Heat Transfer Enhancement in a Tube using Elliptical-Cut Twisted Tape Inserts

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Abstract :

An experimental investigation was carried to improve the performance of heat exchanging devices for reducing material cost and surface area for heat transfer. The effect of Elliptical-cut twisted tape insert on heat transfer, friction factor and thermal performance factor characteristic in a circular tube were investigated for twist ratio (y= 8.0) and five different combinations of major and minor axis ratios (Z=5, Z=4, Z=3.3, Z=3, Z=2.5). The Reynolds numbers were varied in the range 5000-22000. Nusselt numbers obtained from smooth tube were compared with Gnielinski and Dittus-Boelter correlation and errors were found to be average of 12.2% and 9.2% respectively. Friction factor obtained from experiments were compared with Blasius and Petukhov correlation found to be increased by an average of 43.6% and 43% respectively. The obtained results shows that the mean Nusselt number and the mean friction factor in the tube with elliptical-cut twisted tape increase with decreasing major to minor axis ratio (Z).

Keywords - *Elliptical-cut twisted tape insert, Friction factor, Heat exchanger, Heat transfer enhancement,*

I. INTRODUCTION

The technique of improving the performance of heat transfer system is referred to as heat transfer augmentation. It has been commonly known that the performance of heat exchangers, for single-phase flow can be improved by many augmentation techniques. Heat transfer augmentation techniques are widely used in areas such as heat recovery process, air conditioning and refrigeration systems and chemical reactors. In general, heat transfer enhancement technique can be divided into two groups, namely active and passive techniques. The active technique requires extra external power source. The other is passive technique, which requires no direct employment of the external power. Among various techniques, insertion of twisted tapes swirl generator is one of the most promising techniques, which has been widely adopted for heat transfer augmentation.

The swirl generator caused recirculation of an existing axial flow which leads to an improvement of fluid mixing and thus obtained an efficient reduction of the thickness of boundary layer. However, in the process pumping power increased, which will lead to a considerable increase of pumping cost.

The passive methods of heat transfer augmentation techniques have been discussed in detail by P. Murugesan et al. [1], Salman et al. [2] reviewed that passive technique particularly twisted tape with rectangular-cut and v-cut are economical heat transfer augmentation tools. Smith Eiamsa-ard et.al [4] investigation of heat transfer and friction factor characteristics in a double pipe heat exchanger fitted with regularly spaced twisted tape. More information about heat transfer by means of twisted tapes fitted in a circular tube can be viewed in other reports. Based on available literature, it was pointed out that the modification on plain twisted tape (PTT) i.e. small cuts on the tape, gave assurance for both enhancement of heat transfer rate and thermal enhancement factor. The reason behind the high thermal enhancement factor is that those small cut brings pressure drop in system to the reasonable level. The objective of this paper is to study heat transfer and friction characteristics in heat exchanger fitted with Plain twisted tape and Elliptical-cut twisted tape and also to study the enhancement effect of Elliptical-cut with different major to minor axis ratio.

II. LITERATURE REVIEW

2.1 Review paper 1

Bodius Salam et. al. (2013) paper state an Experimental investigation was carried for measuring tube-side heat transfer coefficient, friction factor, heat transfer enhancement efficiency of water for turbulent flow in a circular tube fitted with rectangular-cut twisted tape insert. The Reynolds numbers were varied in the range 10000-19000 with heat flux variation 14 to 22 kW/m^2 of smooth tube and 23 to 40 kW/m2 for tube with inserts.

