HEAT TRANSFER ENHANCEMENT IN TUBULAR HEAT EXCHANGER BY USING TWISTED TAPES WITH VARYING ALTERNATE AXIS LENGTH WITH AL_2O_3/WATER NANOFLUID

[PAPER ID: ICITER-D190]

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ABSTRACT:

Heat transfer enhancement in a tube using twisted tape with alternate axes (TA) at different alternate lengths (in terms of alternate length to twist length ratio, l/y = 0.5, 1.0, and 1.5) and Al_2O_3/water nanofluid have been experimentally investigated. The concentration of nanofluid was varied from 0.05 to 0.15% by volume while the twist ratio (y/W) of 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 20,000. The results show that Nusselt number enhanced with increase in Reynolds number and concentration of nanofluid. Also the Nusselt number and friction factor obtained were increased with decreasing alternate length (l) and twist ratio of twisted tapes. The heat transfer coefficient and friction factor of 0.15% volume concentration of Al_2O_3 nanofluid with l/y=0.5 and twist ratio of 3 was 22.6% and 1.367 times respectively higher compared to water. Also it led to highest thermal performance factor up to 1.43. Nusselt number and friction factor associated with twist ratio of 3 were higher than that of twist ratio of 4 by around 4.2-12.3% and 9.1-12.7% respectively for all combination of twisted taps and nanofluid.
KEYWORDS*:* Heat transfer enhancement, friction factor, swirl flow, twisted-tape, twisted-tape with alternate axes Aluminum Oxide nanofluid*.*

INTRODUCTION:

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. Also, it induces good fluid mixing so as to 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 Al2O3nanofluid in tubular heat exchanger.

Nomenclature	
A_s	heat transfer surface area, m^2
D	diameter, m
L	length, m
u	velocity, m/s
Q	heat transfer rate, W
f	friction factor
h	heat transfer coefficient, W/m^2K
k	thermal conductivity, W/mK
l	alternate length, m
ΔP	Pressure drop, Pa
Nu	Nusselt number
Re	Reynolds number
y	tape pitch length, m
W	tape width, m
y/W	twist ratio
l/y	Ratio of alternate axes length to twist length
TT	twisted tape
TA	twisted tape with alternate length
Greek Symbols	
Ø	Concentration of fluid, percentage by volume
η	thermal performance factor
δ	tape thickness, m
Subscripts	
i	inlet
o	outlet
p	plain tube
t	twisted tape

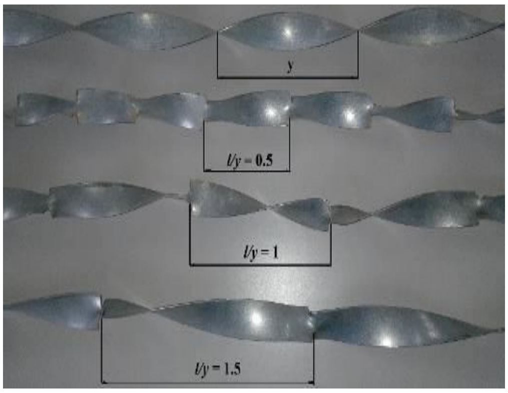
LITERATURE SURVEY:

Panida Seemawute et al. [1] investigated the effect of peripherally-cut twisted tape with alternate axis in a circular tube. The heat transfer rates in the tube fitted with the peripherally-cut twisted tape with alternate axis is enhanced up to 184% of that in the plain tube. Khwanchit Wongchareea et al. [2] investigated the effects of twisted tapes with alternate-axes and wings shape including triangle, rectangle and trapezoid on heat transfer, and flow friction. Nusselt number, and friction factor given by the tape with alternate-axes and trapezoidal wings are higher than those given by the others. S. Eiamsa-ard et al. [3] investigated the effects of the twisted tapes consisting of centre wings and alternate-axes in a round tube. Khwanchit Wongcharee et al. [4] investigated heat transfer, friction and thermal performance characteristics 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 mean Nusselt number than the twisted tape with nanofluid by around 89%. Dnyaneshwar R.Waghole et al. [5] investigate heat transfer and friction factor at various volume concentrations of silver nanofluid for flow in absorber/Receiver and with and without twisted tape inserts. S. Eiamsa-ard et al. [6] investigated heat transfer enhancement in a tube using twisted tapes with alternate axes at different alternate lengths. 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%.

