International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Enhancement and Prediction of Heat Transfer Rate in Turbulent Flow through Circular Tube with Wavy, Clockwise and Anticlockwise Copper Twist Tape Inserts

Kaustubh G. Kulkarni* and Mandar M. Lele

Mechanical Department, Maharashtra Institute of Technology, Savitribai Phule Pune University, Pune, India

Accepted 12 March 2017, Available online 16 March 2017, **Special Issue-7 (March 2017)**

Abstract

Present Experimental work shows result obtain from experimentation of heat transfer enhancement in circular horizontal tube by using wavy clockwise and anticlockwise Copper twist tape inserts with working fluid is air. Experiments conducted on plain circular tube with or without tapes. During experimentation constant heat flux and different mass flow rate condition is used. The wavy clockwise and anticlockwise twist direction tape are of same pitch , varying wave width and different angle of rotation in clockwise and counter clockwise direction as 30°, 45°, 60° respectively. The Reynolds no. varied from 4000 to 11000. Heat transfer coefficient and pressure drop are calculated and results are compared with the plain tube without inserts. Finally heat transfer rate enhances with wavy clockwise and anticlockwise twist direction tape inserts as compared to plain tube varied from 12 % to 56 % with reasonable increment in pressure drop for various inserts. Plain twist tape results are also compared with the same results.

Keywords: *Wavy clockwise and anti clockwise twist direction tape insert, twist ratio, wave width, Heat transfer Enhancement, Reynolds number.*

Introduction

Heat transfer enhancement devices have been used for increasing heat transfer rate and optimizing heat transfer system .Many techniques investigated (ex. Passive techniques and active techniques) for augmentation of heat transfer inside circular tube, a wide range of inserts have been used when turbulent flow is considered. Various methods are used for increasing thermal performance such as rough surfaces, treated surfaces, coiled tubes, swirling flow devices, and surface tension devices.

Twist tape is one of the commonly used passive type swirl turbulator for heat transfer augmentation due to their several advantages as ease of installation, steady performance and simple configurations. Twist tape inserts generate swirling flow which leads to improved fluid mixing between central region and the wall region so, the heat transfer in tubes can be enhanced by fluid mixing. Sarma *et al*. Derived correlations are used to predict convective heat transfer coefficient and friction factor in a tube fitted with twist tapes for a wide range of Reynolds number and Prandtl number. The contribution to thermal performance of the conventional, short-width and center-cleared twist tapes was studied numerically. Configuration optimization of regularly spaced short-length twist tapes in a circular tube.

Turbulent heat transfer was carried out by Wang *et al*. by using computational fluid dynamics (CFDs) modeling. Eiamsa-ard *et al*. observed experimental study on convective heat transfer in a circular tube with short-length twist tapes inserted inside tube under uniform heat flux. Akhavan-Behabadi *et al* Experiments were conducted to study effects of twist tapes on heat transfer rate and pressure drop for R-134a as working fluid in horizontal evaporators Heat transfer rate and friction factor were calculated in circular tube which is equipped with modified twist tape alternate axis for CuO/water nanofluid as a working fluid. Jaisankar *et al.* Conducted experiment on solar water heater to determine thermal performance caused by twist tape. Effect of various aspect on heat transfer and pressure drop were examined in a circular tube fitted with regularly spaced twist tape elements as Twist ratio, space ratio, tape width, rod-diameter and phase angle. Naphon conducted experiments by using conventional twist tape inserts in horizontal double pipe. Ferroni *et al*. conducted experiments in circular tube equipped with physically separated, multiple, short-length twist tapes. Laminar convective heat transfer enhancement in twist tape inserted tube was observed experimentally by Sarma *et al*. In some studies, researchers observed

*Corresponding author: **Kaustubh G. Kulkarni**

the thermal effects of twist tape inserts in modified tube instead of smooth tube, for example; Thianpong *et al.* observed heat transfer enhancement in a dimpled tube with a twist tape swirl generator inserted. They also derived empirical correlations based on the experimental results of their study for prediction the Nusselt number and friction factor for Reynolds number from 12,000 to 44,000. Bharadwaj *et al.* conducted experiments by using conventional type of twist tapes to determine pressure drop and heat transfer characteristics of water in a 75-start spirally grooved tube. Some researchers modified the conventional twist tape geometries, for example; Murugesan *et al.* used V-cut twist tapes to analyse heat transfer and pressure drop in a circular tube.