Nomenclature:		Greek Symbol	
A	heat transfer surface area, m2	δ	Tape thickness, m
D_i	inside diameter of test tube, m	H	Thermal performance factor
D_o	outside diameter of test tube, m	ρ	Density (Kg/m^3)
f	friction factor		
h	heat transfer coefficient, W m-2K-1	Abbreviations	
L	length of test section, m		
Nu	Nusselt number	M	Major axis of elliptical-cut
ΔP	pressure drop, Pa	m	Minor axis of elliptical-cut
Pr	Prandtl number	Z	Ratio of major to minor axis of elliptical cut
Q	Heat transfer rate, W	PTT	Plain twisted tape
T	Temperature, ^{O}C		
W	Tape width, m		
Y	Pitch length of twisted tape, m		
y/W	Twist ratio		
m	Mass flow rate of water (kg/s)		
Re	Reynolds number		
Nu	Nusselt number		
U_m	Mean Velocity (m/s)		
K	Thermal conductivity of water (W/m.K)		
K_w	Thermal conductivity of tube material (W/m.K)		
A_f	Flow area (m^2)		
C_p	Specific heat of water at constant pressure(J/Kg.K)		
q	Heat flux (W/m^2)		
Subscripts			
b	Bulk		
i	Inlet		
o	Outlet		
p	plain tube		
t	twisted tape		
w	Wall		

At comparable Reynolds number, Nusselt numbers in tube with rectangular-cut twisted tape insert were enhanced by 2.3 to 2.9 times at the cost of increase of friction factors by 1.4 to 1.8 times compared to that of smooth tube. Heat transfer enhancement efficiencies were found to be in the range of 1.9 to 2.3 and increased with the increase of Reynolds number

2.2 Review paper 2

P. Murugesan et. al. (2011) in his research present an effect of V-cut twisted tape insert on heat transfer, friction factor and thermal performance factor characteristics in a circular tube were investigated for three twist ratios (y=2.0, 4.4 and 6.0) and three different combinations of depth and width ratios (DR=0.34 and WR=0.43, DR=0.34 and WR=0.34, DR=0.43 and WR=0.34). This paper states that the mean Nusselt number and the mean friction factor in the tube with V-cut twisted tape (VTT) increase with decreasing twist ratios (y), width ratios (WR) and increasing depth ratios (DR). The V-cut twisted tape offered a higher heat transfer rate, friction factor and also thermal performance factor compared to the plain twisted tape. In addition, the influence of the depth ratio was more dominant than that of the width ratio for all the Reynolds number.

2.3 Review paper 3

Smith Eiamsa-ard et.al.(2014) in his research states the effects of addition of multiple twisted tapes in different arrangements and TiO_2 nanoparticles with different concentrations as the working fluid in Heat exchanger. The tube inserted the multiple twisted tapes showed superior thermal performance factor when compared with plain tube or the tube inserted a single twisted tape, due to continuous multiple swirling flow and multi-longitudinal vortices flow along the test tube. The higher number of twisted tape inserts led to an enhancement of thermal performance that resulted from increasing contact surface area, residence time, swirl intensity and fluid mixing with multi-longitudinal vortices flow. Moreover, arrangement of twisted tapes in counter current was superior energy saving devices for the practical use, particularly at low Reynolds number. This was especially the case for quadruple counter tapes in the cross directions (CC-QTs) where heat transfer enhancement with relatively low friction loss penalty was deserved. The use of CC-QTs led to the highest thermal performance factor up to 1.45. Using water with TiO2 nanoparticle as a working fluid yielded a higher thermal performance than using pure water. The tube inserted CC-QTs with TiO2/water nanofluid at concentration of 0.21% by volume provided the highest thermal performance factor 1.59, where heat transfer rate and friction factor increased to 3.52 times and 11.7 times of those in the plain tube with water as the working fluid.

2.4 Review paper 4

Smith Eiamsa-ard et.al.**(**2006) in his experimental investigation of heat transfer and friction factor characteristics in a double pipe heat exchanger fitted with regularly spaced twisted tape elements, were studied**.** The results, obtained from the tube with twisted tape insert, were compared with those without twisted tape. The results show that the heat transfer coefficient increased with twist ratio. Whereas the increase in the free space ratio would improve both the heat transfer coefficient and friction factor. It can be found that enhancing heat transfer with passive method using different types of twisted tape construction in the inner tube of a double pipe heat exchanger can improve the heat transfer rate efficiently. However, the friction factor of the tube with the twisted tape insert also increases. The increase in heat transfer and friction can be explained by the swirling flow as a result of the secondary flows of the fluid.