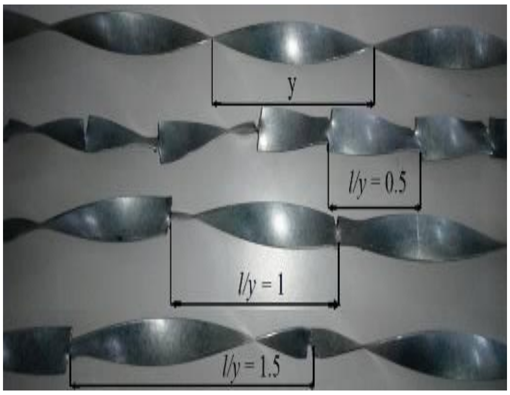
According to the above review, the twisted tapes with alternate axes gave better tradeoff between the increased heat transfer and friction factor than those provided by the typical twisted tape. Also, due to use of Al_2O_3 nanofluid as fluid heat transfer rate and friction factor increases. The benefit 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 20,000.

PHYSICAL MODEL:

The details of twisted-tape with alternate axes (TAs) are presented in Fig.1 (a) and (b). 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 ratio (y/W) of 3 and 4 were prepared. Then, TAs were fabricated by modification of TT. 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 were examined.



(a)



(b)

Fig.1. Pictorial view of twisted tapes with alternate axes at different alternate lengths for (a) y/W = 3 and (b) y/W = 4

NANOFLUID PREPARATION:

In the present study, Al2O3 nanoparticles of size 20–30 nm were mixed with distilled water and stabilizers and then sonicated continuously by ultrasonic vibrator 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 Al2O3nanoparticles required for the given volume concentration of nanofluids is estimated by using Eq. (I).

Volume fraction of Al_2O_3= $\dfrac{V_p}{V_p + V_w}$ .... (I)

EXPERIMENTAL METHOD:

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 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 of 25 liter capacity is used. 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.

Fig. No. 2 Photographic Image of Experimental Setup

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).

$Q = V \times I$ (Energy supplied) ...... (1)

$Q = \dot{m}\, C_P\, (T_{out} - T_{in})$ (Energy absorbed) ...... (2)

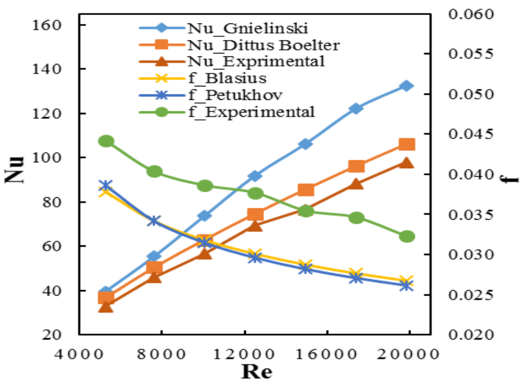
$$h = \frac{Q}{A_s \times (T_{wall} - T_{bulb})} \text{ .... (3)}$$

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

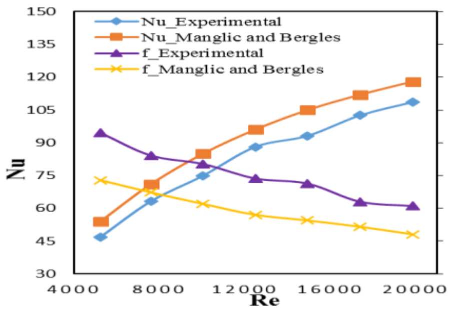
$$Nu = \frac{hD}{k_f},\quad f = \frac{2D \times \Delta P}{\rho u^2 L},\quad \eta = \frac{Nu_t}{Nu_p} \Big/ \left(\frac{f_t}{f_p}\right)^{1/3}$$

EXPERIMENTAL DATA VALIDATION:

As displayed in Figs.3 (a) and (b), the data obtained from the present work are found to be in excellent agreement with the standard correlations of Dittus–Boelter [7] and Gnielinski equation [7] for Nusselt number, Blasius [7] and Petukhov equation [7] for friction factor of plain tube and Manglik and Bergles equation [8] for TT.



(a)



(b)

Fig. 3 Validation of plain tube (a) without typical twisted tape, (b) with typical twisted tape for Nusselt number and friction factor

For Nusselt number, the present results agreement, they were respectively 7.1-10.7 %, 17.1-27.8%, and 7.9-12.8 % lower in comparison with those from Dittus-Boelter, Gnielinski, and Manglik and Bergles correlations. For friction factor, the present results were 18.1-27.9%, 16.8-25.2% and 25.1-31% higher than results obtained from Petukhov, Blasius and Manglik and Bergles correlations.

