9] performed numerical investigation of the heat transfer and friction factor of a plain fitted with the V-cut twisted tape insert with (twisted tape = 2.93) in laminar flow using CFD ckage (FLUENT-6.3.26). We studied Classical twisted tape (CTT) with twist ratios= 2.93, 3.91, 4.89 for comparison. We see that the results that the enhancement of heat transfer rate in the classical and V-cut twisted tape inserts increases with increases the Reynolds numbers and decreases with increasing twist ratio.

Talakala [10] the effects of twisted tape insert were studied numerically on the characteristics of heat transfer and friction factor in plain tube. Water was used as working fluid with Reynolds numbers range (800 to 10,000). With four full width twisted tape inserts (FWT T) of "(TR = 2, 3, 4 and 5)" . The results showed that heat transfer coefficient found to be 2.65 to 3.45, 2.44 to 2.19, 2.11 to 2.64, and 1.87 to 2.35 times respectively in laminar field.

M. M. K. Bhnya et al. [11] An experimental analysis of a triple twisted tapes on heat transfer rate and friction factor were investigated experimentally. The triple twisted tape with four TR (y = 1.92, 2.88, 4.81 and 6.79) for the Reynolds numbers range from 7200 to 50,200. The results showed that the decreasing twisted ratio increases the Nusselt numbers. and friction factor. "The Nusselt numbers and friction factor of using the triple twisted tape inserts were found to be increased up to 3.85 and 4.2 times when are compared with the plain tube", individually.

Prashant [12] is the performance experimental analysis on heat transfer, friction factor and thermal performance characteristic of turbulent flow (7500 $\leq$ Re $\geq$ 13,000) in heat exchanger tube with twisted tape and constant wall heat flux condition. The twisted tape with five different width ratios of 0.34, 0.44, 0.53, 0.62 and 0.72 and constant twisted ratio of 2.5 The experimental results showed that Nusselt numbers increases with increasing Reynolds numbers and increasing width ratio (W/D) of twisted tape. Also, friction factor decreases with increasing Reynolds numbers and decreasing width ratio.

2. Experimental Method

The schematic diagram of the experimental setup is shown in Figure 1 a. The test section consists of double pipe heat exchanger, where hot water flows inside the tube while the cold water flows in shell side. Shell side was produced from PVC tube of (100 mm) inner diameter, (1.25 m) length and (5 mm) thickness. It is insulated from outside by sheet and roll insulation (arm flux) which has (25.4 mm) thickness, ($0.036 \frac{W}{m.\mathring{c}}$) thermal conductivity, to reduce heat losses to the minimum level. The shell was ended by two rubbers of (110) mm in one side and (22) mm in the other side. These caps drilled in the center part to make a hole of (22 mm) diameter. This hole allows the copper to enter tube through it. To prevent the water leakage from the end of the shell side, silicone is used on both shell caps. The inner tube side is made of copper with or without twisted tape. The twisted tape is inserted along the test section. It is made from aluminum strip with tape thickness of 0.8 mm, withfull width W of 19.9 mm and tape length of 1000 mm. The twisted tape is prepared by twisting a straight tape, about its longitudinal axis with four twist ratio (TR=3.5, 4, 4.5, 5).

