Journal of Materials Science & Surface Engineering Vol. 4 (1), 2016, pp 326-331

Contents lists available at http://www.jmsse.org/

Journal of Materials Science & Surface Engineering

Effect of Twisted-Tape Turbulators and Nanofluid on Heat Transfer

Fariborz Forouhandeh[1], Mohammad Akhtari[2], Nasim Faridi Sani[3], Mehdi Aghili[4*]

[1]*Department of Engineering, Shahrood Branch, Islamic Azad University, Shahrood, Iran.*
[2]*Department of Mechanical Engineering, Shahrood Branch, Islamic Azad University, Shahrood, Iran.*
[3]*Department of Chemistry, Sciences Faculty, Arak Branch, Islamic Azad University, Arak, Iran.*
[4]*Department of Chemical Engineering, Shahrood Branch, Islamic Azad University, Shahrood, Iran.*

Article history

Received: 06-Aug-2015
Revised: 19-Nov-2015
Available online: 18-Jan-2016

Keywords:
Nusselt number,
Heat transfer,
Thermal conductivity,
Viscosity

Abstract

Heat transfer and Nusselt number in a double pipe heat exchanger fitted with twisted-tape elements and titanium dioxide nanofluid were studied experimentally. Titanium dioxide nanoparticles with a diameter of 15 nm and a volume concentration of 0.5-2.5% (v/v) were prepared. Thermal conductivity and viscosity of nanofluid were measured using a Brookfield viscometer kd2. Yo and Choi and wang models used to estimate and predict the thermal conductivity and viscosity of nanofluid are more consistent with the experimental data in compared to the other models .The effects of temperature, mass flow rate, and concentration of nanoparticles on the Nusselt number, heat transfer changes in the turbulent flow regime (Re ≥2300), and counter current flow were investigated .When using twisted tape and nanofluid, heat transfer and Nusselt number was about 20 to 35 percent higher thanwhen they were not used. It was also observed that the heat transfer and Nusselt number increases with operating temperature and mass flow rate.The experimental results also showed that 2.5% v/v TiO_2/water nanofluid with twisted tape has slightly higher Nusselt number when compared to 2.5% TiO_2/water nanofluid without twisted tape.

Introduction

High performance heat transfer system is of great importance in many industrial applications. Therefore, the heat transfer enhancement techniques are widely applied in heat exchangers, in order to improve heat transfer coefficient [1–4]. Passive heat transfer augmentation is method to enhance heat transfer without external power. Among the techniques used, insertion of twisted tape in a circular tube is one of the most effective approaches. The inserted twisted tape generates swirling flow and increases turbulence intensity which is major influencing factors for heat transfer enhancement. In fact, using twisted tape increases both desirable heat transfer rate and undesirable friction loss (pressure drop). An appropriate twisted tape modification is a challenge task as a proper design of twisted tape is a main key for heat transfer enhancement at a reasonable friction loss.

Aghayari et al. [5] reported experimental results which illustrated the dispersion of the heat transfer and Overall heat transfer coefficient of AL2O3 nanoparticles in liquid for Turbulent flow in a Double pipe heat exchanger. Impacts of the Reynolds number, volume fraction, temperature and nanoparticle source on the Overall heat transfer coefficient have been investigated. The experimental results showed that the heat transfer coefficient increases with the Reynolds number and the particle concentration. Aluminum oxide nanofluid with concentrations of 0.2 and 0.3 had high thermal efficiency compared to the base fluid. For example, this amount is 1450000 for water at a constant mass flow rate and a temperature of 50°C. This amount is 1565000 and 1580000 for the nanofluid at the concentrations of 0.2 and 0.3, respectively. Thermal efficiency of water and nanofluid with the concentration of 0.1 is 1103842 and 1123123, respectively (in Reynolds of 23000) which is approximately 1.71% higher than the heat transfer of the base fluid. This increase can be attributed to the immigration of the particles, non-uniform distribution of the thermal conductivity and viscosity of the fluid which decreases the boundary layer thickness, resulting in the delay in the development of the thermal boundary layer.

