Journal of Material Science and Mechanical Engineering (JMSME)
p-ISSN: 2393-9095; e-ISSN: 2393-9109; Volume 3, Issue 3; April-June, 2016 pp. 207-212

http://www.krishisanskriti.org/Publication.html

Heat Transfer Enhancement in a Tube by Inserting Twisted Tapes with Alternate Axes at Varying Alternate Length and Al_2O_3/Water Nanofluid

Pritam M. Jadhav[1] and R.M.Warkhedkar[2]

[1]PG Student, GCE, Karad Govt. College of Eng., Karad.
[2]GCE, Karad. Govt. College of Eng., Karad
E-mail: [1]smapritam29@gmail.com, [2]raviwar.wildorchid@gmail.com

Abstract—*Heat transfer, friction factor of Al_2O_3/water nanofluid have been experimentally investigated. The nanofluid was used in a tube inserted with twisted tapes with alternate axes (TA) at different alternate lengths (alternate length to twist length ratio, l/y = 0.5, 1.0, and 1.5). The concentration of nanofluid was varied from 0.05 to 0.15% by volume while the twisted ratio (y/W) 3 and 4 were used. The twisted tapes with alternate lengths as well as a typical twisted tape were tested for Reynolds number varying from 5000 to 20000. The results show that Nusselt number enhanced with increase in Reynolds number and concentration of nanofluid. All the TAs resulted with higher Nusselt number and friction factor than the typical twisted tape. The Nusselt number and friction factor obtained were increased with decreasing alternate length (l) of twisted tapes. The heat transfer coefficient and friction factor of 0.15% volume concentration of Al_2O_3 nanofluid with twist ratio of three and l/y = 0.5 is 22.6% and 1.367 times respectively higher compared to flow of water in a tube. Also it led to highest thermal performance factor up to 1.43.*

Keywords: *Heat transfer enhancement, friction factor, swirl flow, twisted-tape, twisted-tape with alternate axes Aluminum Oxide nanofluid.*

Nomenclature

A	heat transfer surface area
f	friction factor
h	heat transfer coefficient
k	thermal conductivity
l	alternate length
Nu	Nusselt number
ΔP	Pressure drop
Re	Reynolds number
y	tape pitch length
W	tape width
y/W	twist ratio
TT	twisted tape
TA	twisted tape with alternate length
∅	Concentration of fluid, percentage by volume
η	thermal performance factor

Subscripts

i	inlet
o	outlet

p plain tube

t twisted tape

1. INTRODUCTION

Heat exchangers play an important role in various fields such as chemical engineering, metallurgy, electric power generation, etc. The effectiveness of heat exchanger is low i.e. actual heat transfer is low as compared to maximum heat transfer. Enhancement of heat transfer in a heat exchanger is widely applied in industries due to the need of more compact heat exchanger, a lower operating cost, energy saving as well as ecological benefit. To achieve maximum utilization of thermal energy, several heat transfer enhancement techniques have been used. Different enhancement techniques have been broadly classified as passive techniques and active techniques. In passive methods, heat transfer enhancement is done by turbulence promoters (such as special surface geometries, twisted tape, spiral fin) or fluid additives (such as nanofluid), without using any direct external power source.

One important group of devices used in passive method is swirl flow devices which induces the turbulence near the tube wall and increases the residence time of the fluid flow in the tube. The higher turbulence intensity of the fluid close to the tube wall associated with the twisted tape is responsible for good fluid mixing and an efficient redevelopment of the thermal/hydrodynamic boundary layer which results in the improvement of convective heat transfer. Heat transfer enhancing performance of twisted tape is strongly depends on their geometry. Now a days there is trend to use nanofluid in heat exchanger to enhance thermal performance. A nanofluid is a fluid prepared by dispersion of metallic or non-metallic nanoparticles or nanofibers with a typical size less than 100 nm in a liquid. Among above, utilizing nanofluids and passive techniques like inserting turbulence promoters like twisted taps are considered as the effective ones. Therefore, this research work is also deals and decides the feasibility of use of twisted tape with different alternate axes length along with Al_2O_3nanofluid in tubular heat exchanger.