Experimental Set-Up

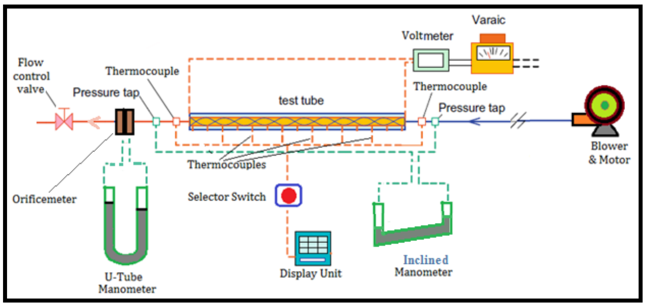

Figure No.1 Experimental set up line diag.

The actual diagram of experimental set-up is given in Fig.1.The experiment consist of a blower for air flow, an orifice meter to measure the volumetric flow rate, the test tube of 700mm length, 26 mm inner diameter (D1), 26.4 mm outer diameter (D2), and 2 mm thickness (t). The wavy clockwise and anticlockwise twist direction tape are tested in this experiment, with three different angle of rotation as 30°, 45° and 60° in clockwise and anti clockwise direction but have same pitch. They are fabricated from copper. An inclined manometer is used to measure pressure drop across the test tube. After air passes the test tube, it enters to the orifice meter for determining volumetric flow rate readings. For this purpose a blower is of 0.24 hp used to force air through the test tube. Constant and uniform heat flux is applied to external surface of the test tube by means of heating with electrical winding. The output power is controlled by a variance transformer to supply constant heat flux along the entire section of the test tube. The outer surface of the test tube is insulated with glass wool and cotton to minimize the convective heat loss to the surroundings. 6 K-type thermocouples have been used for measurement of the external surface temperatures of the test tube wall, which are placed on the outer circumference of the test tube. Also, the inlet and outlet temperatures of the bulk air measured by two K-type thermocouples at given points. Separate U-tube manometer is placed across orifice meter. The volumetric flow rate of air supplied from the blower is controlled by varying control valve position. The experiments are conducted by varying the flow rate in terms of Reynolds numbers from 4000 to 11000 of the bulk air During the experiments the test tube is heated from the external surface, and the data of temperatures, volumetric flow rate, pressure drop of the bulk air and electrical output are recorded after the system is approached to the steady state condition. The Nusselt number, Reynolds number, friction factor, heat transfer enhancement are calculated based on the average outer wall temperatures and the inlet and outlet air temperatures.

Figure No 2 Experimental Set up

Data collection and analysis

The data reduction of the obtained results is summarized in the following procedures:

Heat transfer calculation:

Avg. Surface Temp.,

$T_s = (T_2+T_3+T_4+T_5+T_6+T_7)/6$ (1)

Avg. Temp of air,

$T_b = (T_1+T_8)/2$ (2)

Air head, $ha = h_w * \left(\frac{\rho_w}{\rho_a}\right)$ (3)

Air volume flow rate,

$Q_a = Cd * Ao\sqrt{2 * g * h_{air}}$ (4)

Mass flow rate, $\dot{m} = Q_a * \rho_a$ (5)

Velocity of air, $V = Q_a / A^{Qa}_{ap}$ (6)

Heat carried out,

$q = \dot{m} * Cp * (T_8 - T_1)$ (7)

$$h = \frac{Q}{A\,(T_s - T_b)} \quad (8)$$

$$Re = \frac{VD}{\upsilon} \qquad (9)$$

$$Nu_{th} = 0.023*(Re)^{0.8}*(Pr)^{0.4} \qquad (10)$$

This equation is called Dittus-Boettier equation.

$$f_s = (1.82 \log_{10}Re - 1.64)^{-2} \qquad (11)$$

This equation is used to find friction factor called as Petukhov equation for smooth surface.