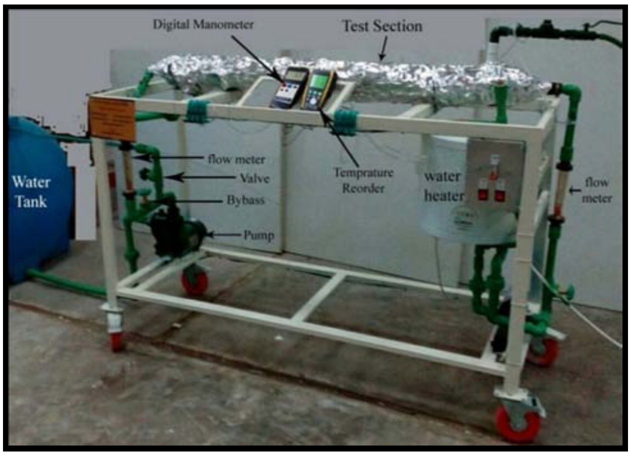

Figure 1. *Experimental test rig.*

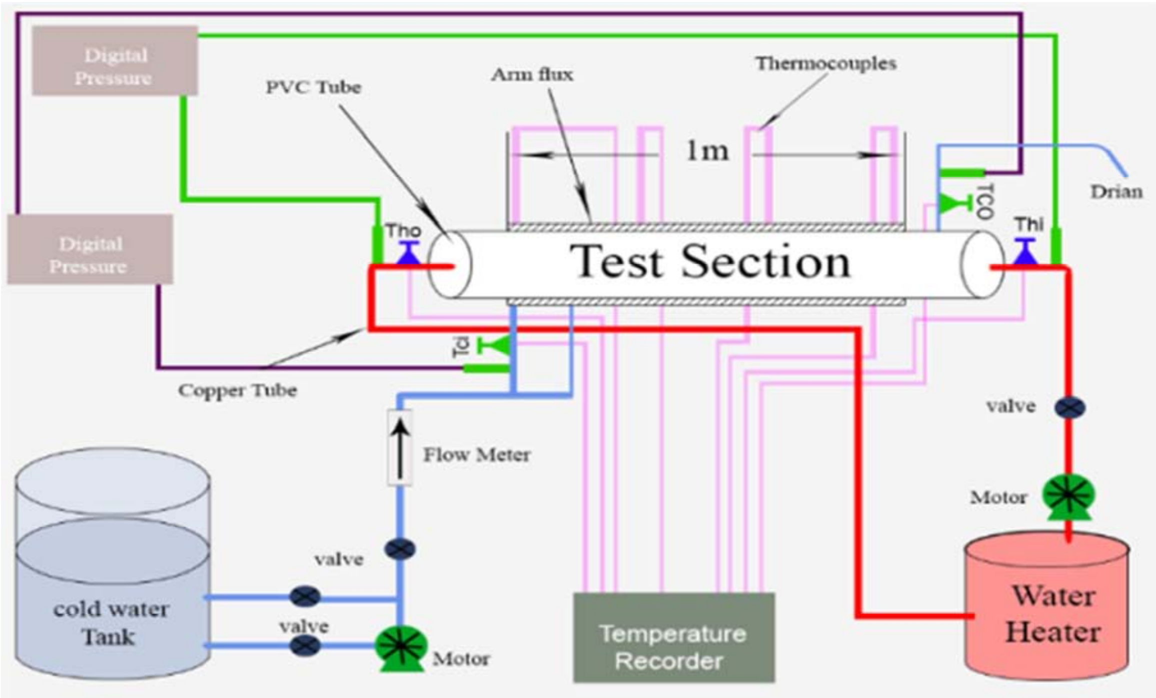

Figure 2. *Schematic diagram for test rig.*

3. Experimental Procedure

(1) All the flow meter and thermocouples are calibrated.
(2) The hot water is used at temperatures is (60°C), heated by used electrical heater and different hot water flow rate.
(3) Cold water temperature (25°C) cooling water by using ice and two mass flow rate (0.016,0.022 kg/s)
(4) The hot water flow through the copper tube, and the cold water flow through PVC tube.
(5) Temperature of water in both side hot and cold are recorded after temperature of both the fluid attains a steady state.
(6) The procedure was repeated for all hot and cold flow rate and for all hot water temperature.

Heat Transfer Can Be Calculated with the Following Equation

$$Q = m\,Cp\,[T_{out} - T_{in}]$$

Reynolds number can be calculated with

$$Re = UD / V$$

Nussult number and friction factor

$$Nu = hD / K$$

$$f = 16 / Re$$

[13]

4. Results and Discussions

Fig. 1, 2 illustrate that the relation between various hot water mass flow rate and heat dissipation of inner side for plain tube and twisted tape tube with TR (5, 4.5, 4, 3.5) and constant cold water mass flow rate,(0.016 and 0.22 kg/s).

It may be seen from these figures that heat dissipation of the twisted tape tube higher than plain tube. The enhancement of heat dissipation for twisted tape tube is (1.4 to 1.65) and (1.814 to 1.97) times than that of plain tube respectively.

The main reason of this enhancement is the introduced secondary flow along lane flow of water which escorted with increase in degree of turbulent, which chiefs to good water mixing, reduces the thermal boundary layer thickness and hence heat transfer increases.