2. LITERATURE REVIEW

Typical (non-modified) twisted tapes have been extensively tested in several systems for heat transfer augmentation. Syam Sundar [1] studied the convective heat transfer coefficient and friction factor in a tube fitted with twisted tape using water/Al_2O_3 nanofluid as the working fluid. Khwanchit Wongcharee et al. [2] investigated heat transfer and friction factor of CuO/water nanofluid with twisted tape with alternate axis in a circular tube. The result shows that the twisted tape with alternate axis with nanofluid gives higher Nusselt number than the twisted tape with nanofluid by around 89%. Khwanchit Wongchareea et al. [3] investigated the effects of twisted tapes with alternate-axes and wings shape including triangle, rectangle and trapezoid on heat transfer, and flow friction in a round tube. Result shows that Nusselt number, as well as friction factor given by the twisted tape with alternate-axes and trapezoidal wings is higher than those given by the others. S. Eiamsa-ard et al. [4] investigated the effects of the twisted tapes consisting of centre wings and alternate-axes in a round tube. Twisted tape with centre wings & alternate axis has 62% higher Nusselt Number than twisted tape. S. Eiamsa-ard et al. [5] investigated heat transfer enhancement in a tube using twisted tapes with alternate axes at different alternate lengths. Result shows that Nusselt numbers associated with the uses of twisted tapes with alternate axes at the ratio of alternate length to twist length (*l/y*) of 0.5 were higher than that of twisted tapes by around 52%.

Dnyaneshwar R.Waghole et al. [6] investigate heat transfer and friction factor at various volume concentrations of silver nanofluid for flow in absorber/Receiver and with twisted tape inserts with twisted tape inserts of different twist ratios in the range 0.577 to 1.732. The enhancement factor for the absorber with tape inserts varied from 135 % to 205 %. K.V. Sharma et al. [7] experiments were conducted with twist ratio of 5, 0.05-0.1% volume concentration of Al_2O_3. Result shows that heat transfer rate with twisted tape and nanofluid of 0.1% volume concentration was 44.71% compared to flow of nanofluid in a plain tube. P.V. Durga Prasad et al. [8] studied analysis on trapezoidal-cut twisted tape insert with Al_2O_3 water based nanofluid. Nusselt number for 0.03% concentrations of nanofluid with trapezoidal-cut twisted tape inserts of y/W = 5 is enhanced by 34.24% as compared to water.

According to the above review, the twisted tapes with alternate axes gave better tradeoff between the increased heat transfer and friction factor than those provided by the typical twisted tape. Also, due to use of Al_2O_3 nanofluid as fluid heat transfer rate and friction factor increases. The benefit of using twisted tapes with alternate axes and Al_2O_3 nanofluid, inspires this work to investigate the twisted tapes with alternate axes at different ratios of alternate length to twist length, l/y=0.5,1.0,and 1.5 with different volume concentrations of Al_2O_3 nanofluid. In this study water used as base fluid for Reynolds number between 5000 and 20000.

3. PHYSICAL MODEL

The details of twisted-tape with alternate axes (TA) are presented in Fig.1. The TAs were made of aluminum strips with thickness of 0.8 mm (δ), width (W) of 17 mm and length of 1000 mm (L). Firstly, typical twisted tapes (TTs) with two different twist lengths (y) of 51 and 68 mm, corresponding and twist

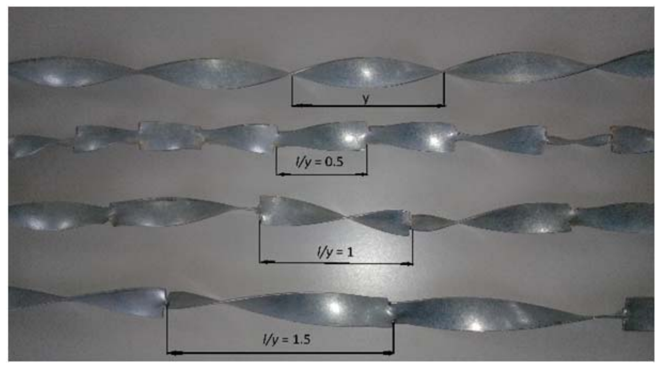

Fig. 1: Twisted tapes with alternate axes at different alternate length for y/W=3.

ratio (y/W) of 3 and 4 were prepared by twisting straight tapes about their longitudinal axes, while being held under tension on lathe machine. Then, TAs were fabricated by modification of TT via the following steps: (1) each tape was cut on both sides with 4 mm depth of cut, at desired length(*l*), (2) both sides at the cut were simultaneously twisted to angle difference of 90^0 4arranged to induce swirl flow with regularly alternate directions. In the experiments, three twisted-tapes with alternate axes (TAs) at different ratios of alternate length to twist length, *l*/y = 0.5, 1.0 and 1.5 are examined.

