IOP Conf. Series: Materials Science and Engineering **350** (2018) 012015 doi:10.1088/1757-899X/350/1/012015

TiO_2/water Nanofluid Heat Transfer in Heat Exchanger Equipped with Double Twisted-Tape Inserts

S. Eiamsa-ard[1], R. Ketrain[2] and V. Chuwattanakul[3]

[1]Faculty of Engineering, Mahanakorn University of Technology, Bangkok, Thailand
[2]Royal Irrigation Department, Samsen Nakornchaisri, Bangkok, Thailand
[3]Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand
Corresponding e-mail: smith@mut.ac.th

Abstract. Nowadays, heat transfer enhancement plays an important role in improving efficiency of heat transfer and thermal systems for numerous areas such as heat recovery processes, chemical reactors, air-conditioning/refrigeration system, food engineering, solar air/water heater, cooling of high power electronics etc. The present work presents the experimental results of the heat transfer enhancement of TiO_2/water nanofluid in a heat exchanger tube fitted with double twisted tapes. The study covered twist ratios of twisted tapes (*y/w*) of 1.5, 2.0, and 2.5) while the concentration of the nanofluid was kept constant at 0.05% by volume. Observations show that heat transfer, friction loss and thermal performance increase as twist ratio (*y/w*) decreases. The use of the nanofluid in the tube equipped with the double twisted-tapes with the smallest twist ratio (*y/w* = 1.5) results in the increases of heat transfer rates and friction factor up to 224.8% and 8.98 times, respectively as compared to those of water. In addition, the experimental results performed that double twisted tapes induced dual swirling-flows which played an important role in improving fluid mixing and heat transfer enhancement. It is also observed that the TiO2/water nanofluid was responsible for low pressure loss behaviors.

1. Introduction

Several techniques have been applied for improving the heat transfer and thermal performance in thermal systems [1-11]. Using nanofluids instead of base or common fluids is one of the techniques for improving the heat transfer in many thermal engineering processes including power generation, chemical production, heat exchanger, cooling processes, air-condition, heating, transportation, microelectronics and chemical processes. In general, the common fluids (water, ethylene glycol, mineral oil, engine oil and transformer oil) possess poorer heat transfer properties than most solids. To improve heat transfer, solid particles in nanoscale known as nanoparticles are mixed with base fluids, forming "nanofluids". Nanofluids are considered as not only a passive technique, but also a promising way, which open a new window to the future of advanced thermal fluid science. Nanoparticles suspended in conventional fluids were extensively utilized in heat exchangers for improving their thermal performance such as Al_2O_3/water [6-7, 9, 12], CuO/water [9, 12, 15-17], and TiO_2-water [18-19]. For their studied range, the heat transfer coefficient monotonically increased with increasing nanofluid concentration. Although, the combined heat transfer enhancement techniques using nanofluid together with typical twisted tape have been extensively studied and reported as literature review shown above, the explanation for the effect of twisted tape architecture together with nanofluid and also nanofluid concentration on the thermal performance is still limited and scarcely reported.

This is the driving force for this research work. The present work proposes the combined technique consisting of the use of TiO_2/water nanofluids and double twisted tapes as the modified tube inserts. The thermal performance was evaluated by simultaneous determining heat transfer and friction loss. The study covered twist ratios of twisted tapes (*y/w*) of 1.5, 2.0, and 2.5) and Reynolds numbers (*Re*) from 5000 to 20,000.

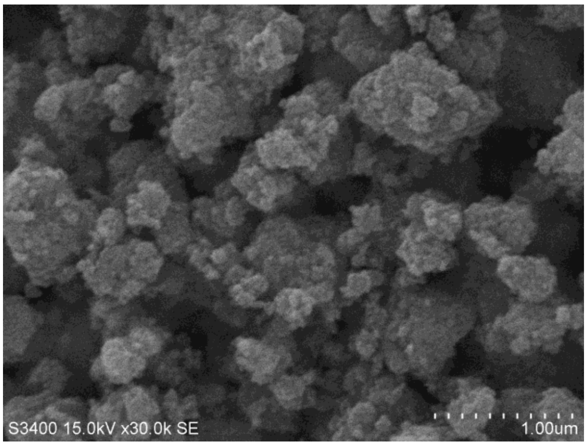


Figure 1. SEM image of TiO_2 nanoparticles.