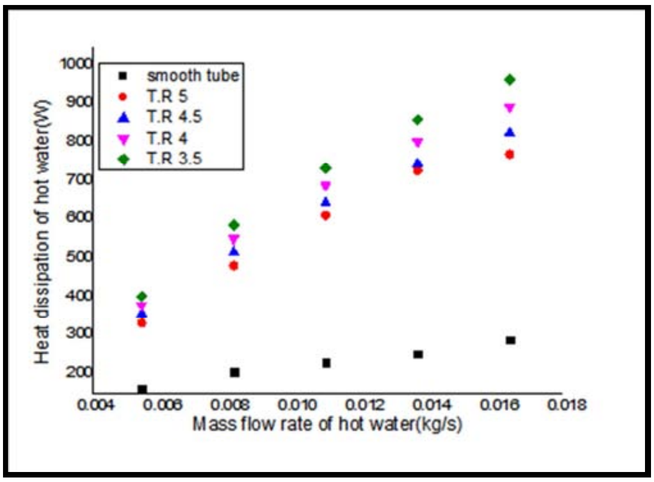

Figure 3. *Effect of hot water mass flow rate on heat dissipation at $\dot{m}_c$=0.016 kg/s for smooth tube and twisted tape (w=19.9 mm).*

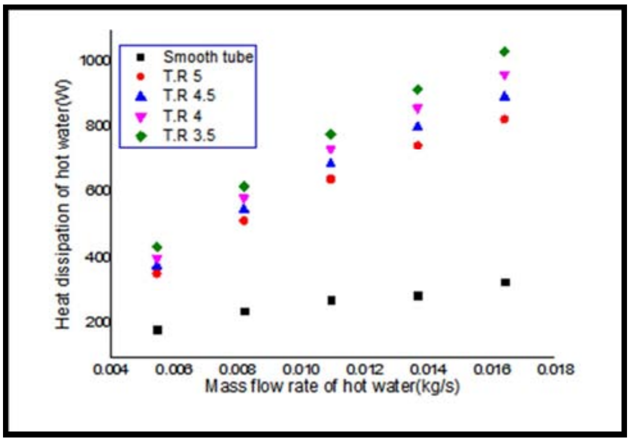

Figure 4. *Effect of hot water mass flow rate on heat dissipation at $\dot{m}_c$=0.022 kg/s for smooth tube and twisted tape (w=19.9 mm).*

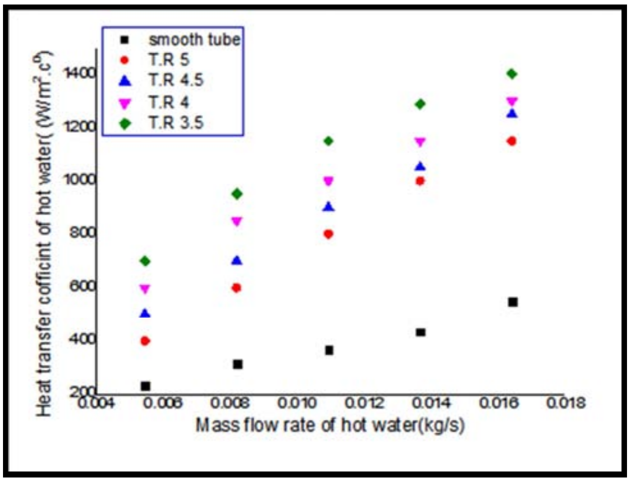

Figure 5. *Effect of hot water mass flow rate on hot water heat transfer coefficient for smooth, twisted tube at $\dot{m}_c$=0.016 kg/s (w=19.9 mm).*

Fig. 3, 4 illustrate the effect of different hot water mass flow rate on the inner heat transfer coefficient side for plain tube and twisted tape tube with TR (5, 4.5, 4, 3.5) at constant mass flow rate of cold water equal to (0.016 and 0.022 kg/s).

It can be seen in these figures that heat transfer coefficient of twisted tape tube (2.03 to 2.41) and (2.1 to 2.74) times than that of plain tube respectively. This is due to faster flow of tube with twisted tape.

Fig. 5, 6 illustrate the effect of different hot water mass flow rate on the Nusselt number for plain tube and twisted tape tube with TR (5, 4.5, 4, 3.5) at constant mass flow rate of cold water equal to (0.016 and 0.022 kg/s). the result shows that Nusselt number of twisted tape tube (1.95 to 2.64) and (2.03 to 2.65) times than that of plain tube respectively.