4. NANOFLUID PREPARATION

In the present study, Al_2O_3 nanoparticles of size 20–30 nm were mixed with distilled water and stabilizers and then sonicated continuously by ultrasonic vibrator generating ultrasonic pulses of 100W at 36 kHz for 5 h to break down agglomeration of the nanoparticles, prior to being used as the working fluid. The desired volume concentrations used in this study were 0.05, 0.1 and 0.15%. For each test a new nanofluid was prepared and used immediately. The weight of

Al_2O_3nanoparticles required for the given volume concentration of nanofluids is estimated by using Eq. (I).

Volume fraction of $Al_2O_3 = \frac{V_{np}}{V_{np}+V_w}$ ……….. (I)

5. EXPERIMENTAL FACILITY:

An Experimental test setup was fabricated for the investigation of performance of twisted tape with alternate axes length. The Schematic diagram of the proposed experimental setup is shown in Fig. 2. Test section consist of copper tube of 1m length having 18 mm and 21 mm inside and outside diameter respectively. The copper tube is heated uniformly by wrapping it with nichrome heater of 20 gauge and 4kW maximum rating. The entire test section is subject to a constant heat flux boundary condition. The electrical output power was controlled by a variac transformer. The heat exchanger tube was insulated lengthwise using ceramic wool to prevent heat transfer to the surroundings. The test section is provided with 12 K-type thermocouples in which ten were brazed to the surface and two located to measure the working fluid inlet and outlet temperatures. The storage tank is made of stainless steel of 25 liter capacity. The liquid which is heated in the test section is allowed to cool by passing it through a chiller. The liquid then flows to the storage tank by gravity. Pressure drop across the test section is measured by providing pressure transducer.

6. DATA ANALYSIS

The balance between the energy supplied by heating and energy absorbed by the flowing liquid is established using Eqs. (1) and (2) for every set of data and the experimental heat transfer coefficient estimated with Eq. (3).

Q = V x I (Energy supplied) …… (1)

Q=m C_p (T_{out}- T_{in}) (Energy absorbed) …… (2)

$h = \frac{Q}{A\,x(T_{wall}-T_{mean})}$…… (3)

Nusselt number, friction factor and thermal performance factor can be calculated as,

$$Nu = \frac{h\,D}{k_f}, \; f = (2D\times \Delta P)/(\rho u^2 L), \; \eta = \frac{Nu_t}{Nu_p} \Big/ \left(\frac{f_t}{f_p}\right)^{(1/3)}$$

The uncertainties of the experimental results are analyzed by the procedures proposed by the Kline and McClintock [10].The experimental results are reproducible within these uncertainty ranges. The maximum uncertainties of non-dimensional parameters are Reynolds number, Nusselt number and friction factor are 6.5%, 8.2% and 6.8%, respectively.

Fig. 2: Photographic image of experimental setup

7. RESULTS AND DISCUSSION

7.1 Validation Test

To verify the reliability of the experimental setup, test between the results of the present plain tube with/ without typical TT inserts and those obtained from standard correlations was performed. The comparisons between the present experimental results and those obtained from the standard shown in fig.3 for Nu and fig.4 for friction factor. For Nusselt number, the present results agreement, they were respectively 7.1-10.7 % and 17.1-27.8% lower in comparison with those from Dittus-Boelter [9] and Gnieslinski [9] correlations. For friction factor, the present results were 18.1-27.9% and 16.8-25.2% higher than results obtained from Petukhov [9] and Blasius [9] correlations.