Friction factor is calculated from the formula given below:

$$f = \frac{\Delta P}{\frac{L}{D} * \frac{\rho a\, V^2}{2}} \qquad (12)$$

The experimental Nusselt number is calculated as given below:

$$Nu = hD/k \qquad (13)$$

The overall enhancement efficiency is expressed as

$$PEC = \eta = \frac{Nu\ with/Nu\ w/o}{(fwith|fw/o)^{1/3}} \qquad (14)$$

Figure. No.3 Wavy clockwise and anticlockwise twist copper tape inserts (having angle of rotation as 30°, 45° and 60° in clockwise and anti clockwise)

Results and discussion

A .Heat Transfer and Overall Enhancement

The variation of Nusselt number with Reynolds number for various wavy clockwise and anticlockwise copper twist tape inserts is shown in Figure 3. Highest Nusselt number was obtained for tape with angle of rotation = 60º, Wave width = 15 mm. The Nusselt number for these inserts varied from 62 % to 75 % compared to plain tube. This result can be attributed to the following reasons. Firstly, the periodic change of swirl direction from clockwise to anticlockwise directions, causes the rapid change in fluid flow, giving proper fluid mixing and uniform temperature. Secondly waviness on tape provide interruption of thermal boundary layer resulting in to turbulent mixing of the flow causing heat transfer enhancement. The variations of friction factor with Reynolds number for inserts are presented in Figure 5 It is observed that the friction factor gradually reduced with rise in Reynolds number. It is observed to be minimum friction factor for insert having angle = 60 º, wave width = 15 mm It is evident from Figures 4, 5 and 6 that when a wavy c-ac copper twist tape is inserted into a plain tube there is a significant improvement in Nusselt number because of secondary flow, with greater enhancement

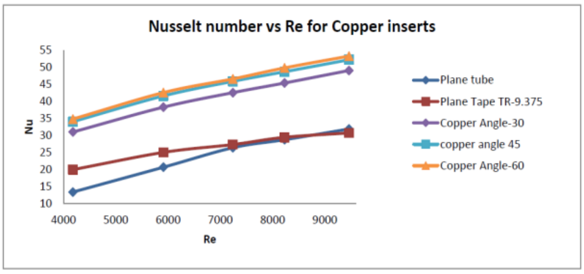

Figure No.4 Nusselt Number vs RE

It is observed that the increase in angle of rotation causes excellent increment in Nusselt number and rise in pressure drop. From Figure 5, the percentage rise in Nusselt number for c-ac wavy twist tapes compared to plain tube are about 52-75 %, 51-87% and 70-92% respectively for tape with angle of rotation 30º , 45º , 60º respectively wave width = 15mm. The overall enhancement ratio is useful to evaluate the quality of heat transfer enhancement obtained over plain tube at constant pumping power. It is found to be more than unity for all the Wavy clockwise and anticlockwise copper twist tape inserts used

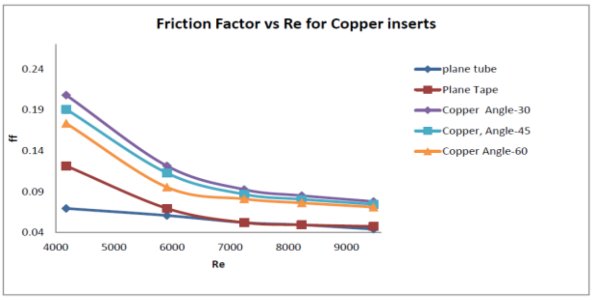

Figure No.5 Friction factor vs Re

Variations of overall enhancement ratio *h* against Reynolds number for various tapes are shown in figure 6. It is observed that overall enhancement tends to decrease gradually with the rise of Reynolds number for all inserts. The maximum value of overall enhancement is 1.75 c-cc wavy twist tape insert having angle of rotation 60º and wave width is 15 mm It is seen in Figure 6 that, for tapes of angle 30º , 45º , 60 º are of decreasing order for a given pitch in the range of Reynolds number from 4000 to 11000. Of the recombined streams. Moreover, the higher twist angle shows the larger difference of plane direction for the adjacent twist lengths, providing more effective disturbance to the flowing fluid. This directly impacts on the developing thermal boundary layer, resulting in enhancement of heat transfer inside the heat exchanger.