Fig. 7, 8 illustrate the effect of different hot water mass flow rate on the overall heat transfer coefficient for plain tube and twisted tape tube with TR (5, 4.5, 4, 3.5) at constant mass flow rate of cold water equal to (0.016 and 0.022 kg/s). the result shows that overall heat transfer coefficient of twisted tape tube (1.97 to 2.54), (2.01 to 2.87) times than that of plain tube respectively.

Fig. 9 illustrate the effect of different hot water mass flow rate on the friction factor water equal to (0.022 kg/s). the result shows that friction factor of twisted tape (68-71) % more than the plain tube without twisted tape.

Fig.10 show the variation of inner tube surface temperature with axial distance at various hot water Reynold's number. It can be noted from these figures that surface temperature decreases with axial distance by (38%). This is due to the counter flow arrangement of the present heat exchanger. But the surface temperature increased with the increase in hot water mass flow rate by (35%).

Fig. 11 illustrate the variation of effectiveness with number of transfer units. Positive relationship can be noted in this figures. This is due to the dependence of the number of transfer units and effectiveness on the overall heat transfer coefficient. Effectiveness of plain tube with twisted tape is greater than that of plain tube without twisted tape by (68.73%).

5. Conclusions

In the present study, the heat transfer enhancement in circular tube fitted with the twisted tapes of having twisted ratio (y) =5, 4.5, 4, & 3.5 at constant width ratio of 1 is experimentally studied in laminar flow region, Reynolds number = 650 to 1950. The key findings based on experimental results of present study are summarized as follows:

1. The heat transfer enhancement offered by twisted tapes of different twisted ratio is significant compared to plain tube.
2. The Nusselt number increases with increasing Reynolds no. and decrease twisted ratio of twisted tape.
3. The friction factor increases with decreasing Reynolds no. and increasing twisted ratio of twisted tape.
4. The enhancement in heat transfer is higher for twisted tape having twisted ratio=3.5 and lower for twisted ratio=5.
5. The increase in Nusselt no. is 6.04%, 7.95%, 9.56% & 15.46% for twisted of twisted ratio =5, 4.5, 4& 3.5 respectively.
6. The increment in thermal enhancement efficiency is higher for low twisted ratio and it decreases with increase twisted ratio of twisted tape at constant mass flow rate.

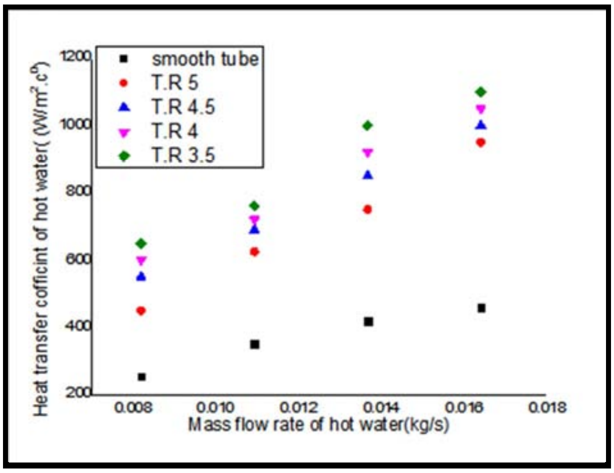

Figure 6. *Effect of hot water mass flow rate on hot water heat transfer coefficient for smooth, twisted tube at $\dot{m}_c$=0.022 kg/s (w=19.9 mm).*

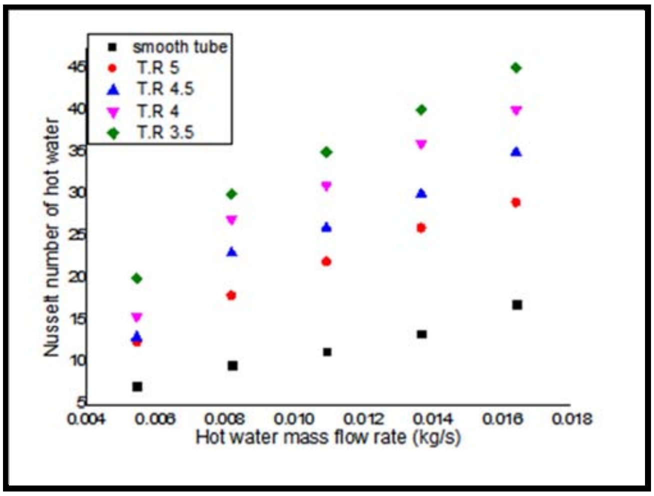

Figure 7. *Variation of hot water mass flow rate with hot water side Nusselt's number at $\dot{m}_c$=0.016 kg/s for smooth tube and Twisted tape.(w=19.9 mm).*