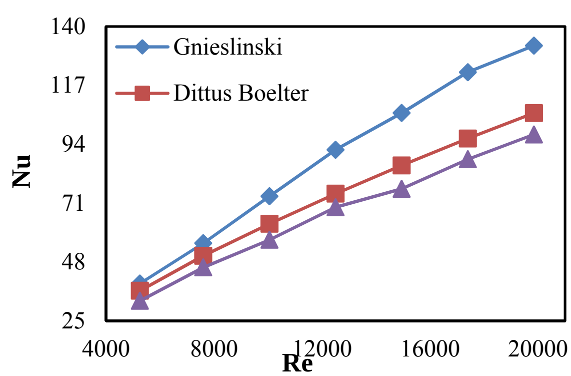

Fig. 3: Validation of Plain tube for Nusselt number.

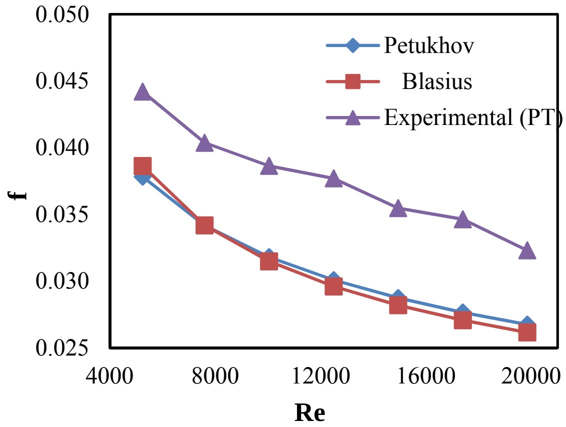

Fig. 4: Validation of Plain tube for friction factor.

7.2 Effect of Twisted Tapes with Alternate Axes.

7.2.1 Heat Transfer

Heat transfer in terms of Nusselt number, given by twisted-tapes with alternate axes at *l/y* = 0.5, 1.0, and 1.5 in concurrence with those by using the TT are shown in Fig. 5. For all twisted tapes with alternate axes, as the

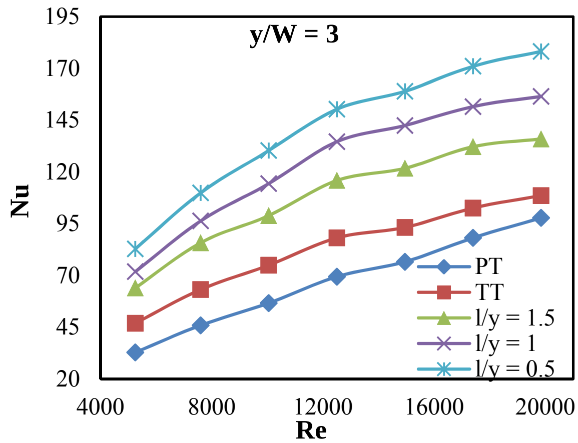

Fig.5: Variations of Nusselt number with Reynolds number for different alternate axes.

Reynolds number increases, the Nusselt number was also increased. The modified twisted tape has been induced the combined effects of the common swirl flow by the twisted tape, and also additional flow fluctuation by alternate axes, giving to excellent results for increase in heat transfer. The twisted tapes with alternate axes at smaller *l/y* ratio gave higher Nusselt numbers than the one with larger *l/y* ratio. The Nusselt number values by the TAs at *l/ y* = 0.5, 1.0, and 1.5 were 56%, 48%, and 42% higher than those by the twisted tape respectively. This is due to fact that the TAs with smaller *l/y* offered higher frequencies of flow splits as they consist of a large number of alternate points, resulting in better fluid mixing and thus heat transfer rate.

7.2.2 Friction Factor

Fig.6 shows variation of friction factor verses Reynolds number for all cases. The friction factors decreased with increasing Reynolds number. The friction factors presented in tubes with twisted tapes with alternate axes were higher than that in the one with twisted tape and plain tube. The enhancement in Nusselt numbers were accompanied with increased in friction factors by 67%, 59%, and 48%, respectively for *l/y* =0.5, 1, and 1.5 as compared to twisted tape.

