2012 4th International Conference on Computer Modeling and Simulation (ICCMS 2012)
IPCSIT vol.22 (2012) © (2012) IACSIT Press, Singapore

Visualization of Flow and Heat Transfer in Tube with Twisted Tape Consisting of Alternate Axis

Panida Seemawute, Smith Eiamsa-Ard

Mahanakorn University of Technology, Thailand

Abstract. Visualization of flow characteristics induced by twisted tape consisting of alternate-axis (*TA*) has been comparatively investigated to that induced by typical twisted tape (*TT*). The visualization was carried out via a dye injection technique. The effects of twist ratios (*y/W*) on heat transfer and fluid friction were also extensively examined. The visualization results show that *TA* give better fluid mixing and thus higher heat transfer rate than *TT*, at similar conditions. In addition, swirl number and thus residence time of a fluid flow is promoted as tape twist ratio decreases, this visualization results is consistent with the superior heat transfer at smaller twist ratio.

Keywords : Twisted tape with alternate-axis (*TA*), Visualization, Heat transfer, Fluid friction

1. Introduction

Nowadays, twisted-tape inserts have widely been applied for enhancing the convective heat transfer in various industries, due to their effectiveness, low cost and easy setting up. Insertion of a twisted tape in a heat exchanger tube is classified as a passive enhancing technique. In general, twisted tape introduces swirl into the bulk flow which consequently disrupts a thermal boundary layer on the tube surface. Mechanisms of heat transfer enhancement by twisted tape inserts can be concluded as follows (1) the decrease of hydraulic diameter which leads to the increase in flow velocity due to portioning of the tube (2) the increase of flow path length due to helical configuration of the twisted tape (3) the increase of shear stress at wall tube and improvement of fluid mixing by secondary or swirl flow and (4) the fin contribution if the tape insert is in good thermal contact with the wall of the tube. Variants of twisted tapes have been evaluated as described below. Murugesan *et al.* [1-2] studied the flow friction and heat transfer characteristics of turbulent flow in a circular tube equipped with tube fitted with V/square-cut twisted tape. Rahimi *et al.* [3] performed the experimental and numerical investigation on the thermal performance of the tube equipped with *TT* and three modified twisted tapes (perforated, notched, and jagged twisted tapes). Eiamsa-ard and Promvonge [4-5] investigated the effect of CCC/serrated twisted tape on thermal performance factor in a round tube. Most of the modified twisted tapes mentioned above, offered higher heat transfer rates than the typical ones. However, the reasons behind those results are unclear since the flow behaviors were not directly explored. For better understanding on the influences of a twisted tape on heat transfer result, the flow structure characteristics in a circular tube were experimentally studied using dye injection, in the present work. Experiments were performed using *TTs/TAs* with three different twist ratios (*y/W*), to generate different swirl intensities.

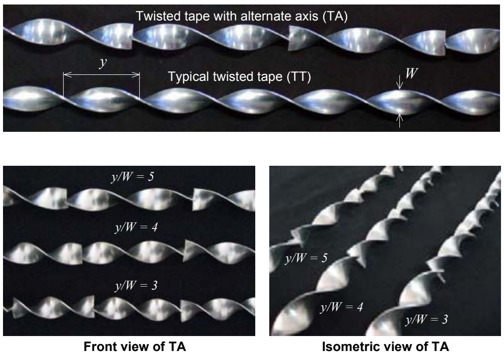


Fig. 1 Twisted tapes used in the present work

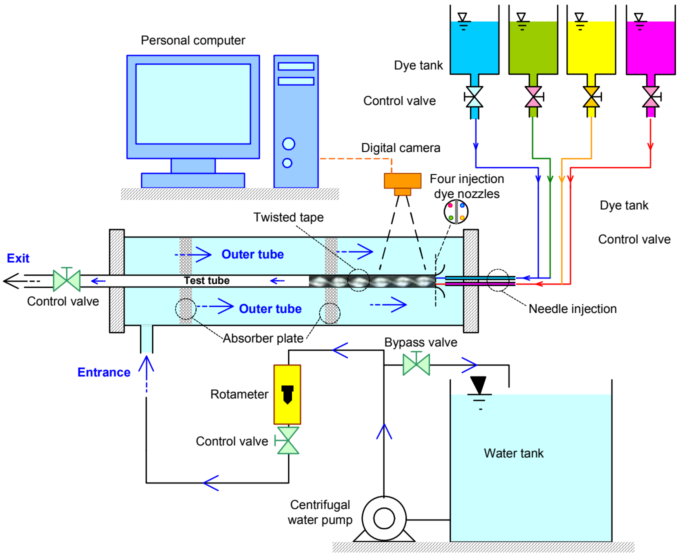


Fig. 2 Schematic diagram of flow visualization setup

2. Twisted Tape with Alternate-Axis (TA)

The details of *TAs* are presented in Fig 1. The *TAs* were made of aluminium strips (*for heat transfer setup*) and acrylic sheet (*for visualization setup*) with thickness of 1.0 mm (δ), width of 18 mm and length of 1000 mm. Firstly, straight tapes were prepared at three desired twist lengths in 180° rotation (y/W = 3, 4 and 5) by twisting straight tapes, about their longitudinal axis, while being held under tension. Then, *TAs* were obtained by modification of *TT* via the following steps: (1) the tape was cut on both sides with 4 mm depth of cut, at every twist length, (2) both sides at the cut were simultaneously twisted to angles difference of 90^{o} with respect to that of the former twist length, which is in arrangement for producing of swirl flow in opposing direction with regard to that of the former twist length.

