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Heat transfer enhancement of heat exchanger tube with multiple square perforated twisted tape inserts: Experimental investigation and correlation development

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ABSTRACT

The present study examines the augmentation in heat transfer and friction in a flow through heat exchanger tube with multiple square perforated twisted tape inserts. The experimental outcomes pertaining to Reynolds number (Re_n) from 5000 to 27000, perforation width ratio (a/W_T) from 0.083-0.333 and twist ratio (T_L/W_T) from 2.0-3.5 have been presented and discussed. Multiple square perforated twist tape brought out considerable enhancement in heat transfer rates over without square perforated multiple twisted tape and plain tube. The maximum enhancement is observed at a a/W_T of 0.250 and T_L/W_T of 2.5. Correlations of Nusselt number, friction factor and thermal hydraulic performance are established in term of Reynolds number and geometrical parameter of twisted tape which can be used to predict the values of Nusselt number, friction factor and thermal hydraulic performance with considerably good accuracy.

1. Introduction

Energy is essentially important for our daily works, therefore it is imperative that energy is utilized effectively and efficiently. Heat transfer coefficient to the flowing fluid need to the enhanced to make the heat exchanger tube compact and efficient one of the most widely used method for enhancement of convective heat transfer involves the creation of turbulence promoters such as dimpled obstacles, baffles, winglets and twisted tape [1,2]. The twisted tape inserts is one of the widely employed passive methods to increase the heat transfer rate. Tube inserted with twisted tapes perform better than the plain tubes as heat transfer enhancement occurs in the twisted tapes due to the swirl flow induced near the tube wall. This creates turbulence near the wall giving rise to more velocities near the boundary and is responsible for better fluid mixing [3–5].

Different types of twisted tapes with modified geometries like twisted tape having wire nails, jagged, perforated, perforated helical, serrated twisted tapes have been well studied by the researchers. Eiamsa-ard et al. [6] experimentally investigated that use of counter-coupling twisted tape insert caused higher Nu_{rs} and f_{rs} than co-coupling twisted tape insert. Eiamsa-ard et al. [7] experimentally found that by inserting twin-delta winged twisted tape insert in heat exchanger tube Nu_{rs} increases as the wing tip angle decreases. Murugesan [8] reported that Nu_{rs} and f_{rs} increase was considerably higher in Trapezoidal-cut twisted tape insert than typical twisted tape insert. Murugasean et al. [9] presented that in a circular tube fitted with twisted tape consisting of wire-nails gave better Nu_{rs} and f_{rs} over plain tube and plain twisted tape inserts due to the swirl flow caused by plain twisted tape and additional turbulence by wire nail inserts.

Wongcharee and Eiamsa-ard [10] found experimentally that the Nu_{rs} of clockwise and counterclockwise alternate-axes twisted tape is higher than that of typical twisted tapes. Eiamsa-ard et al. [11] conducted experiments to find the Nu_{rs} and the f_{rs} characteristics in a test tube fitted with dual twisted tape elements in tandem for several twist ratios of 3.0, 4.0 and 5.0 and space ratios of 0.75, 1.5 and 2.25. Eiamsa-ard et al. [12] found experimentally that full length twisted tape inserts having twist ratios 6 and 8 and the space ratios 1.0, 2.0 and 3.0 fitted in a circular tube can greatly increase the Nu_{rs} and f_{rs}. Sarada et al. [13] investigated the heat transfer characteristics by varying the width of twisted tape inserts with twist ratios (3.0, 4.0 and 5.0) and widths (26-full width, 22, 18,

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Nomenclature

a	Perforated width,m
a/W_T	Perforation width ratio
Ao	Area of orifice plate, m^2
Ap	Area of pipe, m^2
C_p	Specific heat, J/kgK
C_d	Coefficient of discharge
D	Hydraulic diameter of pipe, m
f_{rs}	Friction factor rough surface
f_{ss}	Friction factor plain tube
H	Head difference, m
h	Heat transfer coefficient, W/m^2K
k	Thermal conductivity of air, W/mK
L	Tube length, m
$\dot{m}$	Mass flow rate, kg/s
Nu_{rs}	Nusselt number rough tube
Nu_{ss}	Nusselt number plain tube
$(\Delta P)o$	Pressure drop across orifice plate, Pa
$(\Delta P)_d$	Pressure drop according to Darcy's equation, Pa
ΔP	Pressure drop, Pa
Pr	Prandtl number
Q_u	Useful heat transfer, W
Re_n	Reynolds number
T_{pm}	Mean pipe temperature, K
T_{fm}	Mean fluid temperature,K
T_i	Inlet temperature, K
T_o	Outlet temperature, K
T_L	Twist length, m
T_L/W_T	Twist ratio
V	Air flow velocity, m/s
W_T	Width of tape, m
PCR	Perforated conical ring
WPT	Winglet perforated tapes

Greek Symbols

ρ	Density, kg/m^3
μ	Dynamic viscosity, Ns/m^2
η_p	Performance evaluation factor, dimensionless

14 and 10 mm). The augmentation varied from (36–48%) for full width and (33–39%) for reduced width. Eiamsa-ard [14] found that Nu_{rs} and f_{rs} increase around 10.3 to 169.5% over plain surface for multiple twisted tape vortex generators. Eiamsa-ard et al. [15] studied the thermo-hydraulic performance of single, double and triple helical twisted tape insert fitted in heat exchanger tubes and found that use of double and triple helical twisted tape insert increased Nu_{rs} by 15.6 to 23.4% and f_{rs} by 83–206%.