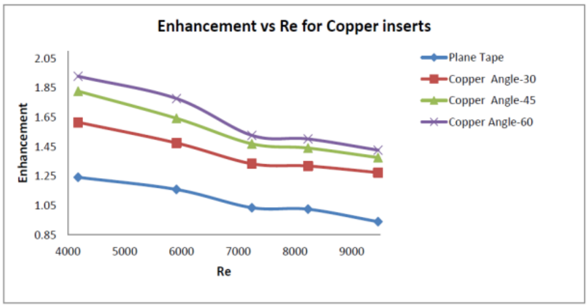

Figure No 6 Overall Enhancement vs Re

Conclusions

The present experimental work has been conducted investigate the potential of wavy clockwise and anticlockwise copper twist tape inserts to enhance the heat transfer rate in a horizontal circular tube with inside diameter 28mm with air as working fluid. The Reynolds number varied from 4000 to 11000. The effects of parameters such as angle of rotation and waviness, Reynolds number on the heat transfer and overall enhancement ratio have been studied.

The following conclusions can be drawn

A. The enhancement of heat transfer with clockwise and anticlockwise wavy twist tape inserts as compared to plain tube varied from 13 to 48% for 60 º angle of rotation and 15 to 35% for 45ºangle of rotation. This enhancement is mainly due to the larger portions of fluid are directed to the opposing direction in the region of the change, leading to the stronger collision of the recombined streams and the spiral motion of the fluid.

B. Increment in angle of rotation causes rise in Nusselt numbers as well as friction factors. The maximum friction factor rise was about 135% for 60º angle of rotation. And 110% for 30 º angle of Wavy twist tape inserts compared to plain tube.

C. The overall enhancement for the tubes with c-cc wavy twist tape inserts is 1.75 for 60 ºangle of rotation and 1.5 for 45º angle of rotation c-ac wavy twist tape insert. Thus the enhanced performance can be achieved using Clockwise and anticlockwise wavy twist tapes as compared to plane twist tape.

Thus, from the considerations of enhanced heat transfer and savings in pumping power by using Clockwise and anticlockwise wavy twist tapes inserts are seen to be attractive for enhancing turbulent flow heat transfer in a horizontal circular tube with air as working fluid.

Nomenclature

A0 - Area of orifice, (m2)
A - Test section inner tube area, (p/4 D2) (m2)
Cp - Specific heat of air, (J/kg K)
Qa - Air discharge through test section (m3/sec)
D - Inner diameter of test section, (m)
H - Pitch, (mm)
w - Width of wavy tape insert,(mm)
H/D - Twist ratio
fth - Friction factor(theoretical) for plain tube
f - Friction factor(experimental) for plain tube
fi - Friction factor obtained using tape inserts
h - Experimental convective heat transfer coefficient, (W/m2K)
hw - Manometer level difference,(m)
hair - Equivalent height of air column, (m)
k - Thermal conductivity, (W/mK)
L - Length of test section, (m)
m - Mass flow rate of air, (Kg/sec)
Nui - Nusselt number (experimental) with tape inserts, (hD/k)
Nu - Nusselt number (experimental) for plain tube
Nuth - Nusselt number for plain tube (theoretical)
Pr - Prandtl number
p - Pitch, (m)
DP - Pressure drop across the test section, (Pa)
Q - Total heat transferred to air (W)
Re - Reynolds number, (r V D/m)
T1, T8 - Air temperature at inlet and outlet, (_k)
T2, T3, T4, T5 - Tube wall temperatures, (_K)
Ts - Average Surface temperature of the working fluid, (_K)
Tb - Bulk temperature, (_K)
V - Air velocity through test section, (m/sec)

References

A.E. Bergles. Ex HFT for fourth generation heat transfer technology. Experimental Thermal and Fluid Science, 26:335– 344, 2002.