Maddah et al [6] investigated heat transfer and overall heat transfer in a double pipe heat exchanger fitted with twisted-tape elements and titanium dioxide nanofluid experimentally. Titanium dioxide nanoparticles with a diameter of 30 nm and a volume concentration of 0.01% (v/v) were prepared. The effects of temperature, mass flow rate, and concentration of nanoparticles on the overall heat transfer coefficient, heat transfer changes in the turbulent flow regime(Re≥ 2300), and counter current flow were investigated. When using twisted tape and nanofluid, heat transfer coefficient was about 10 to 25 percent higher than when they were not used. It was also observed that the heat transfer coefficient increases with operating temperature and mass flow rate. The experimental results also showed that 0.01% TiO2 water nanofluid with twisted tape has slightly higher friction factor and pressure drop when compared to 0.01% TiO2/water nanofluid without twisted tape. The empirical correlations proposed for friction factor were in good agreement with the experimental data.

Maddah et al [7] studied thermal and physical behavior of the Al2O3 Nano-fluid in a horizontal double pipe counter-flow heat exchanger fitted with modified twisted tapes under turbulent flow conditions. The experiments with and without typical twisted tapes and nanofluid were performed under similar operation condition and validated with existing well established correlations to verify experimental setup. Al2O3 nanoparticles with diameters of 21 nm dispersed in water and the concentration was varied from 0.2 to 0.9% by volume. The nanofluid considered as non-Newtonian fluid due to the shear-thinning

Corresponding author. Tel./fax- (910) 2050084
E-mail address: mehdiaghili563@gmail.com

rheological behavior. The mathematical concept of Geometrical Progression was applied to prepare modified twisted tapes. Pitch length of the proposed twisted tapes and consequently the twist ratios changed along the twists with respect to the Geometrical Progression Ratio (GPR) whether reducer (RGPR<1) or increaser (IGPR>1). The experiments were performed using modified tapes with seven different Geometrical Progression Ratios (RGPR = 0.6, 0.75and 0.85, typical twist with GPR=1, IGPR = 1.2, 1.5 and 2) over a Reynolds number range of 5000 to 21000. Regarding the experimental data, utilization of RGPR twists together with nanofluids tend to increase heat transfer and friction factor by 12% to 52% and 5% to 28% as compared with the tube with the typical twisted tapes (GPR=1) and nanofluid. Contrarily, performances were weakened by using for IGPR twists 0.6 t0 0.92 and 0.75 to 0.95 times of those in the typical twisted tapes and nanofluid. Over the range investigated, heat transfer rates were enhanced in term of Nusselt numbers by the RGPR twisted tape with nanofluid up to 4 and with IGPR twists up to 1.84 times of that in the plain tube. Maddah et al [8] investigate synthesis and thermo-physical properties including thermal conductivity and viscosity of Fe3O4 Nanofluid. In this study, Fe3O4 nanoparticles with the size of 20 nm were prepared. The nanoparticles was characterized by X-ray powder diffraction (XRD) analysis and transmission electron microscopy (TEM). Additionally, the effect of many parameters on the Fe3O4 nanoparticles was studied.The thermal conductivity and viscosity of nanofluids are measured and it is found that the viscosity increase is substantially higher than the increase in thermal conductivity. All of the property thermal conductivity, electrical conductivity and viscosity of nanofluids increase with the nanoparticle volume concentration. Theoretical models are developed to predict thermal conductivity and viscosity of nanofluids without resorting to the well established Maxwell and Einstein models, respectively. The proposed models show reasonably good agreement with our experimental results.

Experimental

Sample Preparation

The nanofluid used in the experiment was +99.0% TiO_2 nanoparticles predispersed in water, with an average particle size of 15 nm. The nanofluid was mixed with deionized water. To prepare experimental concentrations, nanofluids with less than 3% nanoparticles were found to be stable and the stability lasted over a week; no intermediate mixing was considered necessary . The volume fraction TiO_2 /water nanofluid sample varied from 0.5-2.5% v/v. NF samples were then underwent mixing by ultra-sonic method between 3 to 4 hours to ensure complete dispersion is achieved. The morphology of TiO_2 nano-particles was studied by using SEM (Figure 1).

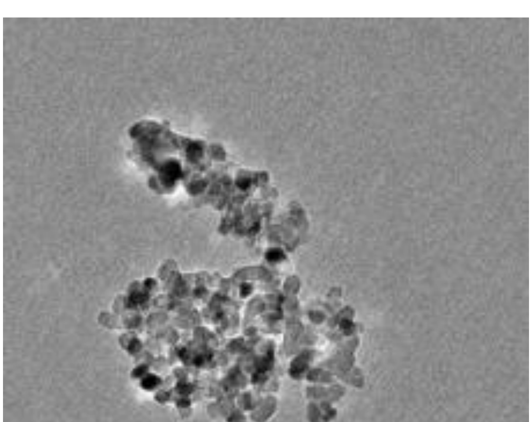


Figure 1: SEM photographs of TiO_2 nanoparticles.