Vashistha et al. [16] have reported that Nu_{rs} and f_{rs} increase by decreasing the twist ratio and counter swirl twisted tape insert gave more Nu_{rs} and f_{rs} as compared to co-swirl. Bhuiya et al. [17] explored the effect of perforated double counter twisted tape inserts with different porosities 1.2, 4.6, 10.4 and18.6% in a circular tube. The results showed that the Nu_{rs} increased with decreasing porosity except for 1.2%. Bhuiya et al. [18] experimentally investigated that in a circular tube fitted with perforated twisted tapes of different porosities Nu_{rs} and f_{rs} got significantly enhanced as compared to that of the plain tube.

Thiangpong et al. [19] examined Nu_{rs} and f_{rs} characteristics of in tubes fitted with perforated twisted tapes with different twist ratios, perforated hole diameter ratios and space length ratios. Gunes et al. [20] performed experimental investigations of Nu_{rs} and f_{rs} characteristics of circular tube with loose-fit twisted tape insert at different twist ratios and hole diameter ratios and found that maximum Nu_{rs} was obtained for twist ratio of 2 and a hole diameter ratio of 0.0714. Shabnanian [21] carried experimental and mathematical studies of an air cooled heat exchanger fitted with three types of tube inserts namely butterfly, classic and jagged twisted tape and found that maximum Nu_{rs} was obtained by the butterfly insert with an inclined angle of 90°. Eiamsa-ard et al. [22] found experimentally that in round tube fitted with serrated twisted tape Nu_{rs} increaseswith the increase in the depth ratio but decreases with increasing the width ratio. Kongkaitpaiboon et al. [23] experimentally investigated the Nu_{rs} and f_{rs} characteristics in PCR with three different pitch ratios 4.0, 6.0 and 12.0 and three different perforated holes 4.0, 6.0 and 8.0 holes and found that PCR augmented heat transfer rate upto 137%.

Thiangpong et al. [24] reported that in a tube fitted with perforated twisted tapes with parallel wings thermal performance increased by 208% for perforated twisted tapes as compared to plain tube. Nanan et al. [25] carried out an experimentally studied influence of perforated helical twisted tapes with different diameter ratio, perforation pitch ratios, helical pitch ratio and twist ratios on Nu_{rs} and f_{rs} and found decrease in f_{rs} with the use of perforated helical twisted tapes in comparison with typical helical twisted tapes and increase in f_{rs} and thermal performance factor with increase of perforation pitch ratio and decrease of diameter ratio. Zhang et al. [26] studied numerically the Nu_{rs} and f_{rs} characteristics in tubes fitted with triple and quadruple twisted tapes. A simulation was carried out to analyse multi-longitudinal vortices formed in the tube due to the presence of triple and quadruple twisted tapes and found that augmentation in Nu_{rs} for triple and quadruple twisted tape to be 171% and 182% respectively, and f_{rs} of 4.06-7.02 times that of plain tube.

Guo et al. [27] studied numerically effect of centrally cleared twisted tapes on Nu_{rs} and f_{rs}, the results showed that Nu_{rs} got enhanced by 7.0 −20.0% for Centrally cleared twisted tape as compared with typical twisted tape. Tamna et al. [28]conducted experiments in a round tube fitted with double twisted tapes in common with 30° V-shaped ribs and concluded that V-ribbed twisted tape yielded highest Nu_{rs} and f_{rs}. Skullong et al. [29] explored the effect of staggered-winglet perforated-tapes (WPT) inserted in a circular tube and concluded that Nu_{rs} and f_{rs} for WPT increased with increase in blockage ration and decrease in three winglet pitch ratio. Chang et al. [30] investigated the effect of broken twisted tape fitted in a tube and concluded that Nu_{rs} and f_{rs} augmented significantly for the tube with broken twisted tape over that of typical twisted tape.

Ahamed et al. [31] experimentally studied Nu_{rs} and f_{rs} characteristics in mild steel twisted tape inserts with holes of different diameter and found increase in Nu_{rs} and f_{rs} with twisted tape inserts. Murugesan et al. [32] experimentally investigated the Nu_{rs} and f_{rs} characteristics in a circular tube fitted with and without V-cut twisted tape insert and found that Nu_{rs} and f_{rs} in the tube with V-cut twisted tape enhanced with reducing twist, width ratios and increasing depth ratios. Rahimi et al. [33] reported that maximum Nu_{rs} was in a tube with jagged twisted tape insert than obtained for classic one.

Saha et al. [34] experimentally investigated that pinching of tapes rather than connecting the tapes with rods is a better proposition from thermo hydraulic performance point of view. Sivashanmugam and Suresh [35] found that Nu_{rs} gets augmented with increasing twist ratio in circular tube inserted with helical screw twisted tape insert. Sivashanmugam and Nagarajan [36] found experimentally that Nu_{rs} for right-left helical twisted tape insert is higher that straight helical twisted tape insert. The studies on previous