J. Guo, A. Fan, X. Zhang, and W. Liu. A numerical study on heat transfer and friction factor characteristics of laminar flow in a circular tube fitted with center cleared twisted tape. International Journal of Thermal Sciences, 50:1263–1270, 2011.

P.K. Sarma, P.S. Kishore, V. Dharma Rao, and T. Subrahmanyam. A combined approach to predict friction coefficients and convective heat transfer characteristics in A tube with twisted tape inserts for a wide range of Re and Pr. International Journal of Thermal Sciences, 44:393–398, 2005.

Y. Wang, M. Hou, X. Deng, L. Li, C. Huang, H. Huang, G. Zhang, C. Chen, and W. Huang. Configuration optimization of regularly spaced short-length twisted tape in a circular tube to enhance turbulent heat transfer using CFD modeling.

S. Eiamsa-ard, C. Thianpong, P. Eiamsa-ard, and P. Promvonge. Convective heat transfer in a circular tube with short-length twisted tape insert. International Communications in Heat and Mass
Transfer, 36:365–371, 2009.

M.A. Akhavan-Behabadi, R. Kumar, A. Mohammadpour, and M. Jamali-Asthiani. Effect of twisted tape insert on heat transfer and pressure drop in horizontal evaporators for the flow of R- 134a. International Journal of Refrigeration,32:922–930, 2009.

K. Wongcharee, and S. Eiamsa-ard. Enhancement of heat transfer using CuO/water nano fluid and twisted tape with alternate axis. International Communications in Heat and Mass Transfer, 38:712–748, 2011.

K. Wongcharee, and S. Eiamsa-ard. Friction and heat transfer characteristics of laminar swirl flow through the round tubes inserted with alternate clockwise and counter clockwise twisted tapes. International Communications in Heat and Mass Transfer, 38:348–352, 2011.

S. Eiamsa-ard, and P. Promvonge. Performance assessment in a heat exchanger tube with alternate clockwise and counter-clockwise twisted-tape inserts. International Journal of Heat and Mass Transfer, 53:1364–1372, 2010.

S. Eiamsa-ard, C. Thianpong, and P. Promvonge. Experimental investigation of heat transfer and flow friction in a circular tube fitted with regularly spaced twisted tape elements. International Communications in Heat and Mass Transfer, 33:1225–1233, 2006.

V. Hejazi, M.A. Akhavan-Behabadi, and A. Afshari. Experimental investigation of twisted tape inserts performance on condensation heat transfer enhancement and pressure drop. International Communications in Heat and Mass Transfer, 37:1376–1387, 2010.

S. Jaisankar, T.K. Radhakrishnan, and K.N. Sheeba. Experimental studies on heat transfer and friction factor characteristics of forced circulation solar water heater system fitted with helical twisted tapes. Solar Energy, 83:1943– 1952, 2009.

S.K. Saha, A. Dutta, and S.K. Dhal. Friction and heat transfer characteristics of laminar swirl flow through a circular tube fitted with regularly spaced twisted-tape elements. International Journal of Heat and Mass Transfer, 44:4211–4223, 2011.

P. Naphon. Heat transfer and pressure drop in the horizontal double pipes with and without twisted tape insert. International Communications in Heat and Mass Transfer, 33:166–175, 2006.

P. Ferroni, R.E. Block, N.E. Todreas, and A.E. Bergles. Experimental evaluation of pressure drop in round tubes provided with physically separated, multiple, short-length twisted tapes. Experimental Thermal and Fluid Science, 35:1357–1369, 2011.

K.G.Kulkarni, S.Y. Bhosale, S.N.Satpute Experimental Investigation of heat transfer enhancement of corrugated twisted tape insert with CFD analysis. International Journal of Research Publications in Engineering and Technology, ISSN: 2454-7875