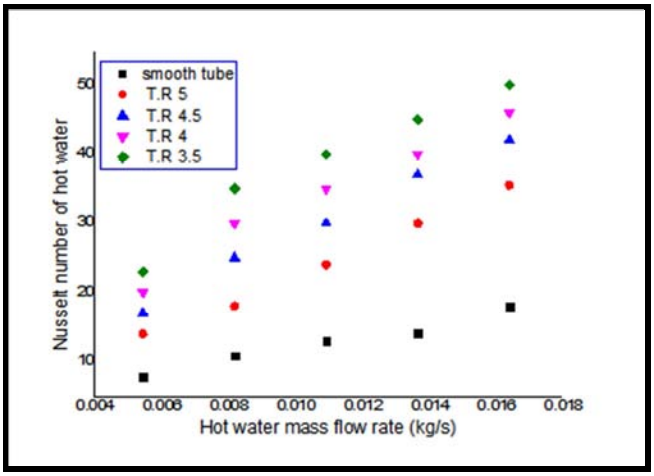

Figure 8. *Variation of hot water mass flow rate with hot water side Nusselt's number at $\dot{m}_c$=0.022 kg/s for smooth tube and Twisted tape. (w=19.9 mm).*

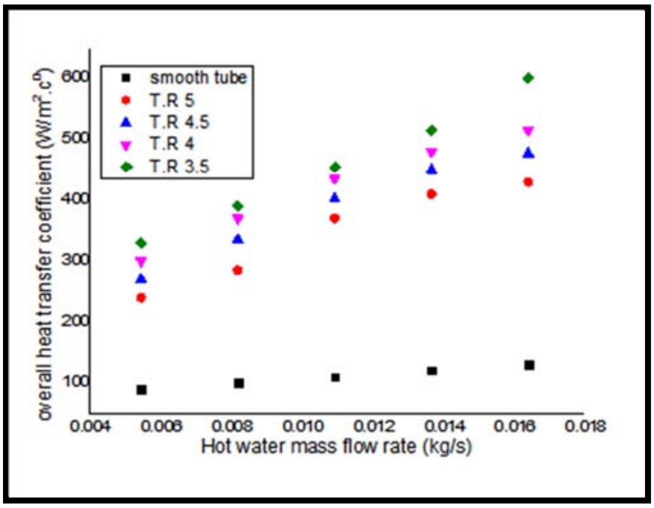

Figure 9. *Effect of mass flow rate on overall heat transfer coefficient at $\dot{m}_c$=0.016 kg/s for smooth tube, Twisted tape (w=19.9 mm).*

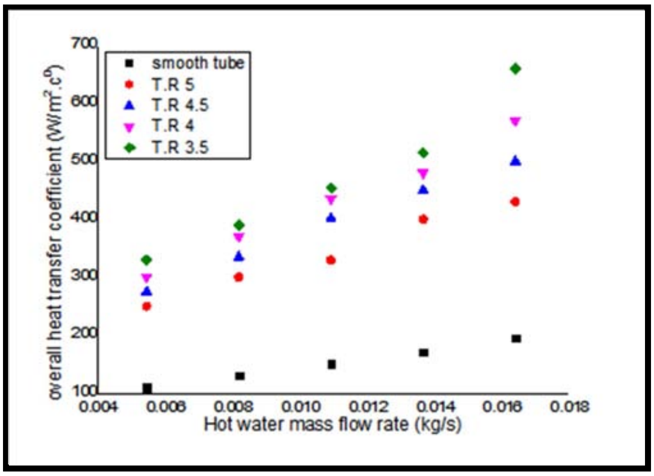

Figure 10. *Effect of mass flow rate on overall heat transfer coefficient at $\dot{m}_c$=0.022 kg/s for smooth tube, Twisted tape (w=19.9 mm).*