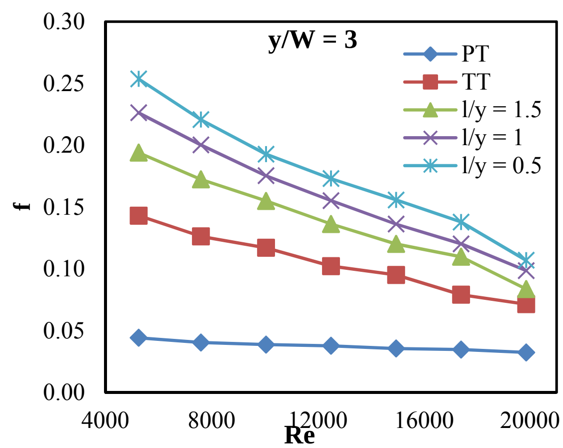

Fig.6: Variations of friction factor with Reynolds number for different alternate axes.

7.2.3 Thermal Performance Factor

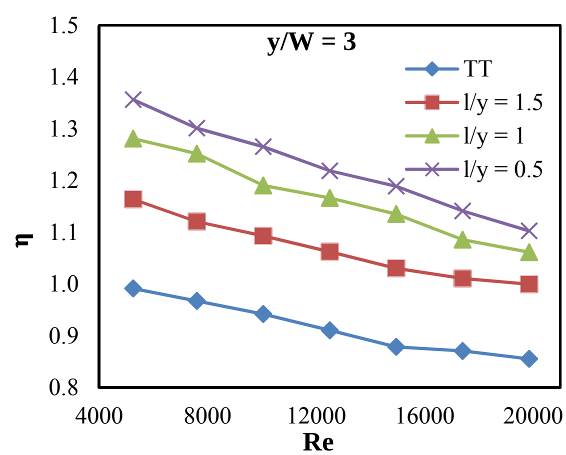

Fig7: Fig.6: Variations of thermal performance factor with Reynolds number for different alternate axes.

Fig.7 demonstrates the thermal performance factors (η) of tubes with tape inserts, which compromises between the heat transfer and friction loss.

For a net energy gain, the value of the thermal performance factor is greater than unity. At given Reynolds number the thermal performance factor increased with decreasing *l/y* ratio. This shows that the enhanced heat transfer rate over the increased friction factor becomes more significant with the uses of twisted tape with alternate axes at lager numbers of alternate points, which produce greater turbulence near the wall. The thermal performance factors associated by TAs of *l/y* = 0.5, 1.0, and 1.5, were respectively, 18.4%, 15.2%, and 11.6% higher than that given by twisted tape.

7.3 Effect of Nanofluid Concentration.

7.3.1 Heat Transfer

Fig.8 presents heat transfer results of the Al_2O_3/water nanofluids with 0.05%, 0.1% and 0.15% by volume concentration in accompanies with twisted tape with *l/y* ratio 5 and twist ratio 3. It was found that Nusselt number increased when increasing nanofluid concentration. For the tubes with all twisted tapes with alternate axes length, the average Nusselt number of nanofluid with Al_2O_3 concentrations of 0.05%, 0.1% and 0.15% by volume, was around 5.2-8.3%, 9.1-14.7%, and 15.5-22.6%, respectively those of the water. In particular, using TA with *l/y* =0.5 induced an effective swirl flows in enhancing mixing and 0.15% volume concentration increases thermal conductivity, so as increase heat transfer. Also, result shows that as Reynolds number increases Nu_t/Nu_p ratio decreases.

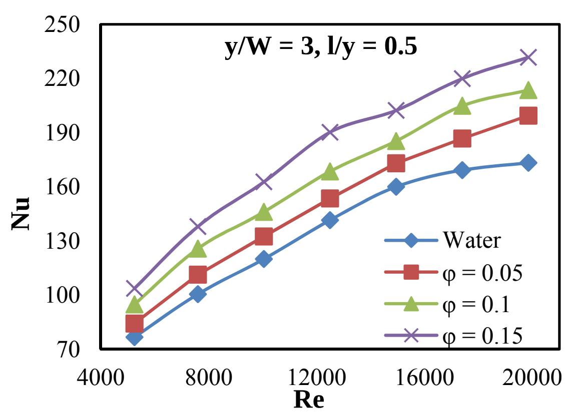

Fig.8: Nusselt number variation with Reynolds Number for nanofluid with y/W = 3, l/y = 0.5.

