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Heat Transfer Intensification with Different Width Swirl Generator

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1. Introduction

Shou-Shing and Huang [1] conducted experimental studies for heat transfer and pressure drop of laminar flow in horizontal tubes with/without longitudinal inserts. They reported that enhancement of heat transfer as compared to a conventional bare tube at the same Reynolds number to be a factor of 16 at Re 4000, while a friction factor rise of only 4.5. Monheit [2] made a comparative study of the thermal performance of ordinary full-width full-length twisted tapes with tapes having modified surface configurations. Eiamsa-ard et al. [3] experimentally find the heat transfer rate and thermo hydraulic efficiency of the combined devices of twisted tape and wire coil by arranging in the form D-coil and DI-coil while the twisted tape was made with two different twist ratios. Dasmahapatra and Raja Rao [4] studied augmentation of heat transfer to viscous non-Newtonian fluids in laminar flow using full width interrupted twisted tapes under the uniform wall temperature condition.

Keywords Reynolds number Nusselt number Heat transfer augmentation Twist ratio · Swirl generator

Methodology

Experimental Procedure

Initially the experiment is carried out without any insert (plain tube experiment). The working fluid air flows through the pipe section with least resistance. The experiment is carried out in similar fashion with straight tape inserts and twisted tape inserts with twist ratios 3 and 5 for widths of 26, 18 and 10 mm. the inserts are made of aluminium. Different types of inserts used are shown in Table 2.1. Each insert is taken and inserted into the test section axially. It is taken care that the strip does not scratch the inner wall of the pipe and get deformed. The presence of the insert in the pipe causes resistance to flow and increases turbulence. For the case of reduced width tapes, the gap between the tube wall and the tape was maintained constant throughout the tube length by brazing metal pins to the edges of the tape.

1.1 Heat Transfer Calculations

1.1.1 Reynolds Number Evaluation

Average Surface temperature of the working fluid, (°C)

$$T_s ¼ \underline{T_2 þ T_3 þ T_4 þ T_5}$$

Bulk temperature, (°C)

Tb ¼ T1 þ T6

Equivalent height of air column, (m)

h qw × hw / qa

Air discharge through test section, (m^3/s)

Qa ¼ Cd × Ao × pffi2ffiffigffiffihffiffiffiaffi

Table 1 Different types of inserts usedwhere

A_0 Cross sectional area of orifice.

Air velocity through test section, (m/s)

V Q_a A

Reynolds number (experimental) for plain tube,

Re V × D / m

where

V Velocity of the fluid

m Kinematic viscosity of the fluid.

Reynolds number (experimental) with tape inserts

Re V × D_h / m

where

Dh hydraulic diameter (m) = 4A :

1.1.2 Nusselt Number Evaluation

For internal flow conditions, if Reynolds number (Re) is greater than 4000 then the flow is said to be turbulent. After the flow is decided i.e. laminar or turbulent then the Nusselt number can be calculated. Nusselt number for plain tube (theoretical) cal- culated below without considering friction which is theoretical Nusselt number and then calculated by considering friction which will be experimental Nusselt number.

Nu_{the} ¼ 0:023$Re^{0:8}Pr^{0:4}$

This equation is called Dittus-Boelter equation. Total heat transferred to air (*Q*), (W)

Q ¼ m × Cp × ðT_1 — T_6Þ

Experimental convective heat transfer coefficient, (W/m^2 K)

h Q / AðT_s — T_bÞ

Nusselt number (experimental) for plain tube

Nu h × D / K

Nusselt number (experimental) with tape inserts

Nui ¼ h × D_h

1.1.3 Friction Factor Evaluation

Friction factor (theoretical) for plain tube

$$f_{the} ¼ 0:25ð1:82 \times log10Re_D — 1:64Þ^{—2}$$

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

Friction factor (experimental) for plain tube

$$f \quad \frac{DP}{\frac{L}{D} \frac{V^2 q}{2}} \quad a$$

where,

DP pressure difference at both ends of test pipe. L length of test pipe.

D Inner diameter of pipe.

Friction factor (experimental) with tape inserts

$$f \quad \frac{DP}{L \; V^2 q}$$

where

Dh hydraulic diameter (m) = $\frac{4A}{}$:

Over all enhancement rational Characteristic

1.2 Heat Transfer Characteristics

The variation of Nusselt number with Reynolds number for straight tape inserts is shown in Fig. 1. Highest Nusselt number was obtained for full width straight tape. The mean heat transfer gain for straight tape inserts varied from 5 to 23% compared to plain tube. This is due to strong turbulence intensity generated by tape inserts leading to rapid mixing of the flow causing heat transfer enhancement.

