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Experimental Investigation of Heat Transfer Enhancement by Using Clockwise and Counter -clockwise Corrugated Twisted Tape Inserts

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Abstract
Present Experimental work shows result obtain from experimentation of heat transfer enhancement in circular horizontal tube by using clockwise and counterclockwise corrugated twisted tape inserts with working fluid is air. Experiments conducted on plain circular tube with or without c-cc corrugated twisted tube. During experiment constant heat flux and different mass flow rate condition. The c-cc corrugated twisted tape are of same pitch and twist ratio but three different angle of rotation in clockwise and counter clockwise direction as 30˚, 60˚, 90˚ respectively. The Reynolds no. varied from 4000 to 10000. Heat transfer coefficient and pressure drop are calculated and results are compared with the plain tube without inserts. Finally heat transfer enhances with clockwise and counterclockwise corrugated twisted tape inserts as compared to plain tube varied from 8 % to 44 % for various inserts. Plain twisted tape results are also compared with the same results.

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 , surface tension devices [1].

Twisted 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 [2].Twisted 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. [3] derived correlations are used to predict convective heat transfer coefficient and friction factor in a tube fitted with twisted tapes for a wide range of Reynolds number and Prandtl number. The contribution to thermal performance of the conventional, short-width and center-cleared twisted tapes was studied numerically [2].
Configuration optimization of regularly spaced short-length twisted tapes in a circular tube for turbulent heat transfer was carried out by Wang et al. [4] by using computational fluid dynamics (CFDs) modeling. Eiamsa-ard et al. [5] examined experimental study on convective heat transfer in a circular tube with short-length twisted tapes inserted inside tube under uniform heat flux.

Akhavan-Behabadi et al [6] Experiments were conducted to study effects of twisted 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 twisted tape alternate axis for CuO/water nanofluid as a working fluid [7-9].

Eiamsa-ard et al. [10] performed experiment in a double pipe heat exchanger fitted with twisted tape elements for heat transfer and friction factor characteristics. They made their analysis for both continuously placed twisted tape and twisted tape placed with various free spaced in circular tube. The heat transfer augmentation and pressure drop during condensation of HFC-134a in a horizontal tube fitted with twisted tapes were experimentally analyzed [11].

Jaisankar et al. [12] Performed experiment on solar water heater to determine thermal performance caused by twisted tape. Effect of various aspect on heat transfer and pressure drop were examined in a circular tube fitted with regularly spaced twisted tape elements as Twist ratio, space ratio, tape width, rod-diameter and phase angle [13].

Naphon [14] conducted experiments by using conventional twisted tape inserts in horizontal double pipe. Ferroni et al. [15] performed experiments in circular tube equipped with physically separated, multiple, short-length twisted tapes. Laminar convective heat transfer enhancement in twisted tape inserted tube was observed experimentally by Sarma et al.[16]. In some studies, researchers observed the thermal effects of twisted tape inserts in modified tube instead of smooth tube, for example; Thianpong et al. [17] observed heat transfer enhancement in a dimpled tube with a twisted 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. [18] performed experiments by using conventional type of twisted tapes to determine pressure drop and heat transfer characteristics of water in a 75-start spirally grooved tube. Some researchers [19] modified the conventional twisted tape geometries, for example; Murugesan et al. [20] used V-cut twisted tapes to analyse heat transfer and pressure drop in a circular tube.

EXPERIMENTAL SET-UP

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 clockwise counterclockwise corrugated twisted tapes are tested in this experiment, with three different angle of rotation as 30˚, 60˚ and 90˚ in clockwise and counterclockwise direction but have same twist ratio =8.333. They are fabricated from aluminium.. Also one plane twisted tape made up of aluminium is tested.

The actual figure of the clockwise counterclockwise corrugated twisted tape insert is given in Fig.2. 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 variac 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 are measured by two K-type thermocouples at given points.