2.5 Review paper 5

W.H.Azmi et. al. (2014) study Experimental determination of heat transfer coefficients of SiO_2/water and TiO_2/water nanofluid up to 3% volume concentration flowing in a circular tube. The investigations are conducted in the Reynolds number range of 5000 to 25000 at a bulk temperature of 30^{o}C. The experiments are undertaken for flow in a circular tube with twisted tapes of different twist ratios in the range of $5 \leq H/D \leq 93$. The heat transfer enhancement is inversely increased with twist ratio. The heat transfer coefficient of SiO_2/water nanofluid at 3.0% volume concentration is 27.9% higher than water flow for the same twist ratio of five and the value of heat transfer coefficient ofTiO_2/water nanofluid evaluated at the same concentration is 11.4% greater than water for twist ratio five. The maximum heat transfer enhancement with twisted tape for TiO2/water and SiO2/water nanofluids is found at 1.0% and 3.0% volume concentration, respectively

III. EXPERIMENTAL SETUP

The apparatus with the basic component and fluid flow system are presented in fig. 1. The test section was made from 1100 mm of copper tube of which 1000 mm was considered to be test section. Elliptical-cuts are introduced in the PTT on the top and bottom alternately in the peripheral region with different ratios of major to minor axis. The following fig. 1 (a), (b), (c), (d) and (e) are of Z= 5, 4, 3.3, 3, and 2.5 respectively. The details of twisted tape are summarized in table 1.

Fig. 1 (a)

Fig. 1 (b)

Fig. 1 (c)

Fig. 1 (e)

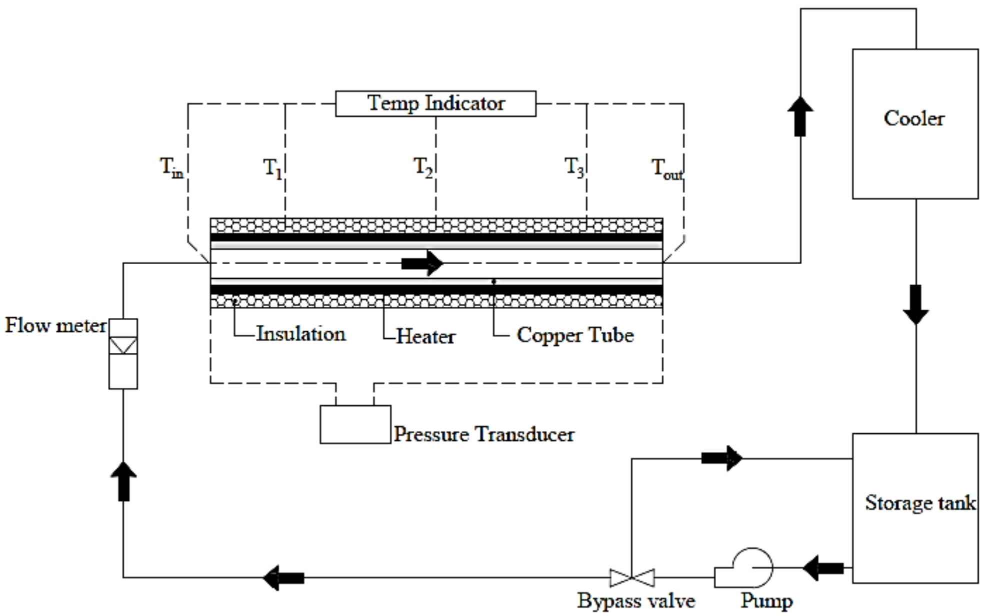

Fig. 2 Schematic Figure of Experimental Setup

Material	Aluminium
Tape width (W)	19 mm
Tape thickness	1 mm
Tape pitch length	152 mm
Twist ratio	8
Major axis (M)	12, 16 and 20 mm
Minor axis (m)	4, 6 and 8 mm
Major to Minor axis ratio (Z)	2.5, 3, 3.3, 4 and 5