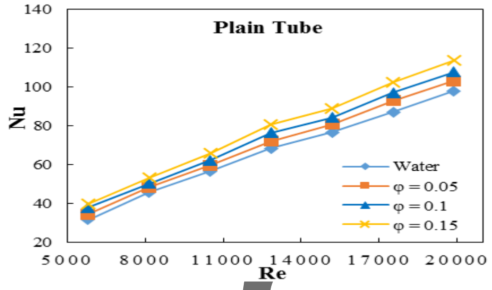
RESULTS AND DISCUSSIONS:

8.1 EFFECT OF TWISTED TAPES WITH ALTERNATE AXES AND AL_2O_3 NANOFLUID:

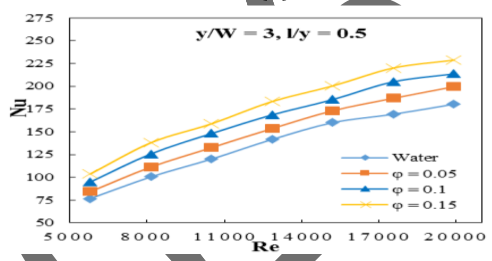
8.1.1 HEAT TRANSFER:

Heat transfer in terms of Nusselt number, is presented in Fig.4 (a), (b) and (c) with 0.05%, 0.1% and 0.15% by volume concentrations of Al_2O_3/water nanofluid in accompanies with plain tube, twisted tape with l/y ratio of 0.5, twist ratio 3 and twisted tape with l/y ratio of 0.5, twist ratio of 4 respectively. As Reynolds number increases, the Nusselt number was also increased. It was found that Nusselt number increased when increasing nanofluid concentration due to increase in thermal conductivity. The modified twisted tape has been induced the combined effects of the common swirl flow by the twisted tape, also additional flow fluctuation by alternate axes, and nanoparticle collisions, giving to excellent results for increase in heat transfer.

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. Nanofluid Al_2O_3 with concentration of 0.15% by volume gave 10.3-14.3% and 6.4-8.2% higher Nusselt number than the ones with Al_2O_3 concentrations of 0.05% and 0.1% by volume, respectively. The twisted tapes with alternate axes at smaller l/y ratio and 0.15% volume concentration of nanofluid gave higher Nusselt numbers than the one with larger l/y ratio.



(a)



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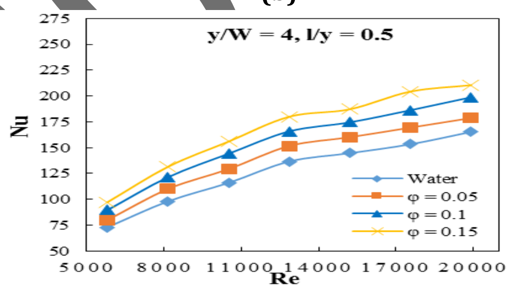


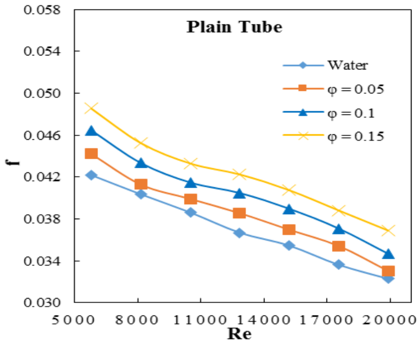
(c)

Fig.4 Variation of Nusselt number with Reynolds number for different vol. concentrations for (a)PT, (b) y/W=3, and (c) y/W=4

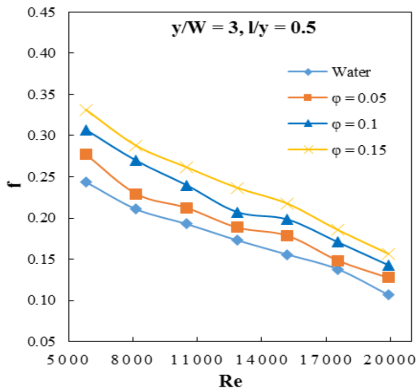
8.1.2 FRICTION FACTOR:

The pressure drop in the nanofluid is a penalty on pumping power. The friction factor results are demonstrated in fig.5 (a), (b) and (c) for 0.05%, 0.1% and 0.15% by volume concentrations of Al_2O_3/water nanofluid in accompanies with plain tube, twisted tape with l/y ratio of 0.5, twist ratio 3 and twisted tape with l/y ratio of 0.5, twist ratio of 4 respectively. Apparently, friction factor increases with increasing concentration of nanoparticles due to the rise of working fluid viscosity and shear force on tube wall acted by nanoparticles. The friction factors caused by the twisted tapes with alternate axes are considerably higher than those generated by the twisted tapes.

In addition, the concurrent use of nanofluid and twisted tape causes greater friction than the use of twisted tape alone. As found, the nanofluids with concentrations of 0.05%, 0.1% and 0.15% provide friction factors higher than the water by around 2.3-8.4, 10.8-18.5 and 21.1-30.6 %, respectively. In other words, nanofluid with Al_2O_3 concentration of 0.15% by volume caused 18.8-22.2 and 10.3-12.1 % higher friction factors than the ones with Al_2O_3 concentrations of 0.05% and 0.1% by volume, respectively.