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 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 10000 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 1: Experimental set up

Figure 2 : c – cc corrugated insert

DATA COLLECTION AND ANALYSIS

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

Heat transfer calculation:

$Ts = (T2 + T3 + T4 + T5 + T6 + T7)/6$ …………… (1)

$Tb = (T1 + T8)/2$ ……………… (2)

Discharge of air, $Qa = Cd * Ao * \sqrt{(2 * g * ha)}$……… (3)

Velocity of air flow, $V = Qa / A$ …………………… (4)

Reynolds number, $Re = VD / \upsilon$ ………………… (5)

$Q = m * Cp * (T8 - T1)$ ………………… (6)

$h = \frac{Q}{A(Ts - Tb)}$ ………………… (7)

$Nu = hD / k$ ………………… (8)

$f = \frac{\Delta P}{\frac{L}{D} * \frac{\rho_a V^2}{2}}$ ……………… (9)

$\eta = \frac{(Nu_i / Nu)}{(f_i / f)^{0.333}}$ ………………. (10)

Validation of experimental result for plain tube

In this study, experimental results of Nusselt number and friction factor for the plain tube are obtained and validated with equations of Dittus Boelter and Petukhov as given below;

$Nu_{th} = 0.023 * (Re)^{0.8} * (Pr)^{0.4}$ ………… (11)

$f_s = (1.82 \log_{10} Re - 1.64)^{-2}$ ……………. (12)

Figure 3 : c – cc corrugated inserts

The comparisons of Nusselt number and friction factor for the present plain tube with existing correlations are shown in Figs. 4 and 5, respectively. These figures shows that validation experiments of heat Transfer rate in terms of Nusselt number and friction factor for the plain tube are acceptable with the results obtained

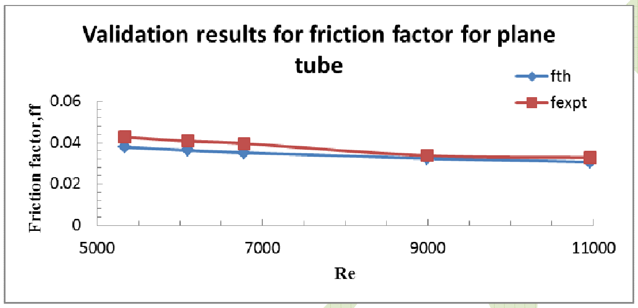

Figure 4: Validation results for friction factor

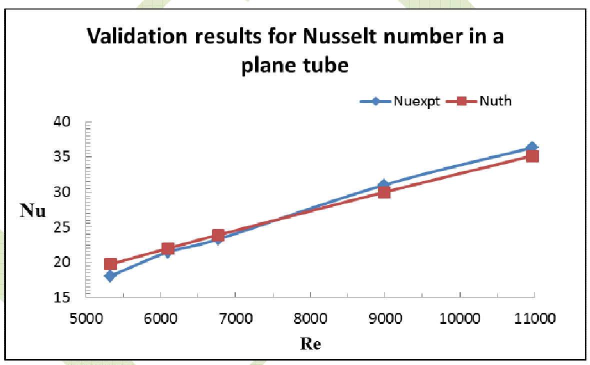

Figure 5: Validation results for Nusselt number

Theoretical Values of Nusselt No. and friction factor are obtained by using Dittus-Boelter and Petukhov equations. The results of present plain tube and previous equations are nearly the same and this provides reliable results for heat transfer and friction factor in a tube with c-cc corrugated twisted tape inserts. In this present experimental work The Reynolds numbers were ranged from 4100 to 11000 i.e. the range of Reynolds number used is for turbulent flow. The results of the tests carried for performance checking of present clockwise counterclockwise corrugated twisted tape are discussed further in results and discussion.

RESULTS AND DISCUSSION

A .Heat Transfer and Overall Enhancement

The variation of Nusselt number with Reynolds number for various clockwise and counterclockwise corrugated inserts is shown in Figure 6. Highest Nusselt number was obtained for tape with angle of rotation = 90º , Twist ratio = 8.33 Wave width = 12 mm. The Nusselt number for these inserts varied from 34 % to 85 % compared to plain tube. This result can be attributed to the following reasons. Firstly, the periodic change of swirl direction from clockwise to counterclockwise directions and vice versa, causes the sudden change of fluid arrangement, giving better fluid mixing and uniform temperature. Secondly corrugations on tape provide more efficient interruption of thermal boundary layer resulting in to superior chaotic mixing of the flow causing heat transfer enhancement. The variations of friction factor with Reynolds number for inserts are presented in Figure 7. 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 = 90 º ,wave width = 12 mm and twist ratio =8.33. It is evident from Figures 6, 7 and 8 that when a c-cc corrugated twisted tape is inserted into a plain tube there is a significant improvement in Nusselt number because of secondary flow, with greater enhancement being realized at lower Reynolds numbers and 90º angle of rotation.