Table 1 Details of twisted tape

The nichrome resistance wire was spirally wound uniformly on the outer surface of the test section to supply the heating power. Mica sheet was sheet and ceramic wool. The heating wire was connected to 240 volt main. Three thermocouples were placed on three equally placed points of the test section to measure the outer surface temperature of the tube. Two thermocouples were placed at the inlet

Table 2 Specification of the Experimental Setup

Sr No	Equipment Name	Dimension Range / Capacity	Remark
1	Test Section(Copper Tube)	Length= 1m, ID= 18mm , OD= 23mm	
2	Nichrome Wire Heater	3 kW, 20 Gauge, 240V, 5A	Surface Temp=550^{0}C
3	Insulation (Ceramic wool)	Thickness=20mm	K=0.12 W/mk
4	Pressure sensor	1 bar to 5 bar	
5	Pump	0.5HP	
6	Thermocouple(K Type)	0^{0}C to 1260^{0}C	Least Count= 0.1^{0}C
7	Rotameter	2 L/min to 20 L/min	Least Count= 0.5 l/min
8	Storage Tank	25Litre	

IV. DISCUSSION

A. *Validation of Plain Tube with/without Twisted Tape*

As displayed in Figs. 3(a–b), the data obtained from the present work are found to be in excellent agreement with the standard correlations of Dittus–Boelter (1930) and Gnielinski (1976) equation for Nusselt number, Blasius and first Petukhov (1970) equation for friction factor of plain tube.

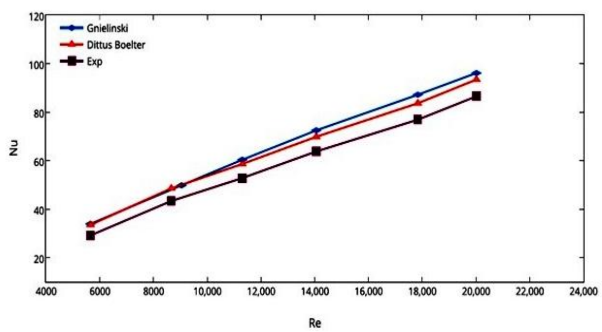

Fig. 3 (a)

and outlet of the tube to measure the inlet and outlet water temperature respectively. Pressure sensor was used of the tube to measure the inlet and outlet water temperature respectively. Pressure sensor was used to measure pressure difference. The details of the experimental set up are summarized in table 2.

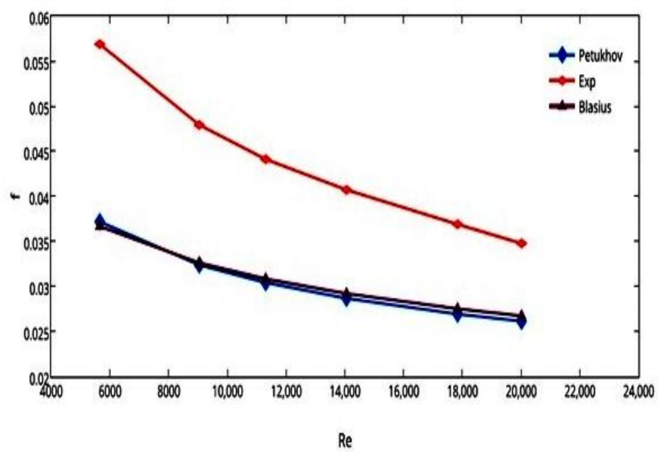

Fig 3 (b)

The deviations of the present data from the mean experimental Nusselt number of plain tube were 9.2% and 12.2% lower than that of the Dittus-Boelter and Gnielinski correlations respectively. Experimental mean friction factors of plain tube were respectively 43.6% and 43% higher than that of the Blasius and Petukhov correlations

Nusselt number correlations for the plain tube:

Correlation of Dittus-Boelter:

$$Nu = 0.023Re^{0.8}Pr^{0.4} \qquad (1)$$

Correlation of Gnielinski:

$$Nu = \frac{(f/8)(Re-1000)Pr}{1+12.7(f/8)^{1/2}(Pr^{2/3}-1)} \qquad (2)$$

Friction factor correlation for the plain tube:

Correlation of Petukhov:

$$f = (0.79 \ln Re - 1.64)^{-2} \qquad (3)$$

Correlation of Blasius:

$$f = 0.318\, Re^{-0.25} \qquad (4)$$

B. Effect of Elliptical-Cut Twisted Tape

The heat transfer and friction factor increase with increasing minor axis and decreasing major axis are shown in Fig. 4(a–b). It can be also interpret as decreasing Major to Minor axis ratio i.e. Z, the heat transfer and friction factor were increases. This implies that for the higher minor axis and lower major axis, the vorticity behind the cut are further promoted resulting in an increasing turbulence and additionally enhanced the heat transfer and friction factor. As found, the average Nusselt number for the tube with PTT and Elliptical-cut twisted tape of Z=5, Z=4, Z=3.3, Z=3,Z=2.5 are respectively, 19.3%, 41.8% , 53.83%, 68.5%, 73.16% and 84.5% higher than those given by the plain tube.

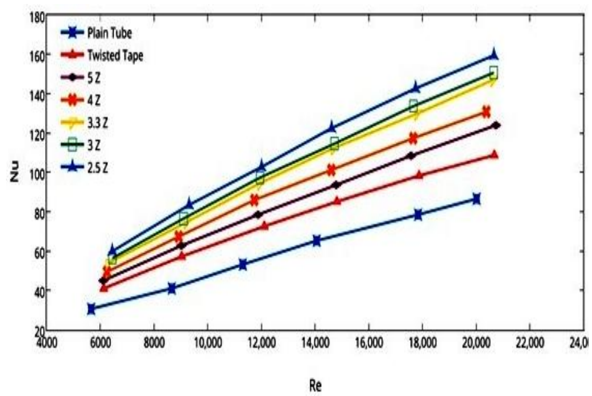

Fig. 4 (a)

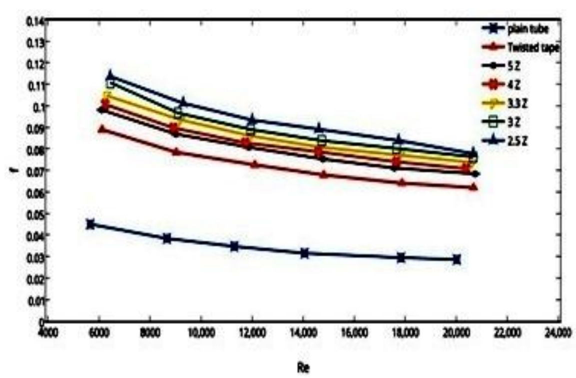

Figure 4 (b) shows the variations of friction factor with Reynolds number. Friction factors for both plain tube and tube with inserts decreased with the increase of Re. The effect of twisted tape on friction factor was found that friction factors in the tube with tape inserts were considerably higher than those in the plain tube. In addition, Elliptical-cut twisted tape consistently caused higher friction factor than the single one. The present experimentation found that average Friction factor for PTT, Z=5, Z=4, Z=3.3, Z=3 and Z=2.5 are higher than plain tube by 1.12%, 1.35, 1.43, 1.53, 1.62 and 1.75 respectively. The obtained results show that the lower major to minor axis ratio (Z) gave more heat transfer and friction factor than those tapes with a higher major to minor axis ratio (Z).

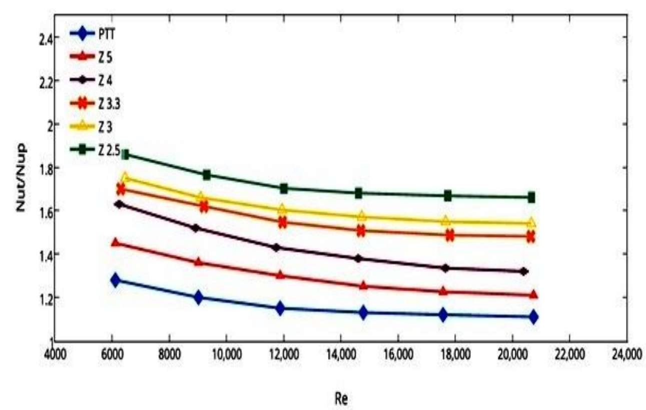

Fig. 5 (a)

In addition, it was found that the Nusselt number ratios of twisted tape to plain tube Nut/Nup were decreasing and friction factor ratios of twisted tape to plain tube ft/fp were increasing with increasing Reynolds number as shown in the fig.