Heat transfer Experimental set-up and procedure

The experiment to investigate heat transfer characteristic of nanofluid were carried out using the experimental apparatus as shown in figure 2. It mainly consisted of a test section, receiving tanks in which working fluids are stored, heating and cooling system, temperature, flow meter, Rota-meter, pressure measurement system and data acquisition system. The working fluids were circulated through the loop by using variable speed pumps of suitable capacity. The test section is of 1.5 m length with counter flow path within horizontal double pipe heat exchanger in which hot nanofluid was applied inside the tube while cooling water was directed through the annulus. The inner tube was made of smooth copper and has inner and outer diameter of 8.13mm and 9.53 mm while the annulus was stainless steel with inner diameter of 27.8mm and wall tube thickness of 6mm. The section was thermally isolated in order to minimize heat losses to surrounding by plastic tubes . 8 T-type thermocouples with 0.1℃ precision were taped along the inner tube wall at equally space to measure the circumferential temperature variation. All of the thermocouples were calibrated before fixing them. The inlet and outlet temperature of the fluids were measured by calibrated RTD's. All of the temperature data were recorded by data logger. To measure the pressure drop across the test section, differential pressure transmitter was mounted at the pressure tab located at the inlet and outlet of the section. The nanofluid flow rate of were measured by a magnetic flow meter which were placed at the entrance of the test section. For each test run, it was essential to record the data of the temperature, volumetric flow rates and pressure drop across the section at steady state conditions. Two storage tanks were made of stainless steel at capacity of 50 lit to collect the fluids leaving the test section. The cooler tank was of 4.5 kw capacity with a thermostat to keep water temperature constant. The provision of thermostat helps to achieve steady state conditions faster. The temperature of inlet water was maintained around 30º C and the flow rate of the water was kept constant at 500 lit/hr. similar to the cooling tank, a 4 kw electronic heater with a thermostat was installed to maintain the temperature of the nanofluid constant at 40º C. hot nanofluid was pumped from the fluid tank through the inner tube included twisted tapes at different Reynolds number between 5000 to 21000. To ensure the steady state condition for each run, the period of around 20-30 minutes depending on Reynolds number and twisted tapes was taken prior to the data record. The twisted tapes were made from aluminum sheet with tape thickness (d) of 1 mm,width (W) of 5mm, and length of 1.5m.The tape thickness of 1mm was chosen to avoid an additional friction in the system that might occur by the thicker tape. To produce the modified twisted tape, the typical twists changed by changing twist ratio and geometrical progression ratio along the twist (Figure 3).

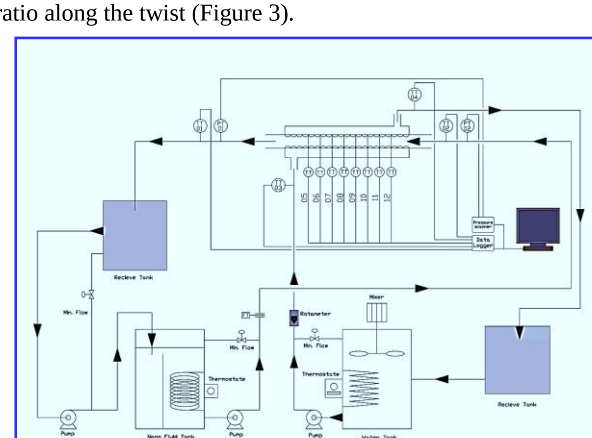


Figure 2: Schematic diagram of the experimental setup.

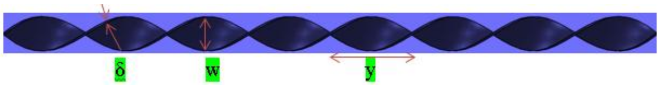


Figure 3: Geometries of typical twisted tape

Data Reduction

In the present study, the TiO_2 dispersed in water with volume concentrations of 0.5-2.5 % v/v. During the test, cold water absorbed heat from hot nanofluid. The heat transfer rate from the heating fluid was calculated from the following equation:

$$Q_{nf} = \dot{m}_{nf} Cp_{nf} (T_{out} - T_{in})_{nf} \quad (1)$$

where Q_{nf} is the heat transfer rate of the nanofluid and $\dot{m}_{nf}$ is the mass flow rate of the nanofluid. The heat transfer rate into the cooling water was calculated from the following equation:

$$Q_w = \dot{m}_w Cp_w (T_{out} - T_{in})_w \quad (2)$$

In this study, the supplied heat by the hot nanofluid was found to be 3% higher than the received heat. This deviation can be interpreted by convection and radiation heat loss along the test section. The average heat transfer rate is:

$$Q_{ave} = \frac{Q_w + Q_{nf}}{2} \quad (3)$$

The average value of experimental heat transfer coefficient and mean Nusselt number of the nanofluid are evaluated as the following:

$$h_{nf} = \frac{q_{ave}}{\bar{T}_{wall} - T_{b,nf}} \quad (4)$$

$$Nu_{nf} = \frac{h_{nf} D}{K_{nf}} \quad (5)$$

Where $\bar{T}_{wall}$ is the mean wall surface temperatures measured by 8 stations lined between the inlet and outlet of the test tube.

$$\bar{T}_{wall} = \sum \frac{T_{wall}}{8} \quad (6)$$

In which T_{wall} is the local wall temperature.

$T_{b,nf}$ is mean bulk nanofluid temperature :

$$T_{b,nf} = \frac{T_{in} + T_{out}}{2} \quad (7)$$

The flow regime can be defined from Reynolds number based on the flow rate at the inlet of the test tube. For purely viscous non-Newtonian fluid, the Reynolds number is defined as follows:

$$Re = \frac{\rho_{nf} {v_{nf}}^{2-n} {d_i}^n}{m\gamma^{n-1}} \quad (8)$$

Where v_{nf} is the mean velocity of the nanofluid and d_i diameter of the tube.

Friction factor can be calculated from the following equation:

$$f_{nf} = \frac{\Delta P_{nf}}{(L/d_i)\rho_{nf}({v_{nf}}^2/2)} \quad (9)$$

Where, f_{nf} is the friction factor of the nanofluid, ΔP_{nf} is the measured pressure drop of the nanofluid and L is the length of the tube.

The Prandtl number and Peclet number of the nanofluid can be evaluated from the following equations:

$$Pr_{nf} = \frac{m\gamma^{n-1} Cp_{nf}}{K_{nf}} \quad (10)$$

$$Pe_{nf} = \frac{v_{nf} d_p}{\alpha_{nf}} \quad (11)$$

Where d_p is the diameter of the nanoparticles and α_{nf} is the thermal diffusivity of the nanofluid.

The performance evaluation analysis (η) is defined as the enhanced convective heat transfer coefficient (h_E) to the non-enhanced one (h_{NE}) at the same pumping power.

$$\eta = \frac{h_E}{h_{NE}} \quad (12)$$

$$\mathrm{Nu} = Nu_0 . \left(1 + \frac{52Gr}{pr}\right)^{0.28} \quad (13)$$

To compare friction factor, Blasius correlation [9] for water and Duangthongsuk and Wongwises correlation [10] for nanofluid were employed:

Blasius correlation:

$$f = 0.316Re^{-0.25} \quad (14)$$

and Duangthongsuk and Wongwises correlation:

$$f_{nf} = 0.961\varphi^{0.052} Re_{nf}^{-0.375} \quad (15)$$

The models used to compute thermal conductivity for comparison were:

a) Maxwell model [12]

$$K_{nf} = K_w \left[\frac{1 + 2\varphi\left(\dfrac{1 - \frac{K_w}{K_{np}}}{2\frac{K_w}{K_{np}} + 1}\right)}{1 - \varphi\left(\dfrac{1 - \frac{K_w}{K_{np}}}{\frac{K_w}{K_{np}} + 1}\right)}\right] \quad (16)$$

Where, K_{nf} is the thermal conductivity of the nanofluid, K_{np} is the thermal conductivity of the nanoparticles, and K_w is the thermal conductivity of the base fluid.

b) Hamilton–Crosser model which can be expressed as the following form [13]:

$$K_{nf} = K_w \left[\frac{K_{np} + (n-1)K_w - \varphi(n-1)(K_w - K_{np})}{K_{np} + (n-1)K_w + \varphi(K_w - K_{np})}\right] \quad (17)$$

$$n = {}^{3}/_{\Psi}$$

In which, n is shape factor and Ψ is the sphericity defined as surface area of a sphere with a volume equal to the average surface area of the particle.

c) Yu and Choi model which was defined as follows [14]:

$$K_{nf} = \left[\frac{K_{np} + 2K_w - 2\varphi(1+\beta)^3(K_w - K_{np})}{K_{np} + 2K_w + \varphi(1+\beta)^3(K_w - K_{np})}\right] \quad (18)$$

