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Heat transfer enhancement by tapered twisted tape inserts

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ABSTRACT

The effects of inserted tapered twisted tapes, their taper angle and twist ratio on heat transfer rate, pressure drop and thermal performance factor characteristics have been reported. The experiments were carried out by using the tapered twisted tapes with 4 different taper angles which $\theta = 0.0^\circ$ (typical twisted tape), 0.3°, 0.6° and 0.9°. At each taper angle, the tapered twisted tapes were twisted at three different twist ratios (y/W) of 3.5, 4.0 and 4.5. All tapes were tested under turbulent flow regime for Reynolds numbers between 6000 and 20,000. A twist ratio is defined as the ratio of twist length (y) to twisted tape width at the large end (W). The plain tube was also tested for comparison. Heat transfer enhancement and friction loss increased with decreasing taper angle and twist ratio. Thermal performance factor tended to increase with increasing taper angle and decreasing tape twist ratio. For the present range, the tube with the tape with taper angle (θ) of 0.9° and twist ratio (y/W) of 3.5 yielded the maximum thermal performance factor of 1.05 at Reynolds number (Re) of 6000.

1. Introduction

Swirl generators have been extensively applied for convective heat transfer enhancement in several engineering and industrial applications such as: solar air/water heater, shell and tube heat exchanger, air conditioning, refrigeration, gas cooled nuclear reactor, chemical reactor, chemical and petrochemical industries, etc [1–3]. A twisted tape insert is one of the promising swirl generators for enhancing heat transfer for both laminar and turbulent flows. Heat transfer enhancement by twisted tape insert is attributed to its promoting the transverse mixing and producing swirl flow or vortex inside a heat exchanger leading to an efficient disruption of thermal boundary layer and breaking down the viscous sub-layer. In addition, a twisted tape is easily installed in an existing plain tube heat exchanger and cost-competitive.

Twisted tapes with various geometries were proposed and utilized in research works. Salman et al. [4] reported the effect of the quadrant-cut twisted tapes at different cut depths ($w = 0.5$, 1.0, and 1.5 cm) on the heat transfer enhancement characteristics in a circular tube. Their results indicated that heat transfer coefficient significantly increased with decreasing cut depth. Salman et al. [5] also studied the behaviors of heat transfer and friction factor in a tube equipped with twisted tape inserts with different alternative angles ($\theta = 30^\circ$, 60° and 90°). For their studied range, heat transfer coefficient increased with increasing alternative angle. Murugesan et al. [6,7] examined the effect of square-cut and V-cut twisted tape inserts on the heat transfer enhancement, pressure drop and thermal performance characteristics. Zhang et al. [8] compared heat transfer in a converging-diverging tubes fitted with and without regularly-spaced twisted tape. Their results revealed that the tube with regularly-spaced tapes yielded considerably higher heat transfer coefficient than the one without twisted tape. Patil and Babu [9] employed twisted tapes with different twist ratios in a square duct and found that heat transfer and pressure loss were insignificantly affected by changing tape twist ratio. Vazifeshenas and Delavar [10] invented center-cleared twisted tapes for heat transfer enhancement. They found that the tube with center-cleared twisted tapes yielded considerably higher heat transfer coefficient than the plain tube alone. Liu and Bai [11] reported the formation and development of helical vortices by short twisted tapes and mentioned that vortex intensity increased with increasing swirl intensity.

In some research studies, tape inserts were in form of helical screw tape inserts. Most inserts in this form gave high heat transfer coefficients and thermal performance factors [12,13]. Sivashanmugam and Suresh [12] employed typical helical screw tapes with different at twist lengths ($y = 1.95$, 2.93, 3.91 and 4.89) for heat transfer enhancement in a circular tube. Their results found that heat transfer coefficient increased with decreasing twist length.

Abbreviation: T-TT, tapered twisted tape; TT, typical twisted tape.

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Nomenclature

A heat transfer surface area, m^2
C_p specific heat of fluid, $J\,kg^{-1}\,K^{-1}$
D diameter of the test tube, m
f friction factor = $\Delta P/((L/D)(\rho U^2/2))$
h heat transfer coefficient, $W\,m^{-2}\,K^{-1}$
I current, A
k thermal conductivity of fluid, $W\,m^{-1}\,K^{-1}$
L length of the test section, m
$\dot{m}$ mass flow rate, $kg\,s^{-1}$
Nu Nusselt number = hD/k
P pressure of flow in stationary tube, Pa
ΔP pressure drop, Pa
Pr Prandtl number = $\mu c_p/k$
Q heat transfer rate, W
Re Reynolds number = $\rho UD/\mu$
t thickness of the test tube, m
T temperature, K
$\tilde{T}$ mean temperature, K
U mean axial flow velocity, $m\,s^{-1}$
V voltage, V
w twisted tape width at the small end of tape, m
W twisted tape width at the large end of tape, m
y twist length, m

Greek symbols
ρ fluid density, $kg\,m^{-3}$
μ fluid dynamic viscosity, $kg\,s^{-1}\,m^{-1}$
θ taper angle, degree
η thermal performance factor

Subscripts
b bulk
conv convection
i inlet
o outlet/outer
p plain
t twisted tape
w wall

Jaisankar et al. [13] invented helical twisted tape in left-right arrangement. The tape induced bidirectional swirl flow, giving better heat transfer than the typical helical twisted tape which induced unidirectional swirl flow.