The variations of friction factor with Reynolds number for straight tape inserts are presented in Fig. 2. It is observed that the friction factor gradually reduced with rise in Reynolds number. It is observed to be maximum for full width straight tape insert.

S. No.	Twist ratio (T.R)	Width of tape insert (mm)
1	3 and 5	26, 18 and 10
2	Straight tape	26, 18 and 10
3	Plain tube	–

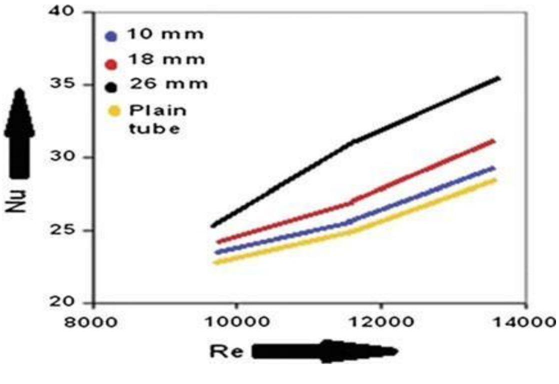


Fig. 1 Variation of Nusselt number with Reynolds number for straight tape inserts

Fig. 2 Variation of friction factor with Reynolds number for straight insertsFig. 3 Variation of Nusselt number with Reynolds number for twist ratio = 3

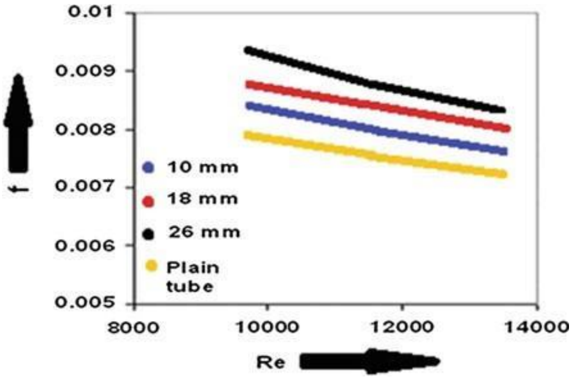
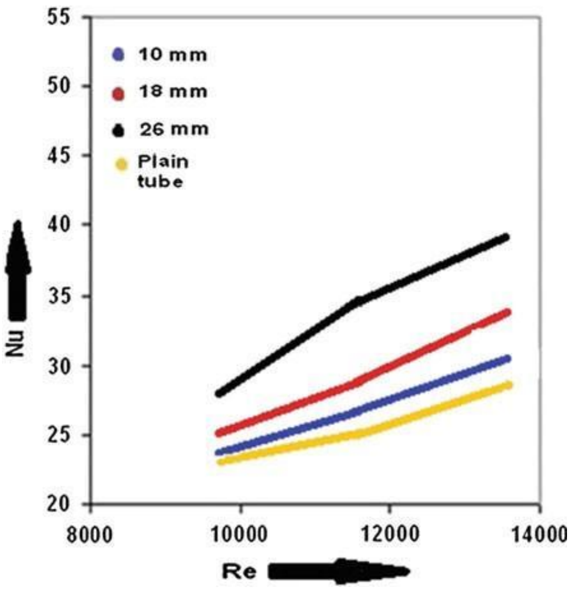


Fig. 4 Variation of Nusselt number with Reynolds number for twist ratio = 5



It is evident from Figs. 2 and 3, that when a twisted tape is inserted into a plain tube there is a significant improvement in Nusselt number, this enhancement is mainly due to the centrifugal forces resulting from the spiral motion of the fluid and partly due to the tape acting as fin. It is observed that the reduction in tape width causes reduction in Nusselt numbers as well as reduction in pressure drop. From Fig. 4, the percentage increase in Nusselt numbers for reduced width tapes com-
pared to plain tube are about 12–24% and 21–35% respectively for tape widths of

10 and 18 respectively for twist ratio = 3. For full width tapes, the percentage increase is observed to be 60–68% compared to plain tube.

From Fig. 4, the percentage increase in Nusselt numbers for reduced width tapes compared to plain tube are about 3–7% and 8–17% respectively for tape widths of 10 and 18 mm respectively for twist ratio = 5. For full width tapes, the percentage increase is observed to be 29–38% compared to plain tube.