3. Flow visualization setup

The flow visualization was carried out using dye injection technique. The system consisted of an acrylic tube fitted with *TT/TA*, a water pump, a water filter, a settling chamber, four injection needles, and a digital camera as shown in Fig. 2. A control valve and rotameter were respectively equipped downstream and upstream of the test section for controlling fluid flow rate. In the experiment, the water flow rate was maintained, corresponding to the desired Reynolds number. Four different dyes (red, blue, green and yellow) were injected at different position to signify flow field indued by *TAs*. The flow behaviors of the tube with *TTs*, were also visualized for comparison.

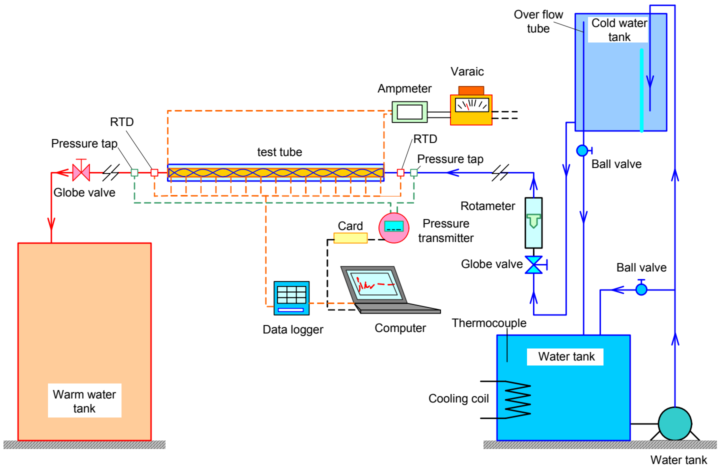


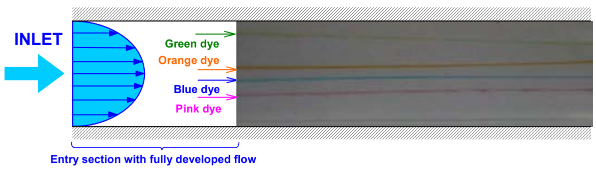
Fig. 3 Schematic diagram of experimental heat transfer setup

4. Heat Transfer Setup

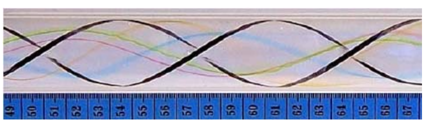
Experiments were carried out in an open loop rig as shown in Fig. 3. The heating test tube was made of copper with thickness of 1.5 mm, inner diameter of 19 mm and length of 1000 mm. The tube was wound with ceramic beads coated electrical SWG Nichrome heating wire. The terminals of the Nicrome wire were connected to the varaic transformer. The electrical output power was controlled via a variac transformer. The K-type thermocouple beads were tapped along the local tube wall for 15 stations to monitor temperatures of the surface tube wall. The heating tube and thermocouple were well insulated to minimize heat loss to surrounding. The pressure taps were located around 50 mm upstream and 150 mm downstream of the test section. The length between both tapes was around 1200 mm. The heat transfer and pressure drop experiments were conducted individually. The heat transfer experiment was conducted under a uniform heat flux. On the other hand, the pressure drop (friction) tests were performed under an isothermal condition without turning on the heater.

5. Results

The flow patterns in the tubes with/without *TA* by dye injection methods are presented in Fig. 4. A common axial flow is found in the plain tube as depicted in Fig. 4(a). On the other hand, a common swirl flow is induced by *TTs*. With *TAs*, fluid stream which directly encounters a crosswise edge of the tape at an alternate point, is separated (for example, the stream represented by the blue with *TA* at $y/W = 3$ in Fig. 4b). This potentially promoted fluid mixing, signified by the dissolve of the blue stream behind the alternate point. Moreover, there is also collision of streams delivered from different sides of twisted tape when they encounter each other behind the alternate point. In the same axial distance, the tape with smaller twist ratio produces more helical number than the one with larger twist ratio, this directly results in longer residence time which help to prolong heat transfer between tube wall and fluid.