The comparative studies of heat transfer enhancement by modified twisted tapes and typical twisted tape were also reported. Rahimi et al. [14] compared heat transfer augmentation by modified twisted tapes (perforated, notched and jagged twisted tapes) with that by the typical one. Their results found that jagged twisted tape gave better heat transfer while perforated and notched twisted tapes gave poorer heat transfer than the typical one. Wongcharee and Eiamsa-ard [15] studied the effect of tape shape (triangle, rectangle and trapezoid twisted tapes) on the heat transfer enhancement and found that coefficient characteristics. Under similar conditions, the trapezoid tape gave the highest heat transfer coefficient. Eiamsa-ard et al. [16] modified the twisted tape by twisting a straight tape to form a twisted tape then bending the twisted tape into a helical shape to form "helically twisted tape". The helically twisted tape was subjected to a comparative test with a typical helical tape. The experimental results showed that the helically twisted tape gave lower heat transfer coefficient but higher thermal performance than the typical one. Recently, Eiamsa-ard et al. [17] further modified helically twisted tape by varying tape number (single, dual and triple-helical twisted tapes. The experimental results showed that the dual and triple-helical tapes yielded higher heat transfer coefficient than the single one. Bas and Ozceyhan [18] reported the heat transfer and pressure drop in a tube equipped with twisted tape inserts at different clearance ratios and twist ratios, by using Taguchi method. Their results indicated that heat transfer coefficient increased with the decreases of twist ratio and clearance ratio. Beigzadeh et al. [19] applied the hybrid model, including back propagation network and genetic algorithm, to predict the thermal and flow characteristics in a channel equipped with multiple twisted tapes while the multi-objective optimization with genetic algorithm was applied for the optimization.

For better heat transfer enhancement, twisted tapes were applied together with other heat transfer enhancement techniques [20–23]. Bhattacharyya and Saha [20] equipped centre-cleared twisted-tapes with a circular duct and found that the combined devices yielded significantly higher heat transfer enhancement than the circular duct alone. Similarly, Promvonge et al. [21] reported that the use of helical-ribbed tube equipped with twin twisted tapes resulted in noticeably higher heat transfer coefficient the use of the ribbed tube alone. Again, Promvonge et al. [22] examined the heat transfer characteristics of a square duct equipped with combined winglet vortex generators and twisted tapes. Their results showed that the duct with combined winglet vortex generators and twisted tapes gave higher heat transfer coefficient and thermal performance than the one with only twisted tapes. Khoshvaght-Aliabadi and Eskandari [23] combined the effects of conductive and convective heat transfer enhancement by using Cu-water nanofluids as the working fluids in the tube equipped with twist tapes. Their experiments were carried out using the non-uniform twist tapes with different twist lengths (low–high, high–low, low–high–low, and high–low–high). They reported that the simultaneous use of the nanofluid and twisted tapes resulted in superior heat transfer than the individual use of a single technique. Among the studied tapes, the one with low to high twist lengths gave the maximum heat transfer coefficient. In the similar way, Chougule and Sahu [24] studied the heat transfer coefficient of tube equipped with helical twisted tape using Al_2O_3/water and CNT/water nanofluids at different particle volume fractions as the testing fluids. Their results showed that the use of the helical tape together with the nanofluids resulted in better heat transfer than the use of the tape or the nanofluids alone.

Based on the above literature review, the heat transfer enhancement by twisted tapes is strongly dependent on tape geometry. In common, a thermal performance factor as an overall heat transfer enhancement is dependent on both heat transfer coefficient and friction loss. The good heat transfer enhancement device should give a reasonable trade-off between the increased heat transfer coefficient and friction loss. The present investigation focuses on the developments of the twisted tape geometry with aims to reduce a pressure drop and increase a thermal performance factor. The tapered tapes proposed in the present work are expected to cause lower friction loss than a typical twisted tape, attributed to their smaller cross-section areas in axial direction. The effects of taper angles ($\theta = 0.0°$ (typical twisted tape), 0.3°, 0.6° and 0.9°) and twist ratios (y/W = 3.5, 4.0 and 4.5), on the thermal enhancement factor are studied. The experiments are carried out in a turbulent regime for Reynolds numbers between 6000 and 20,000, under a uniformly heated wall condition. The experimental results of the heat transfer rate (Nu), pressure drop (f) and thermal performance obtained by using tapered twisted tapes were compared with those by the use of typical twisted tape inserts.