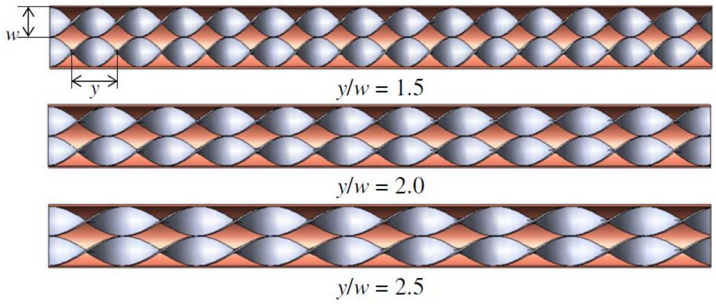


Figure 2. Double twisted tape with three twist ratios**.**

2. Experimental setup

2.1. TiO_2/water nanofluid

The nanoparticles used in the present work are AEROXIDE® TiO_2 P25, the product of Evonik Degussa. Figure 1 shows the scanning electron microscopy (SEM) photograph of the TiO_2 particles. Prior to testing, TiO_2 nanoparticles were dispersed in de-ionized water (the base fluid) at concentrations (ϕ) = 0.05% by volume. Then, the mixture was sonicated continuously for 180 minutes in an ultrasonic bath under ultrasonic pulses of 100 W at 36±3 kHz for the uniform dispersion of particles. Moreover, the sonication treatment significantly improved the stability of suspension. It took longer than 180 minutes after preparation for TiO_2 nanoparticles to start precipitation. Thus, TiO_2 nanoparticles were still well dispersed in water before feeding into the tube.

2.2. Double twisted tapes

Figure 2 demonstrated the geometries of the double twisted tapes. The tapes were made of thin aluminum sheets with a thickness of 0.8 mm and a width of 10 mm (*w*). Each twisted tape was fabricated by twisting a straight tape, about its longitudinal axis, while being held under tension. Twisted tapes were twisted at twist lengths (180^o/twist length) of 15, 20 and 25 mm corresponding to twist ratios (*y/w*) of 1.5, 2.0, and 2.5, respectively. In the experiments, double twisted tapes were inserted into the inner tube of double-pipe heat exchanger.

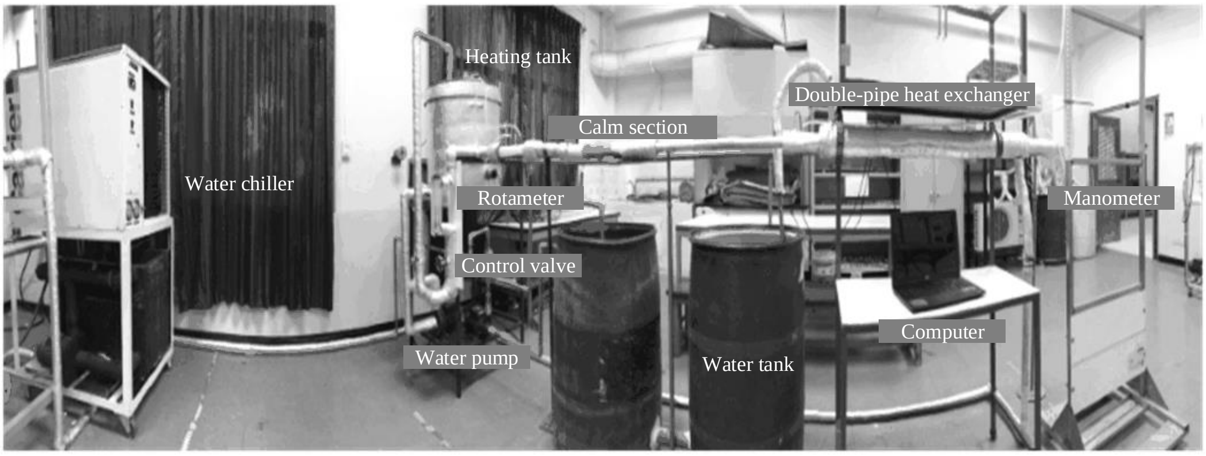


Figure 3. Photograph of the experimental setup.