Brinkman [15] suggested and equation for calculating the viscosity of the suspension, which is defined as follows

$$\mu_{nanofluid} = \frac{1}{(1-\varphi)^{2.5}}\mu_{water} \quad (19)$$

$$\mu_{nanofluid} = (1+2.5\varphi)\mu_{water} \quad (20)$$

Batchelor [16] introduced a correlation for calculating the viscosity of nanofluids with spherical shape nanoparticles, which is defined as:

$$\mu_{nf} = (1+2.5\varphi+6.2\varphi^2)\mu_w \quad (21)$$

The thermal conductivity of nanofluids:

In order to validate the experimental data of thermal conductivity obtained by QTM, the thermal conductivity of nanofluid was measured at temperature 35ºC and various particle volume concentrations under steady state. The experimental data were shown in figure 4 along with the calculated values from stated well-known correlations and models. As the figure indicates, the results showed a good correspondence between the measured value and Yo and Choi model.

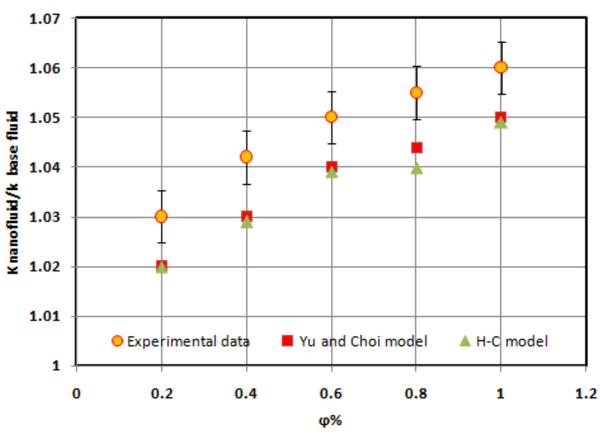


Figure 4: Comparison of the thermal conductivity between measured data and calculated value from the other correlations

The viscosity of the nanofluid

To validate the ATS apparatus to measure the viscosity of nanofluid, the obtained results at different shear rates were compared with wang model results. Figure 5 shows the comparison of evaluated data with presented prediction model. As the figure indicates, the experimental results were in close agreement with calculated values using wang model results. However, there is a deviation between the measured values and predicted results of Einstein model. As shown in Fig. 5, the results showed that the viscosity of nanofluids increases with increasing particle volume concentration.

Figure 6(a,b) shows the effects of temperature and concentration of TiO_2 nanofluid in terms of the Q average at the temperatures of 30 and 40ºC, respectively. As can be seen, Q average of the nanofluid under the condition of same Reynolds number is greater than the base fluid. For example, this value is 19% for the nanofluid with a concentration of 0.6 at the temperature of 30ºC compared to the base fluid (the Reynolds number of 27000). This amount is 25% at the temperature of 40ºC. This increase can be attributed to the thermal conductivity. There are several mechanisms to increase the thermal conductivity of the nanofluid: the formation of the liquid layer on the surface of the nanoparticles, Brownian motion, classification of particles, the transmission of the phonons projectiles in the nanoparticles, and the increase of the thermal conductivity of fluids with the increase of the nanoparticles in the pipe wall. The increase in the thermal conductivity can increase the heat transfer coefficient in the thermal boundary layer near the tube wall. Temperature is one of the factors increasing the thermal conductivity of the nanofluid and thereby increasing the heat transfer .

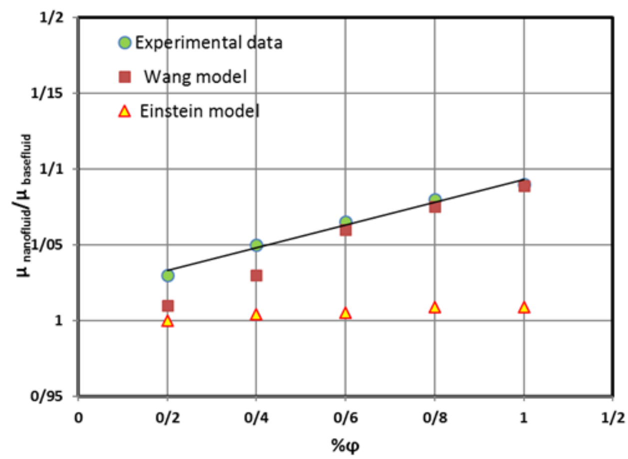


Figure 5: Comparison of the viscosity between measured data and calculated value from the other correlations