(a)



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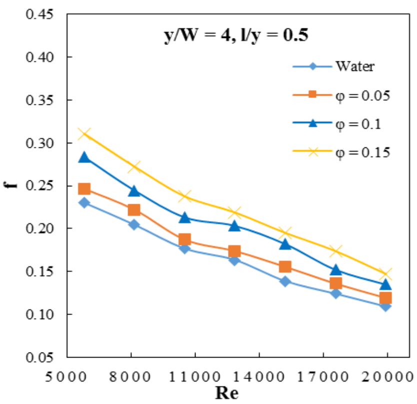
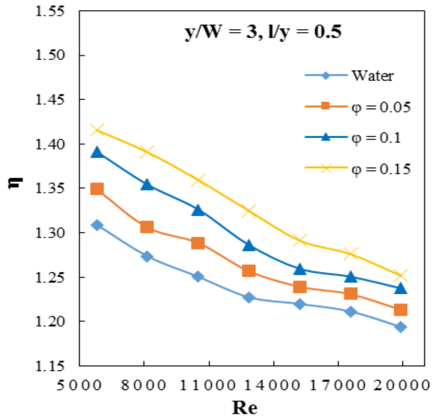


(c)

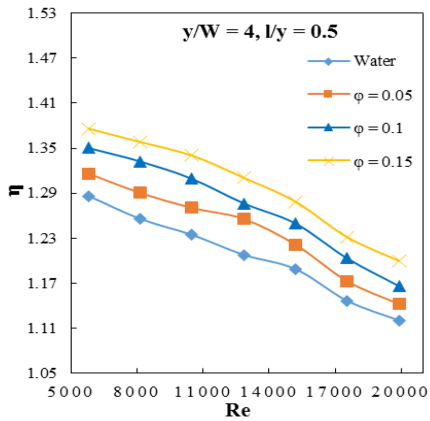
Fig.5 Variation of friction factor with Reynolds number for different vol. concentrations for (a)PT, (b) y/W=3, and (c) y/W=4

8.1.3 THERMAL PERFORMANCE FACTOR:

The variation of thermal performance factor (η) with Reynolds number is illustrated in fig. 6 (a) and (b) for different concetrations of nanofluid. This implies that the use of nanofluid and twisted tape is feasible in terms of energy saving at lower Reynolds numbers. The results also show that the thermal performance factor increases with increasing concentration of nanofluid. The use of nanofluid with twisted tape with alternate axes provides considerably higher thermal performance factor than that of nanofluid with twisted tapes for all Reynolds number studied. This is a result of a superior efficient of fluid disturbance and thus heat transfer caused by the twisted tape with alternate axes compared to the twisted tape at the same pumping power. 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.



(a)



(b)

Fig.6 Variation of thermal performance factor with Reynolds number for different vol. concentrations for (a) y/W=3, (b) y/W=4

8.2 EFFECT OF TWIST RATIO OF TWISTED TAPES:

8.2.1 HEAT TRANSFER:

It is observed from the results that the Nusselt number increases with the decrease of twist ratio (y/W) of the twisted tape inserts. The reason for heat transfer augmentation is that, twisted tape inserts increase turbulence in the flow and effective mixing of the nanofluids takes place. The twisted tapes promote swirl and turbulence, as a result of which the boundary layer breaks and aids in heat transfer enhancement. The turbulence in the fluid with inserts of low twist ratio is more than that of the one having more twist ratio. Nusselt numbers associated with twist ratio of 3 were higher than that of twist ratio 4 by around 4.2-12.3 % for all combination of twisted taps and volume concentrations of Al_2O_3 nanofluid concentrations.

8.2.2 FRICTION FACTOR:

Heat transfer enhancement in a tube flow blockages, partitioning of the flow and secondary flow. Flow blockages increase the pressure drop and leads to viscous effects, because of a reduced free flow area. Twist tape with twist ratio of 3 has more number of twists than twist tape with twist ratio of 4. Friction factor associated with twist ratio of 3 were higher than that of twist ratio of 4 by around 9.1-12.7% for all combination of twisted tapes and Al_2O_3 nanofluid concentrations.

8.2.3 THERMAL PERFORMANCE FACTOR:

It is observed from the results that thermal performance factor increases with the decrease of twist ratio and increase of nanoparticle concentration. Thermal performance factor associated with twist ratio of 3 were higher than that of twist ratio of 4 by around 5.1-9.3 % for all combination of twisted tapes and Al_2O_3 nanofluid concentrations. This indicates the effect of decreasing twist ratio on thermal performance factor was more pronounced for the heat transfer improvement as positive effect than friction loss as negative effect.

CONCLUSIONS:

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) The thermal performance factor increases with increase in number of tapes as well as volume concentration of nanoparticle for the same mass flow rate.
5) 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.
6) 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%, 10.8-18.5% and 21.1-30.6% higher than that of Water.
7) 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.
8) Nusselt number as well as friction factor increased with decreasing twist ratio.
9) 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.

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