2.3. Data reduction

The thermos-physical properties of the nanofluid were calculated as a function of nanoparticle volume concentration (ϕ) together with properties of base fluid and nanoparticles. The density of nanofluid was evaluated using the simple formula for mixture:

$$\rho_{nf} = (1-\phi)\rho_{water} + \phi\rho_{np} \tag{1}$$

The specific heat of the nanofluid was evaluated from

$$c_{p,nf} = \frac{\phi\rho_{np}c_{p,np} + (1-\phi)\,\rho_{water}c_{p,water}}{\rho_{nf}} \tag{2}$$

The thermal conductivity was calculated as seen below

$$\frac{k_{nf}}{k_{water}} = \frac{k_{np} + 2k_{water} + 2\phi(k_{np} - k_{water})}{k_{np} + 2k_{water} - \phi(k_{np} - k_{water})} \tag{3}$$

Viscosity of nanofluids was calculated via the general Einstein's formula

$$\mu_{nf} = \mu_{water}(1+\eta\phi) \tag{4}$$

Nusselt number is calculated using the following equation

$$Nu = hD/k \tag{5}$$

The friction factor is written as following equation below

$$f = (D/L)(2\Delta P/\rho U^2) \tag{6}$$

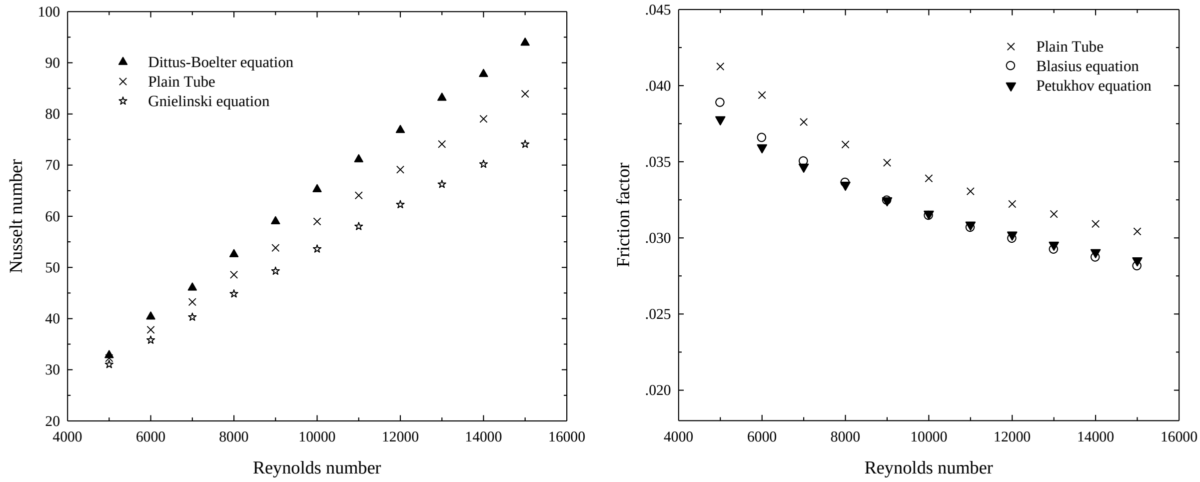
The thermal performance factor (η) under same pumping power criteria is given by

$$\eta = \left(Nu / Nu_p\right) / \left(f / f_p\right)^{1/3} \tag{7}$$

3. Validation experiments of plain tube with water as the base fluid

Initially, the accuracies of the experimental data including heat transfer (*Nu*) and friction factor (*f*) were validated by comparing the present results (of distilled water as the base fluid in the plain tube) with the predictions of Dittus-Boelter and Gnielinski correlations for Nusselt numbers and those of Blasius and Petukhov correlations for friction factors. The comparisons are shown in Fig. 4. Apparently, the present data agree well with those of the standard correlations. This can be concluded that the results from the present experimental system are reliable. Thus, the facility was employed for further investigation with double twisted tapes and TiO_2/water nanofluid.