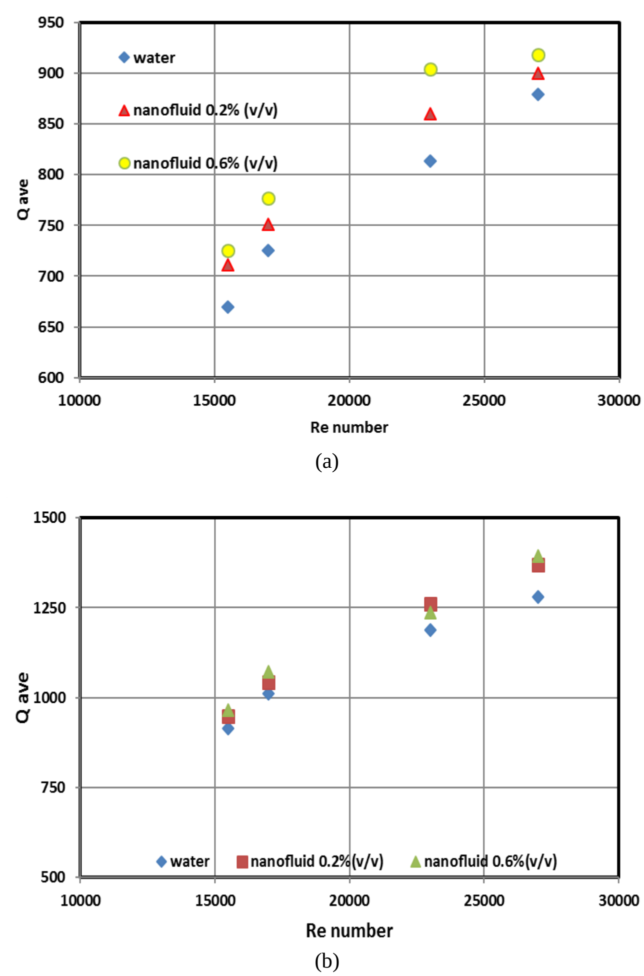
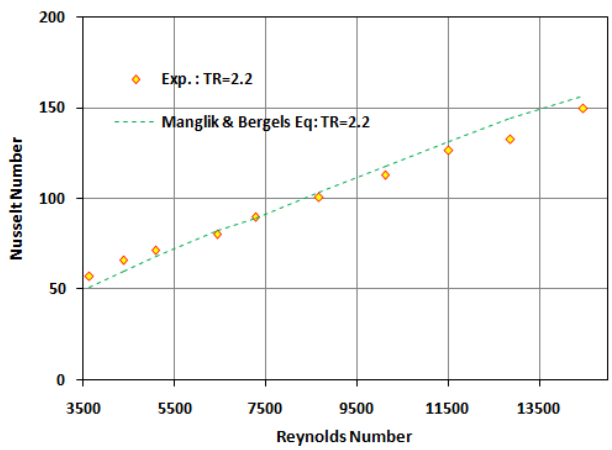


Figure 6: heat transfer average of TiO_2 nanofluid versus Reynolds number for various volume concentrations (T = 30ºC, 40ºC).

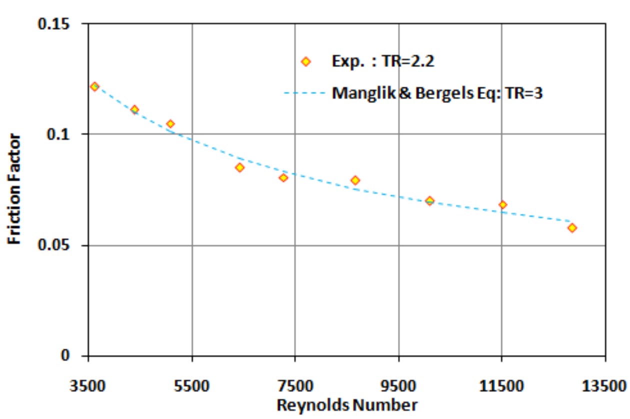
To verify the experimental procedure with twisted tape inserts, the tests with empty water and TiO_2 nanofluid were conducted at two different twist ratio and results compared with the estimating correlation results as shown in figure 7 (a,b). The verifying correlations for Nusselt number and friction factor of single phase like water were proposed by Manglik and Bergles [11] for the plain tube fitted with twisted tapes under turbulent flow as the following form:

$$Nu = \left(1+\frac{0.769}{\left(\frac{y}{w}\right)}\right)\left[0.023Re^{0.8}Pr^{0.4}\left(\left(\frac{\pi}{\pi-\left(\frac{4\delta}{d_i}\right)}\right)^{0.8}\left(\frac{\pi+2-\left(\frac{2\delta}{d_i}\right)}{\pi-\left(\frac{4\delta}{d_i}\right)}\right)^{0.2}\right)\right]$$

$$f = \left(1+2.06\left(1+\left(2\frac{\frac{y}{w}}{\pi}\right)^{2}\right)^{-0.74}\right) * \left[0.079Re^{-0.25}\left(\frac{\pi}{\pi-\left(\frac{4\delta}{d_i}\right)}\right)^{1.75}\left(\frac{\pi+2-\left(\frac{2\delta}{d_i}\right)}{\pi-\left(\frac{4\delta}{d_i}\right)}\right)^{1.25}\right]$$



(a)

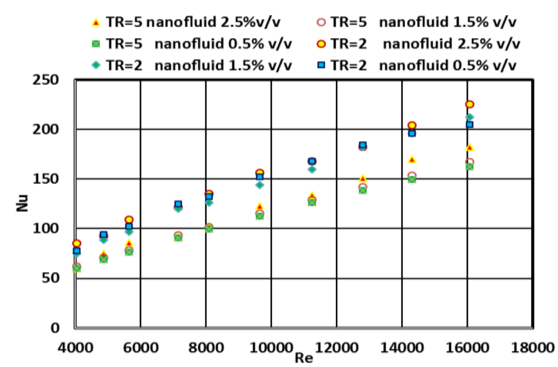


(b)

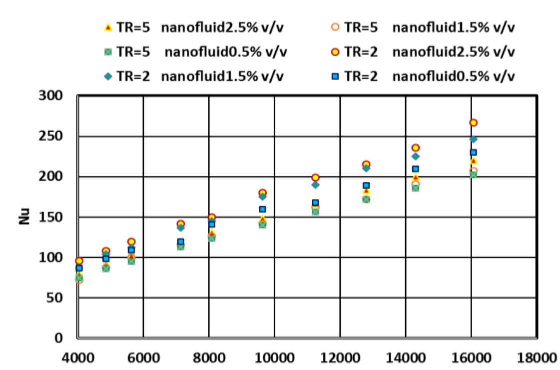
Figure 7: Validation of plain tube with twisted tapes and water : (a) Nusselt number and (b) friction factor

Figure 8(a,b) represent the dependency of Nusselt number of nanofluid on Reynolds number. According to these figures, as Reynolds number and temperature increase in nanofluid containing titanium dioxide 0.5-2.5% (v/v) in water as base fluid, the Nusselt number increases. For the sake of argument, at Reynolds number equal to 16000 for water at 30ºC and 40ºC and twisted ratio 2 (φ=2.5% v/v) the Nusselt number values are 225 and 267, respectively. The experimental results show that titanium dioxide nanofluid has higher Nusselt number in comparison with water as base fluid. If mass flow rate increases, then rise in temperature has severe effect on the Nusselt number . Therefore, not only nanoparticle concentration but also the nanofluid operating temperature and the corresponding effects on dispersion would all affect the heat transfer of nanofluid . As expected, the Nusselt number obtained from the tube with twisted-tape insert is significantly higher than that without twisted-tape insert. It is worth noting that particle surface properties and heat exchanger design are important and must be taken into consideration. One reason for this difference in heat transfer at high Reynolds numbers is the high viscosity of nanofluid. In general, the fluid containing rod-shaped particles, due to severe reactions, has high viscosity and high density in shear flow. Particle concentration and movement of particles in the flow are other factors that affect the heat transfer. The transitional move is assumed the main mechanism for increasing the thermal conductivity of nanoparticles.The mobility of finer particles increases the coefficient of thermal conductivity of nanofluids more than the coarse particles.

Twisted-tape inserts increase the heat transfer coefficients with relatively small increase in the pressure drop. They are known to be one of the earliest swirl flow devices employed in the single phase heat transfer processes. Because of the design and application convenience they have been widely used over decades to generate the swirl flow in the fluid. Size of the new heat exchanger can be reduced significantly by using twisted tapes in the new heat exchanger for a specified heat load. Thus, it provides an economic advantage over the fixed cost of the equipment. Twisted tapes can be also used for retrofitting purpose. They can increase the heat duties of the existing double tube heat exchangers. Twisted tapes with multitube bundles are easy to fit and remove and thus enable tube side cleaning in fouling situations. Inserts such as twisted tape, wire coils, ribs, and dimplesmainly obstruct the flow and separate the primary flow fromthe secondary flows. This causes the enhancement of the heat transfer in the tube flow. Inserts reduce the effective flow area thereby increasing the flow velocity.