1.3 Overall Enhancement Characteristics

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 tape inserts used. Variations of overall enhancement ratio η against Reynolds number for twist ratios 3 and 5 are shown in Figs. 5 and 6 respectively. It is observed that overall enhancement ratio tended to decrease gradually with the rise of Reynolds number for all twist ratios. The maximum value of overall enhancement ratio is 1.62 for full width twisted tape insert with twist ratio equal to 3.

It is seen in Fig. 4 that, for tapes of widths 26, 18 and 10 mm curves are of decreasing order in the range of Reynolds number from 7000 to 14,000. It is observed from Fig. 5 that even the tapes of 10 mm width have an η value of about 1.03–1.20 times over the plain tube. The gradual reduction of these curves basically represents the same performance of reduced width tapes as that of the full width

Fig. 5 Variation of overall enhancement with Reynolds number for twist ratio = 3

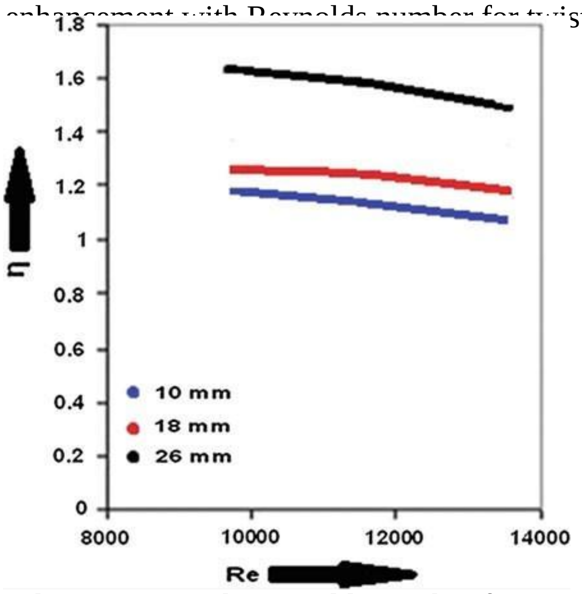
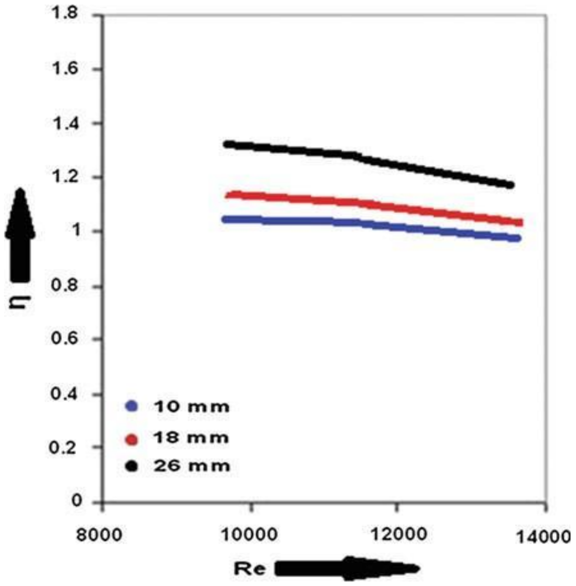


Fig. 6 Variation of overall enhancement with Reynolds number for twist ratio = 5



tape. Thus the same performance can be achieved using reduced width tapes with 15–61% material saving at higher Reynolds number and/or lower twist ratios.

4 Conclusions

This Paper present experimental investigation of reduced width twisted tape inserts to enhance the rate of heat transfer in a horizontal circular tube with inside diameter 27.5 mm with air as working fluid. The effects of parameters such as twist ratio, Reynolds number on the heat transfer and overall enhancement ratio are studied. The following conclusions can be drawn.

- The enhancement of heat transfer with twisted tape inserts as compared to plain tube varied from 35 to 49% for full width. This enhancement is mainly due to the centrifugal forces resulting from the spiral motion of the fluid.
- Reduction in tape width causes reduction in Nusselt numbers as well as friction factors. The maximum friction factor rise was about 19% for 26 mm and only 17.3% for reduced width inserts compared to plain tube.
- The overall enhancement ratio of the tubes with full width twisted tape inserts is 1.62 for full width—26 mm.
- Nusselt numbers decreased by a maximum of 29%, for tape widths of 10 mm, respectively compared to full width twisted tape inserts.

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