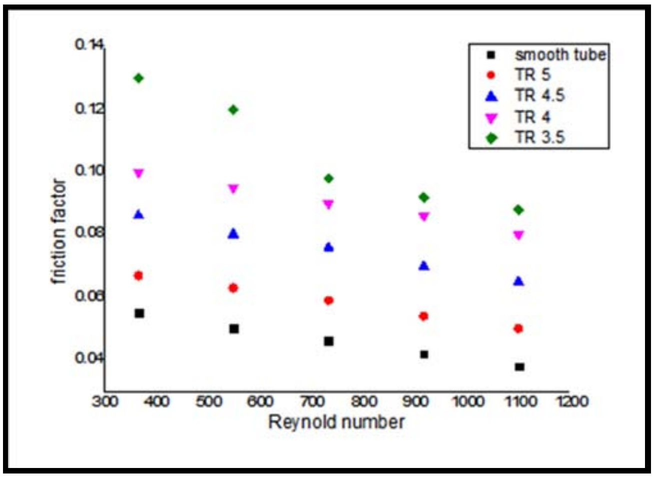

Figure 11. *The effect of Reynolds number and different twisted ratio on friction factor for distilled water at$\dot{m}_c$=0.022 kg/s (w=19.9 mm).*

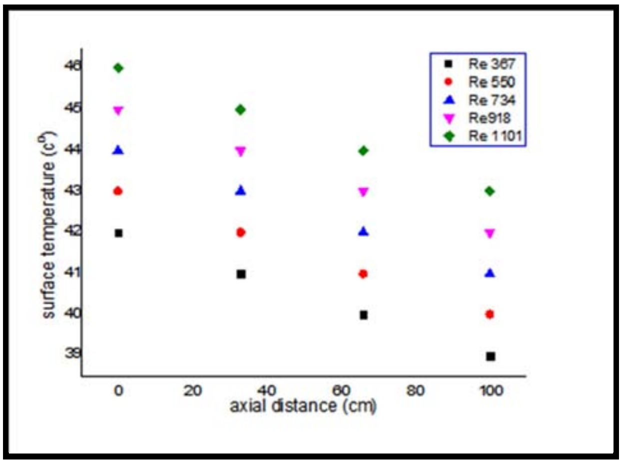

Figure 12. *Variation of surface temperature with axial distance for Twisted tape at different Reynold number. w=19.9 mm).*

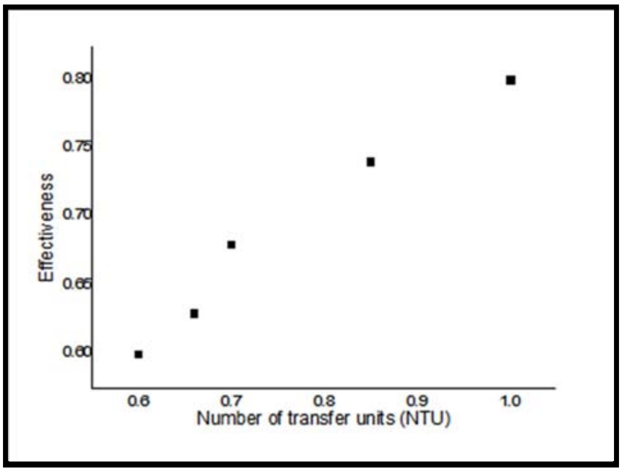

Figure 13. *Variation of effectiveness with number of transfer units (NTU) in twisted tape with (W=19.9 mm) and TR=(3.5).*

Nomenclature

A = surface area of test tube, m2
Cp = specific heat at constant pressure, J/kg K
D = tube diameter, m
f = friction factor
h = convective heat transfer coefficient, W/m2 K
k = thermal conductivity, W/m K
L = length of tube, m
$\dot{m}$ = mass flow rate, kg/s
Nu = Nusselt number
Pr = Prandtl number
Q = heat transfer rate, W
Re = Reynolds number
T = temperature, °C
u = mean velocity in tube, m/s
U = overall heat transfer coefficient, W/m2 K
P= density, kg/m3
μ = dynamic viscosity, kg/m s
Subscripts
c = cold
h = hot
i =inner
o = outer
w = water

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