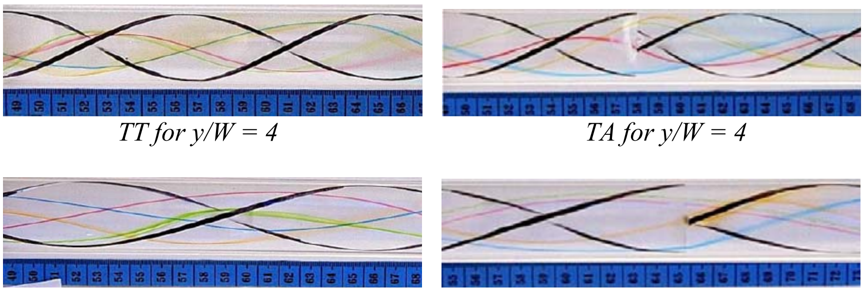


(a) axial flow through plain tube



TT for y/W = 3

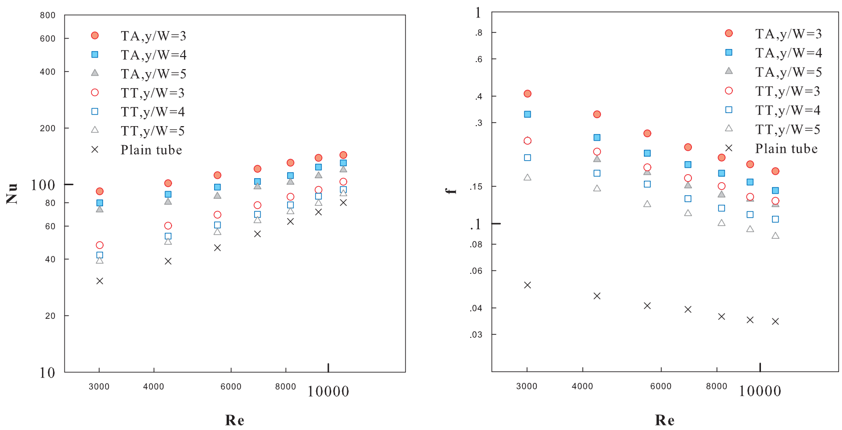
TA for y/W = 3



(b) swirl flow induced by *TT/TA* at *Re* ≈ 500

Fig. 4 Axial and swirl flow patterns by dye injection techniques

Effect of *TAs* at various twist ratios, *y/W* = 3, 4 and 5 on the Nusselt number is shown in Fig. 5a. For all runs, Nusselt number is consistently increases with increasing Reynolds number. This can be explained by the fact that the rise of Reynolds number leads to an increase in degree of turbulence intensity and thus improvement of convection heat transfer. At a certain Reynolds number and a twist ratio, the use of the *TA* yields a higher heat transfer rate than that of the use of the typical one (*TT*). This result is corresponded to the superior chaotic mixing as described above, and consequently results in more violent interruption on thermal boundary layer, and thus more efficient heat transfer though the tube wall. Figure 5b shows the relationship between the friction factor and Reynolds number in the tube fitted with the *TA*. For similar operating conditions, the friction factor generated by *TA* was higher than that generated by the typical one or the plain tube. The flow fluctuation in the tube with the *TA* is assumed to be main factor of the amplifying friction loss of fluid flow.



(a) *Nu* (b) *f*

Fig. 5 Variation of Nusselt number and friction factor with Reynolds number

6. Summaries

In the present work, the flow pattern, heat transfer and friction factor are reported. It is found that the tube with TA provides a better fluid mixing in the tube than those *TT* which leads to higher heat transfer rate and also friction factor. At the same axial distance, the tape with smaller twist ratio provides more swirl number and thus longer residence time which help to prolong heat transfer between tube wall and fluid.

7. Acknowledgement

The authors would like to acknowledge with appreciation, the Energy Policy and Planning Office, Ministry of Energy, Thailand (EPPO) for financial support of this research.

8. References

[1] MURUGESAN P; MAYILSAMY K; SURESH S. Turbulent Heat Transfer and Pressure Drop in Tube Fitted with Square-Cut Twisted Tape [*Chinese J Chem Eng*] 2010, PP:609-617.

[2] MURUGESAN P; MAYILSAMY K; SURESH S; SRINIVASAN P.S.S. Heat Transfer and Pressure Drop Characteristics in a Circular Tube Fitted with and without V-Cut Twisted Tape Insert [*Int Comm Heat and Mass Transfer*] 2011, PP: 329-334.

[3] RAHIMI M; SHABANIAN S.R; ALSAIRAFI A.A. Experimental and CFD Studies on Heat Transfer and Friction Factor Characteristics of a Tube Equipped with Modified Twisted Tape Inserts [*Chem Eng and Proc: Proc Intensification*] 2009, PP:762-770.

[4] EIAMSA-ARD S; PROMVONGE P. Thermal Characteristics in Round Tube Fitted with Serrated Twisted Tape [*App Therm Eng*] 2010, PP:1673-1682.

[5] EIAMSA-ARD S; PROMVONGE P. Performance Assessment in a Heat Exchanger Tube with Alternate Clockwise and Counter-Clockwise Twisted-Tape Inserts [*Int J Heat and Mass Transfer*] 2010, PP: 1364-1372.