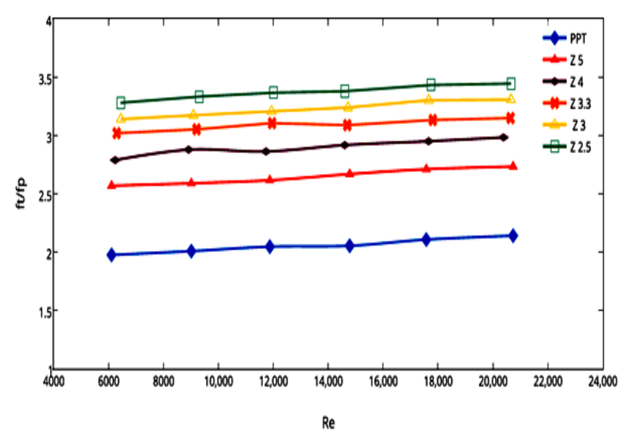

Fig. 5 (b)

C. Thermal Performance Factor

Thermal performance factor (η) at equal pumping power is defined as the ratio of the convective heat transfer coefficient of the tube with a twisted tape to that of the plain tube. The thermal performance factors for Elliptical-cut twisted tape are found to be greater than those for the plain twisted tape (PTT) for the same Reynolds number. The thermal enhancement factor for all twisted tapes tends to decrease with an increasing Reynolds number shown in Fig. 7. With the use of PTTs, thermal performance factors were in a range between, 1.01–0.86 for the twist ratio y=8. On the other hand, the use of Elliptical-cut twisted tapes offered thermal performance factors in a range between 1.05–1.21, 1.15–0.91, 1.21–1.05, 1.19-1.03 and1.25-1.09 respectively for the major to minor axis ratios Z=5.0, 4.0, 3.3, 3 and 2.5. The mean thermal performance factor for Elliptical-cut twisted tape with lower major to minor axis ratio is higher than those offered by the tapes with higher major to minor axis ratios. The mentioned data indicates that the use of Elliptical-cut twisted tapes gave more efficient heat transfer enhancement than the application of PTT.

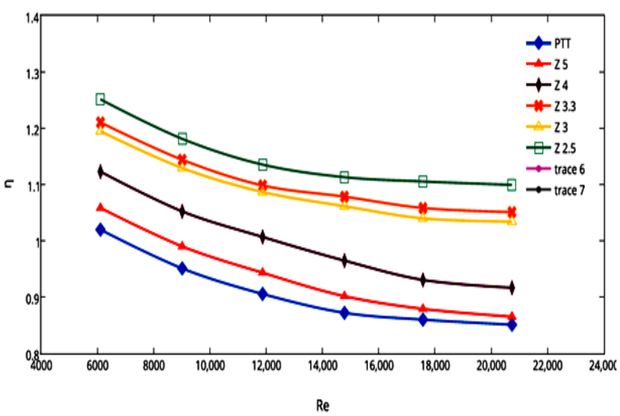

Fig. 6

V. CONCLUSIONS

Experimental investigations of heat transfer, friction factor and thermal performance factor characteristics of circular tube fitted with plain twisted tape and Elliptical-cut twisted tape for different major to minor axis ratio Z have been tested. The conclusion can be drawn as follows:

- The Elliptical-cut twisted tape offered a higher heat transfer rate, friction factor and also thermal performance factor compared to the plain twisted tape. In addition, the influence of the increasing minor axis was more dominant than that of the decreasing major axis for all the Reynolds number.
- The thermal performance factors for lower major to minor axis (Z) ratio cases are more than one indicating that the effect of heat transfer enhancement due to the enhancing tool is more dominant than the effect of the rising friction factor and vice versa.

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