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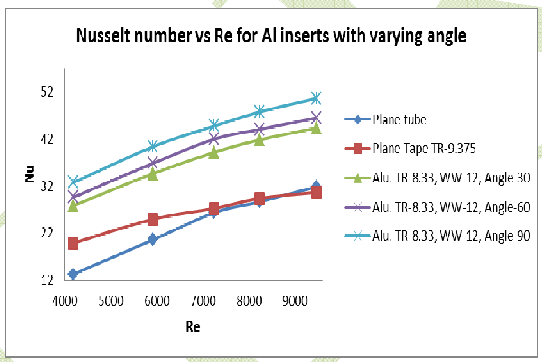

Figure No. 6 Variation of Nusselt number for different insert configurations

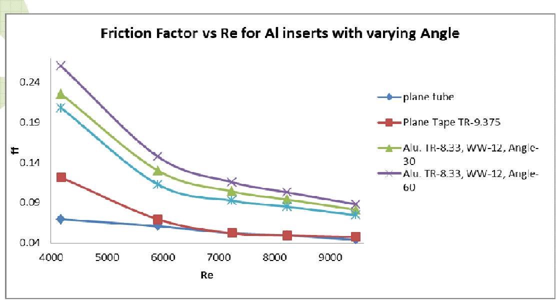

Figure 7: Variation of friction factor for different insert Configurations

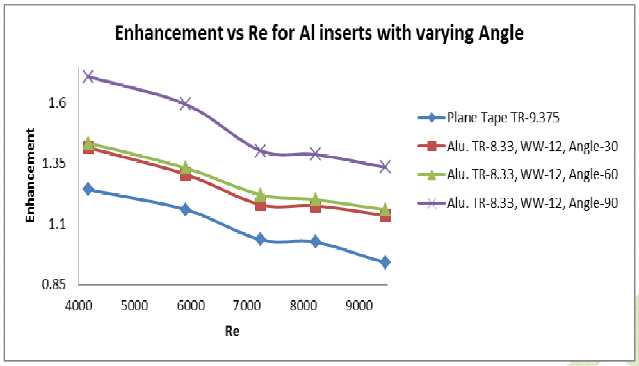

Figure 8: Variation of Enhancement for different insert configurations

It is observed that the increment in angle of rotation causes increment in Nusselt numbers as well as rise in pressure drop. From Figure 6, the percentage rise in Nusselt numbers for c-cc corrugated twisted tapes compared to plain tube are about 31- 95%, 31-87% and 25-88% respectively for tape with angle of rotation 90º , 60 º , 30 ºrespectively for twist ratio =8.33 and wave width = 12mm. 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 c-cc corrugated twisted tape inserts used.

Variations of overall enhancement ratio *h* against Reynolds number for various tapes are shown in figure 8. It is observed that overall enhancement tended to decrease gradually with the rise of Reynolds number for all twist ratios. The maximum value of overall enhancement is 1.65 c-cc corrugated twisted tape insert having angle of rotation = 90º with twist ratio equal to 8.33 and wave width is 12 mm It is seen in Figure 8 that, for tapes of angle 30º , 60º , 90 º are of decreasing order for a given pitch in the range of Reynolds number from 4000 to 9500.

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. 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.

CONCLUSIONS

The present experimental work has been conducted investigate the potential of clockwise and counterclockwise corrugated twisted tape inserts to enhance the heat transfer rate in a horizontal circular tube with inside diameter 26mm with air as working fluid. The Reynolds number varied from 4000 to 9500. The effects of parameters such as angle of rotation and corrugation, 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 corrugated twisted tape inserts as compared to plain tube varied from 12 to 46% for 90 º angle of rotation and 10 to 39% for 60ºangle 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 175% for 60º angle of rotation. and 150% for 30 º angle of c-cc corrugated twisted tape inserts compared to plain tube.

C. The overall enhancement for the tubes with c-cc corrugated twisted tape inserts is 1.65 for 90 º angle of rotation and 1.4 for 60º angle of rotation c-cc corrugated twisted tape insert. Thus the enhanced performance can be achieved using Clockwise and counterclockwise corrugated twisted tapes as compared to plane twisted tape.

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

Future work may be extended to:

A. Change the tape material from Aluminium to copper

B. Internal corrugated test tube can be used with different inserts.

C. Compound enhancement techniques maybe applied i.e. the tape inserts can be coupled with spring coil inserts for better enhancement.

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)
D**P -** 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)

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