(a)



(b)

Figure 8: Validation of plain tube with twisted tapes and nanofluid with Nusselt number (a,T=30ºC,b,T=40ºC)

Conclusions

Experimental results obtained with the TiO2 nanofluid(0.5-2.5% v/v) heat exchanger and twisted tape ratio 2 and 5 can be summarized as follows:

1. Using titanium oxide nanofluid with the volume concentration of 2.5% v/v in the double pipe heat exchanger with the twisted tape and without the twist tape increases the heat transfer about 12% and 20% as compared to the base fluid.
2. Using titanium oxide nanofluid with the volume concentration of 2.5% in the double pipe heat exchanger with the twisted tape and without the twist tape increases the Nusselt number about 25% and 32% as compared to the base fluid.

References

1. R.L. Webb, Performance evaluation criteria for use of enhanced heat transfer surfaces in heat exchanger design, Int. J. Heat Mass Transfer 24 (1981) 715–726.
2. L. Wang, B. Sunden, Performance comparison of some tube inserts, Int. Commun. Heat Mass Transfer 29 (2002) 45–56.
3. S.W. Chang, K.W. Yu, M.H. Lu, Heat transfer in tubes fitted with single, twin and triple twisted tapes, J. Exp. Heat Transfer 18 (2005) 279–294.
4. S.W. Chang, Y. Zheng, Enhanced heat transfer with swirl duct under rolling and pitching environment, J. Ship Res. 46 (2002) 149–166.
5. R. Aghayari, H. Maddah, F. Ashori, A. Hakiminejad, and M. Aghili, "Effect of nanoparticles on heat transfer in mini doublepipe heat exchangers in turbulent flow,"Heat andMass Transfer, 2014.
6. H. Maddah ,Effect of Twisted-Tape Turbulators and Nanofluid on Heat Transfer in a Double Pipe Heat Exchanger, Journal of Engineering, Volume 2014, Article ID 920970, 9 pages, http://dx.doi.org/10.1155/2014/920970
7. H. Maddah, Experimental Study of Al2O3/Water Nanofluid Turbulent Heat Transfer Enhancement in the Horizontal Double Pipes fitted with Modified Twisted Tapes, International Communications in Heat and Mass Transfer.
8. H. Maddah et al, H. Maddah et al ,Synthesis and Thermo-physical Properties of Fe3O4 Nanofluid, Journal of Materials Science & Surface Engineering Vol. 2 (1), 2015, pp 109-113
9. R. B. Bird, W. E. Stewai, and E. N. Lightfoot, Transport Phenomena, JohnWiley & Sons, 2nd edition, 2002.
10. W. Duangthongsuk and S. Wongwises, "An experimental study on the heat transfer performance and pressure drop of TiO2 water nanofluids flowing under a turbulent flow regime,"International Journal of Heat andMass Transfer, vol. 53, no. 1–3, pp. 334–344, 2010.
11. R.M. Manglik, A.E. Bergles, Heat transfer and pressure drop correlations for twisted-tape inserts in isothermal tubes, part II: transition and turbulent flows, Transaction of ASME, Journal Heat Transfer 115 (1993) 890–896.
12. L. Syam Sundar, K.V. Sharma Turbulent heat transfer and friction factor of Al2O3 Nanofluid in circular tube with twisted tape inserts, Int. J. of Heat and Mass Transfer 53 (2010) 1409–1416.
13. R.L. Hamilton, O.K. Crosser, Thermal conductivity of heterogeneous two component systems, I&EC Fund. 1 (3) (1962) 187.
14. W. Yu, S.U.S. Choi, The role of interfacial layers in the enhanced thermal conductivity of nanofluids: a renovated Maxwell model, J. Nanoparticle Res. 5 (2003) 167.
15. H.C. Brinkman, The viscosity of concentrated suspensions and solution, Journal of Chemical Physics 20 (1952) 571–581.
16. G. K. Batchelor, "The effect of Brownian motion on the bulk stress in a suspension of spherical particles," Journal of Fluid Mechanics, vol. 83, no. 1, pp. 97–117, 1977.