7.3.2 Friction Factor

The effect of nanofluid concentration on friction factor is shown in fig.9 for twisted tape with alternate axes at *l/y*=0.5 and twist ratio 3. For the present range, nanofluid with Al_2O_3 concentrations of 0.05%, 0.1% and 0.15% by volume respectively caused 2.3-8.4%, 10.8-21.5% and 18.1-30.6% higher friction factor compared to those of the base fluid. The increase of friction loss is directly caused by the increases of fluid viscosity and shear force on tube wall acted by nanoparticles. However, the results indicate that utilizing nanofluid in the present concentration range is an insignificant friction loss penalty. Also, result shows that as Reynolds number increases f_t/f_p ratio decreases.

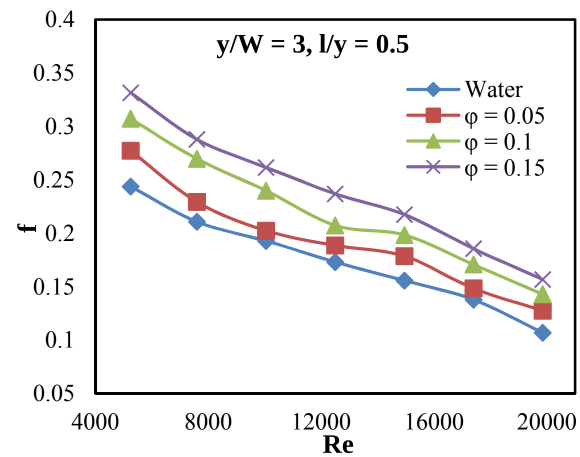

Fig.9: Friction factor variation with Reynolds Number for nanofluid with y/W = 3, l/y = 0.5.

7.3.3 Thermal Performance Factor

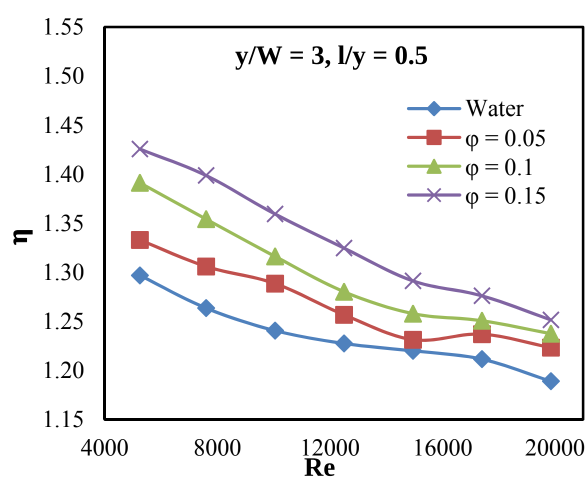

Fig.10: Thermal performance factor variation with Reynolds Number for nanofluid with y/W = 3, l/y = 0.5.

Fig.10 shows the effect of nanofluid concentration on thermal performance factor. Evidently, nanofluid with higher Al_2O_3 concentrations yielded higher thermal performance factors. Depending on Reynolds number, thermal performance factors given by nanofluid with Al_2O_3 concentrations of 0.05%, 0.1% and 0.15% by volume were 0.95-1.23, 0.98-1.29 and 1.01-1.43 respectively. Comparatively, nanofluid with Al_2O_3 concentration of 0.15% by volume offered 6.3-16.6% and 3.1-11.2% higher thermal performance factors than the ones with Al_2O_3 concentrations of 0.05% and 0.1% by volume, respectively. This indicates the effect of increasing Al_2O_3 nanoparticles on thermal performance factor was more pronounced for the heat transfer improvement as positive effect than friction loss as negative effect.

