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Heat transfer and pressure drop characteristics in a circular tube fitted with and without V-cut twisted tape insert ☆

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ABSTRACT

The 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). The obtained results show 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). Subsequently an empirical correlation also was formulated to match with experimental results with ±6% variation for the Nusselt number and ±10% for the friction factor.

1. Introduction

Heat transfer augmentation techniques are widely used in areas such as heat recovery process, air conditioning and refrigeration systems, and chemical reactors. Passive and active methods of heat transfer augmentation techniques have been discussed in detail by Webb [1]. Dewan et al. [2] reviewed that passive techniques particularly twisted tape and wire coil insert are economical heat transfer augmentation tools. Eiasma-ard et al. [3–7] experimentally investigated the heat transfer and friction factor characteristics in a circular tube fitted with different tube inserts and proposed correlations for the Nusselt number and friction factor. Chang et al. [8,9] experimentally compared the heat transfer and friction factor characteristics of smooth twisted tape with broken and serrated twisted tape inserts. More information about heat transfer by means of twisted tapes fitted in a circular tube can be viewed in other reports [10–14]. Based on the available literature, it was pointed out that the modification on plain twisted tape (PTT) i.e. small cuts on the tape [6–9], gave assurance for enhancement of both heat transfer rate and thermal enhancement factor. The reason behind the high thermal enhancement factor is that those small gaps bring pressure drop in the system to the reasonable level. The objective of this paper is to study heat transfer and friction characteristics in double pipe heat exchanger fitted with PTT and VTT with twist ratios of y = 2.0, 4.4 and 6.0 respectively and also to study the enhancement effect of V-cut with different DR and WR ratios.

2. Experimental details

The layout of experimental setup is shown in Fig. 1. It consists of two concentric tubes in which hot water flows through the inner tube and cold water flows in counter flow through annulus. In the experimentation plain twisted tapes (PTT) with twist ratios 2, 4.4 and 6.0 are shown in Fig. 2a.V-cut twisted tapes (VTT) of twist ratios 2, 4.4 and 6.0 with different DR and WR are shown in Fig. 2b.

V-Cuts are introduced in the PTT on both top and bottom alternately in the peripheral region with different dimensions of depth and width to improve the fluid mixing near the walls of the test section. The cold water was made to flow at 0.166 kg s^{-1} whereas the hot water flow rate was adjusted from 0.033 kg s^{-1} to 0.12 kg s^{-1}. As steady state conditions were reached, the inlet and outlet temperatures of hot, and cold water and the pressure drop were recorded for the case of plain tube, PTT and VTT. The details of experimental set up, all twisted tape inserts and operating conditions are summarized in Table 1.

3. Data reduction

The data reduction [3,10] of the measured results is summarized as follows:

The overall heat transfer coefficient

$$U = \frac{Q_{avg}}{A_i \Delta T_{lm}} \quad (1)$$

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Nomenclature

A	Area, m^2
d	Tube diameter, m
d_e	Depth of V cut, mm
D_h	Hydraulic diameter, m
f	Friction factor
h	Heat transfer coefficient, W/m^2 K
H	Pitch length based on 180°
k	Thermal conductivity, W/m K
L	Tube length, m
Nu	Nusselt number
Pr	Prandtl number
ΔP	Pressure drop
Q_{avg}	Average heat transfer rate, W
Re	Reynolds number
ΔT_{lm}	Logarithmic mean temperature difference, °C
U	Overall heat transfer coefficient, W/m^2 K
u	Velocity, m/s
W	Tape width, mm
w	Width of V cut, mm
y	Twist ratio
μ	Dynamic viscosity, kg/m-s
ρ	Density, kg/m^3
η	Thermal Performance Factor

Subscripts

a	Annulus
avg	Average
i	Inner
o	Outer

Abbreviations

DR	Depth ratio (d_e/W)
PTT	Plain twisted tape
VTT	V-cut twisted tape
WR	Width ratio (w/W)

The percentage error between heat loss and heat gain by the fluids were found out to be 2% to 8% [4,5]. Thus it was concluded that the heat loss to the surroundings was reasonably small.