IOP Conf. Series: Materials Science and Engineering **350** (2018) 012015 doi:10.1088/1757-899X/350/1/012015



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

Figure 4. Verification test of the present plain tube with water as base fluid.

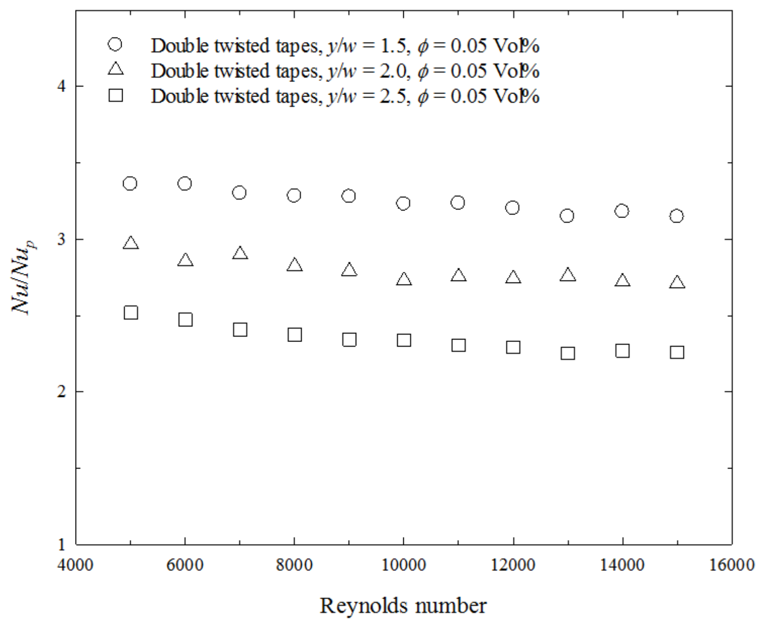


Figure 5. Influence of ϕ on *Nu*.

4. Results and discussion

4.1. Heat transfer

In this section, the effect of combined heat transfer enhancement technique using TiO_2/water nanofluids in double-pipe heat exchanger fitted with double twisted tapes on the heat transfer (*Nu*), friction factor (*f*) and thermal performance factor (η) are reported. Figure 5 depicts the variation of Nusselt number with Reynolds number for water and TiO_2/water nanofluid in the tube equipped with double twisted-tapes with twist ratios (y/w) = 1.5, 2.0 and 2.5. The Reynolds number was varied from 5000 to 20,000. Evidently, Nusselt number increases with increasing Reynolds number. At a given Reynolds number, all TiO_2/water nanofluids give higher Nusselt number than water as the based fluid. The higher heat transfer by nanofluids arises from: (i) the ability of suspended nanoparticles enhancing thermal conductivity; (ii) movement of nanoparticles delivering energy exchange. In addition, heat transfer increases as twist ratio of twisted tape decreases (or twist number increases). This can be attributed to the increase of swirling/turbulence intensity as well as the improved consistency of swirl flow which leads to thinner thermal boundary layer and better heat transfer. The use of the nanofluid in the tubes equipped with twisted tapes with *y/w* = 1.5, 2.0 and 2.5 resulted in heat transfer enhancement by 5.18%, 4.94% and 4.74%, respectively, compared to that of water.