8. CONCLUSION

1) All twisted tapes with alternate axes gave higher Nusselt number, friction factor and thermal performance factor than twisted tape inserts for water and different concentrations of nanofluids due to extra turbulence at alternate points.
2) Nusselt number, friction factor and thermal performance factor increased with decreasing alternate length. For water, Nusselt numbers associated with TAs at l/y = of 0.5, 1.0, and 1.5 were higher than that of twisted tape by 56%, 48%, and 42%, respectively. Also the enhancement in Nusselt numbers were accompanied with increased in friction factors by 67%, 59%, and 48%, respectively for l/y =0.5, 1, and 1.5 as compared to twisted tape.
3) The optimum tradeoff between enhanced heat transfer and increased friction factor was found by the use of that twisted taps with alternate axes at l/y = 0.5, which gave the highest heat transfer.
4) For water and all concentrations of nanofluid, the ratio of Nusselt number of the tube with twisted tape insert to the Nusselt number of the tube without twisted tape insert (Nu_t/Nu_p) decreases with increase in mass flow rate.
5) For water and all concentrations of nanofluid, the ratio of friction factor of tube with twisted tape insert to the friction factor of tube without twisted tape insert (f_t/f_p) increases with increase in mass flow rate.
6) The thermal performance factor increases with increase in number of tapes as well as volume concentration of nanoparticle for the same mass flow rate.
7) The Nusselt number with Al_2O_3 nanofluid of 0.05%, 0.1% and 0.15% by volume concentration were higher than that of the Water by 5.2- 8.3%, 9.1-14.4% and 15.5-22.6% respectively.
8) The friction factor of Al_2O_3 nanofluid with concentration of 0.05%, 0.1% and 0.15% by volume were respectively 2.3-8.4%, 10.8-21.5% and 18.1-30.6% higher than that of Water.
9) The thermal performance factor with nanofluid Al_2O_3 of 0.05%, 0.1% and 0.15% by volume concentration were higher than that of the Water by 3.7- 5.7%, 8.5-14.4% and 12.2-19.6% respectively.
10) Nusselt number as well as friction factor increased with decreasing twist ratio. Nusselt numbers associated with twist ratio =3 were higher than that of twist ratio = 4 by around 4.2-12.3% for all combination of twisted taps and nanofluid. Also friction factor associated with twist ratio =3 were higher than that of twist ratio = 4 by around 9.1-12.7 for all combination of twisted tapes and nanofluid.

REFERENCES

[1] L. Syam Sundar, K.V. Sharma, “Turbulent heat transfer and friction factor of Al_2O_3 nanofluid in circular tube with twisted tape inserts”, *International Journal of Heat and Mass Transfer* 53 (2010) 1409 - 1416.

[2] Khwanchit Wongcharee, Smith Eiamsa-ard, “Enhancement of heat transfer using CuO/water nanofluid and twisted tape with alternate axis”, *International Communications in Heat and Mass Transfer* 38 (2011) 742–748.

[3] Khwanchit Wongchareea, Smith Eiamsa-ard, “Heat transfer enhancement by twisted tapes with alternate-axes and triangular, rectangular and trapezoidal wings”, *Chemical Engineering and Processing* 50 (2011) 211–219.

[4] S. Eiamsa-ard, K. Wongcharee, P. Eiamsa-ard, C. Thianpong “Thermohydraulic investigation of turbulent flow through a round tube equipped with twisted tapes consisting of centre wings and alternate-axes”, *Experimental Thermal and Fluid Science* 34 (2010) 1151–1161.

[5] S. Eiamsa-ard, P. Somkleang, C. Nuntadusit, C. Thianpong, “Heat transfer enhancement in tube by inserting uniform/non-uniform twisted-tapes with alternate axes: Effect of rotated-axis length”, *Applied Thermal Engineering* 54 (2013) 289-309.

[6] Dnyaneshwar R.Waghole, R.M.Warkhedkar, V.S.Kulkarni, R.K.Shrivastva, “Experimental Investigations on Heat Transfer and Friction Factor of Silver Nanofliud in Absorber/Receiver of Parabolic Trough Collector with Twisted Tape Inserts”, *Energy Procedia* 45 (2014) 558 – 567.

[7] Khwanchit Wongcharee, Smith Eiamsa-ard, “Enhancement of heat transfer using CuO/water nanofluid and twisted tape with alternate axis”, *International Communications in Heat and Mass Transfer* 38 (2011) 742–748.

[8] P.V. Durga Prasad, A.V.S.S.K.S. Gupta and K. Deepak, “Investigation of Trapezoidal-Cut Twisted Tape Insert in a Double Pipe U-Tube Heat Exchanger using Al2O3/Water Nanofluid”, *Procedia Materials Science* 10 (2015) 50 – 63.

[9] F.P. Incropera, P.D. Witt, T.L. Bergman, A.S. Lavine, Fundamentals of Heat and Mass Transfer, *John-Wiley & Sons*, 2006.

[10] S.J. Kline, F.P. McClintock, Describing uncertainties in single-sample experiments, Mechanical Engineering 75 (1953) 3-8.