The annulus side heat transfer coefficient (h_a) is estimated using

$$\frac{h_a D_h}{k} = 0.023\, Re^{0.8}\, Pr^{0.4} \tag{2}$$

The tube side heat transfer coefficient (h_i) is determined using

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_a} \tag{3}$$

Thus,

$$Nu_i = \frac{h_i d_i}{k} \tag{4}$$

Friction factor

$$f = \frac{\Delta p}{\left[\frac{L}{d_i}\right]\left[\frac{\rho u^2}{2}\right]} \tag{5}$$

4. Experimental results and discussion

4.1. Validation of plain tube with/without twisted tape

As displayed in Figs. 3(a–b) and 4(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 [15] for friction factor of plain tube and Manglik and Bergles [12] equation for PTT. The deviations of the present data from the above equations fall within ±8.4% for the Nusselt number and ±10% for the friction factor (Fig. 3(a–b)) in the case plain tube and ±10% for the Nusselt number and ±20% friction factor (in literature, PTT results

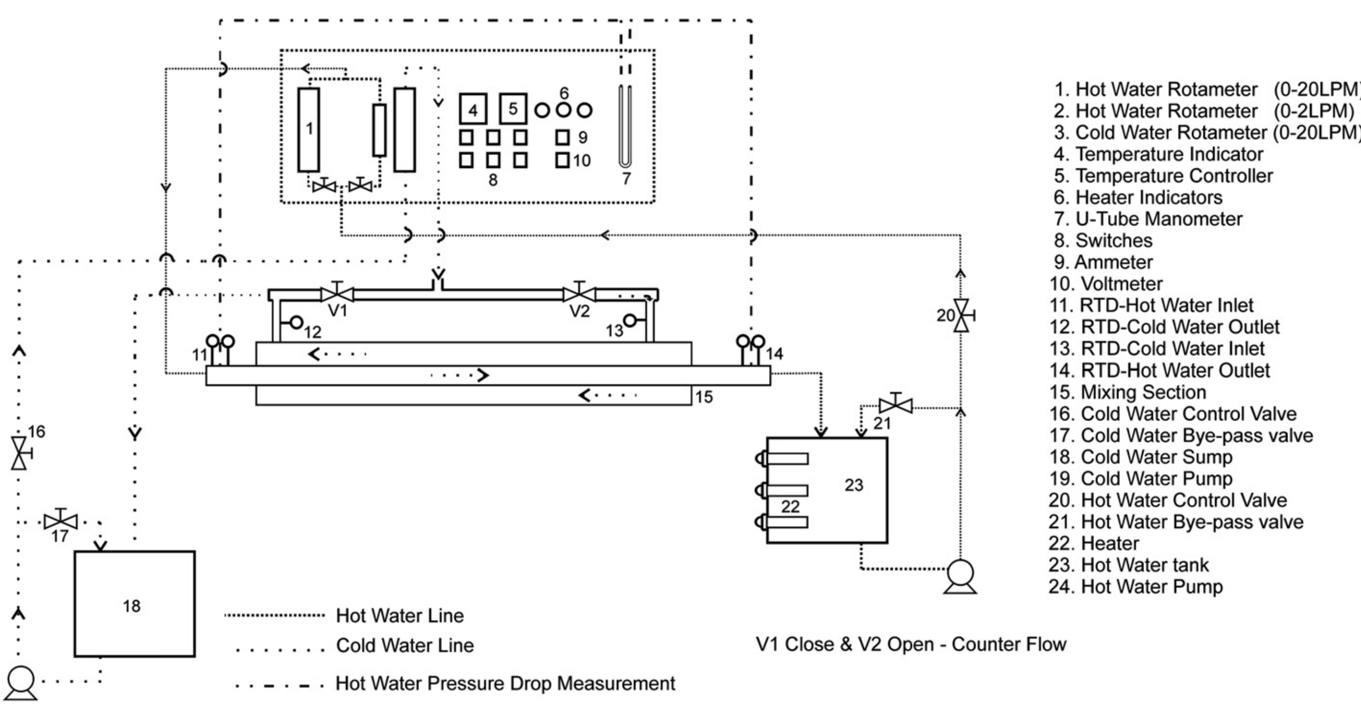

Fig. 1. Experimental setup.