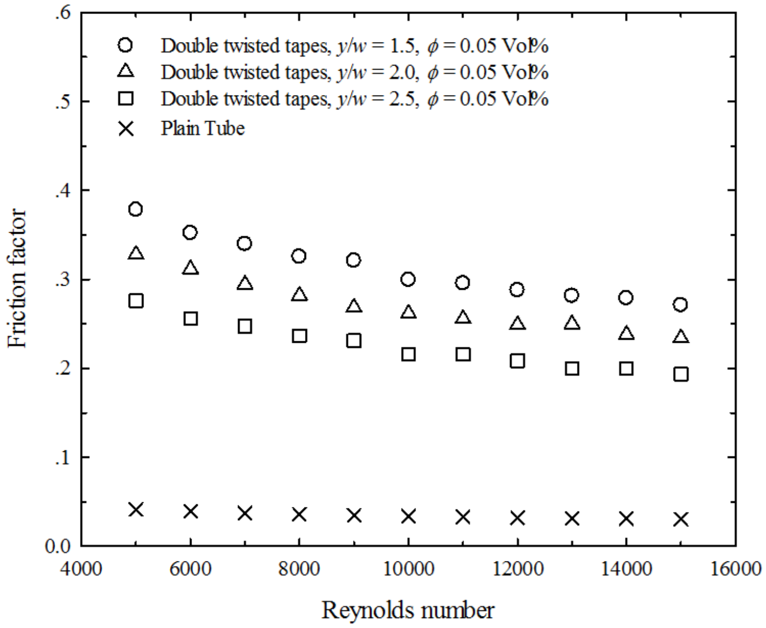


Figure 6. Influence of ϕ on *f*.

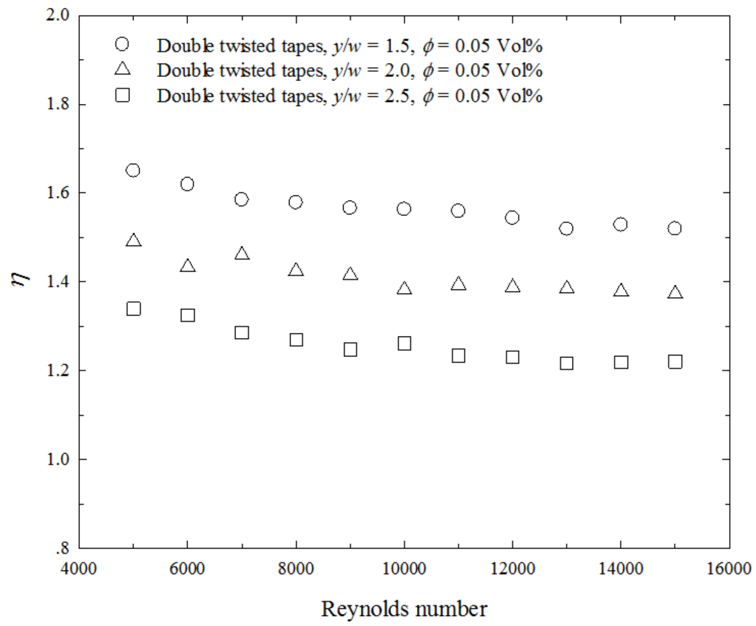


Figure 7. Influence of ϕ on η.

4.2. Friction factor

The effect of TiO_2/water nanofluids on the friction factor (*f*) in tube with double twisted-tapes is presented in Fig. 6. In general, the friction factor of tube with double twisted-tape inserts was higher than that the plain tube due to the swirling flow and the dissipation of dynamic pressure of the fluid at high viscosity loss near the tube wall. When twist ratio (*y/w*) decreases, friction factor increases. At a given Reynolds number, nanofluids cause higher friction factor than water (the based fluid). The rise in friction factor is due to the rise in viscosity of the nanofluids as compared to that of water. In addition, friction factor increases as twist ratio decreases. This result can be explained by the same reasons for heat transfer or Nusselt number.

4.3. Thermal performance factor
As shown above, the heat transfer enhancement technique increases both heat transfer (advantage) and friction loss (disadvantage). The overall performance or benefit can be evaluated by simultaneous determining heat transfer and friction loss in the form of thermal performance factor which is expressed in Eq. (8). Over the range investigated, the thermal performance factors of TiO_2/water nanofluid in the tubes with double twisted-tapes at *y/w* = 1.5, 2.0 and 2.5 are higher than that of the based fluid in the plain tube by around 56.6%, 41.1% and 25.9%, respectively, as seen in Fig. 7. The maximum thermal performance factors of TiO_2/water nanofluid in the tubes with double twisted-tapes at *y/w* = 1.5, 2.0 and 2.5 are 1.65, 1.49 and 1.33 are obtianed at *Re* = 5000.

5. Conclusion
The experimental results show that the use of nanofluid together with double twisted-tapes leads to the increases of heat transfer, friction loss and thermal performance as compared to those of the base fluid in the plain tube. Heat transfer, friction loss and thermal performance increase with decreasing twist ratio *(y/w)*. The Nusselt numbers of the nanofluid in the tubes equipped with the double twisted-tapes at *y/w* = 1.5, 2.0 and 2.5 increase by 224.8%, 179.6% and 134.8% over the base fluid in the plain tube. The highest thermal performance factor of 1.65 was obtained by the use of the nanofluid in the tube equipped with the double twisted-tapes at *y/w* = 1.5.

6. References
[1] Koolnapadol N, Sripattanapipat S and Skullong S 2014 *J. Res. Appl. Mech. Eng*. **4** 166
[2] Eiamsa-ard S, Yongsiri K, Nanan K and Thianpong C 2012 *Chem. Eng. Proc.: Proc. Intensification* **60** 42
[3] Matsunaga T and Sumitomo T 2014 *J. Res. Appl. Mech. Eng.* **2** 65
[4] Kongkaitpaiboon V, Nanan K and Eiamsa-ard S 2010 *Int. Comm. Heat Mass Transfer* **37** 560
[5] Nanan K and Eiamsa-ard P 2014 *J. Res. Appl. Mech. Eng.* **2** 103
[6] Sharma K V, Syam Sundar L and Sarma P K 2009 Int. *Comm. Heat Mass Transfer* **36** 503
[7] Syam Sundar L and Sharma K V 2010 *Int. J. Heat Mass Transfer* **53** 1409
[8] Suresh S, Venkitaraj K P, Selvakumar P and Chandrasekar M 2012 *Exp. Therm. Fluid Sci*. **39** 37
[9] Eiamsa-ard S, Somkleang P, Nuntadusit C and Thianpong C 2013 *App. Therm. Eng.* **54** 289
[10] Thianpong C, Eiamsa-ard P, Promvonge P and Eiamsa-ard S 2012 *Energy Procedia* **14** 1117
[11] Thianpong C, Yongsiri K, Nanan K and Eiamsa-ard S 2012 *Int. Comm. Heat Mass Transfer* **39** 861
[12] Suresh S, Venkitaraj K P and Selvakumar P 2011 *Superlattices and Microstructures* **49** 608
[13] Eiamsa-ard S 2010 *Int. Comm. Heat and Mass Transfer* **37** 644-651
[14] Promvonge P and Eiamsa-ard S 2007 *Int. Comm. Heat Mass Transfer* **34** 72
[15] Eiamsa-ard S and Wongcharee K 2012 *Int. Comm. Heat Mass Transfer* **39** 1453
[16] Wongcharee K and Eiamsa-ard S 2012 *Int. Comm. Heat Mass Transfer* **39** 251
[17] Wongcharee K and Eiamsa-ard S 2011 *Int. Comm. Heat Mass Transfer* **38** 742
[18] Eiamsa-ard S, Kiatkittipong K and Jedsadaratanachai W 2015 *Eng. Sci. and Tech., Int. J.* **18** 336
[19] Perarasu V T, Arivazhagan M and Sivashanmugam P 2012 *J. Hydro.* **24** 942