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Effect of square wings in multiple square perforated twisted tapes on fluid flow and heat transfer of heat exchanger tube

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ABSTRACT

This work presents, an experimental study on Nusselt number (Nu_{rs}) and friction factor (f_{rs}) of heat exchanger circular tube fitted with multiple square perforated with square wing twisted tape inserts. The experimental determination encompassed the geometrical parameters namely, wing depth ratio (W_d/W_T) of 0.042–0.167, perforation width ratio (a/W_T) of 0.250, twist ratio (T_L/W_T) of 2.5, and number of twisted tapes (N_T) of 4.0. The effect of multiple square perforated twisted tape with square wing has been investigated for the range of Reynolds number (Re_n) varied from 5000 to 27,000. The maximum enhancement in Nu_{rs} and f_{rs} is observed to be 6.96 and 8.34 times of that of the plain circular tube, respectively. Correlations of Nu_{rs}, f_{rs} and η_p are established in term of Re_n and geometrical parameters of wings twisted tape which can be used to predict the values of Nu_{rs}, f_{rs} and η_p with considerably good accuracy.

1. Introduction

The heat exchanger (HE) is fundamental component of power and refrigeration cycles, which encourages the transfer of heat from one medium to another by virtue of temperature difference [1,2]. Industrial equipment utilizes heat exchanger to exchange or transfer heat energy from one medium of fluid to other at various temperatures [3,4]. Numerous technological process exchanges heat to cool one fluid and heat up the other, as in food and petrochemical industries, electronics and power production, air-conditioning, refrigeration, and space uses [5–7]. An array of tubes encased in a casing for heating or cooling it down is the major aim of a heat exchanger. Heat exchanger parts like fans, condensers, coolants, extra tubes, alongside numerous elements assume a part in enhancing heating and cooling efficiency [8,9].

Twisted tapes are the metallic strips twisted with some suitable techniques at desired shape and dimension, inserted in the flow. The twisted tape inserts are popular and widely used in heat exchangers for heat transfer enhancement besides twisted tape inserts promote heat transfer rate with less friction factor penalty on pumping power. Insertion of twisted tapes in a tube provides a simple passive techniques for enhancing the convective heat transfer by introducing swirl into the bulk flow and disrupting the boundary layer at the tube surface due to repeated changes in the surface shape. This is to say such tapes induce turbulence and superimposed vortex motion which induces a thinner boundary layer and consequently results in a better heat transfer rate and higher local heat transfer due to the changes in the twisted tape shape. However, the pressure drop inside the tube will be increased by introducing the twisted tape to insert. Hence a lot of investigators have been carried out experimentally and numerically to investigate the optimal design and achieve the best thermal performance with less friction loss [10–13].

Noothong et al. [10] studied Nu_{rs} and f_{rs} description of a concentric double circular tube with single TT insertion with Twisted

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Nomenclature

a	Perforated width (m)
a/W_T	Perforation width ratio (dimensionless)
Ao	Area of orifice plate (m^2)
Ap	Area of tube (m^2)
C_p	Specific heat (J/kg K)
C_d	Coefficient of discharge (dimensionless)
D	Hydraulic diameter of pipe (m)
f_{rs}	Friction factor twisted tape (dimensionless)
f_{ss}	Friction factor plain tube (dimensionless)
H	Head difference (m)
h	Heat transfer coefficient (W/m^2 K)
k	Thermal conductivity of air (W/m K)
L	Tube length (m)
$\dot{m}$	Mass flow rate (kg/s)
Nu_{rs}	Nusselt number twisted tape tube (dimensionless)
Nu_{ss}	Nusselt number plain tube (dimensionless)
$(\Delta P)o$	Pressure drop across orifice plate (Pa)
$(\Delta P)_d$	Pressure drop according to Darcy's equation (Pa)
Δ P	Pressure drop (Pa)
Pr	Prandtl number (dimensionless)
Q_u	Useful heat transfer (W)
Re_n	Reynolds number (dimensionless)
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 (dimensionless)
V	Air flow velocity (m/s)
W, W_T	Width of tape (m)
W_d	Wing depth (m)
W_d/W_T	Wing depth ratio (dimensionless)
y	Pitch length of twisted tape (m)
y/W	Pitch ratio (dimensionless)
PCR	Perforated conical ring
WPT	Winglet perforated tapes
HE	Heat exchanger
TT	Twisted tape
PT	Plain tube)

Greek symbols

ρ	Density (kg/m^3)
η_p	Performance evaluation factor (dimensionless)
θ	Taper angle (degree)

ratios namely, $y = 5.0$ and 7.0. TT induced the swirling stream inside the tube resultant in the augment in Nu_{rs}. The augmentation in Nu_{rs} by using Twist ratios, $y = 5.0$ and 7.0 were 188.9% and 159.65%, respectively. Sarada et. al. [11] examined the Nu_{rs} and f_{rs} characteristics in a horizontal circular tube with/without TT inserts by varying their width and air as the working fluid for Re_n varied from 7000 to 13,800.

Eiamsa-ard et. al. [12] examined the impact of the TTs with centre wings in a tube. They inferred that improvement of $Nu_{rs}$and f_{rs} as comparison to smooth tube were maximum in the order of 2.89 and 3.12 times, respectively. Wongcharee and Eiamsa-ard [13] investigated TTs with alternate-axes and wings in a round tube. They reported that both Nu_{rs} and f_{rs} increments with the utilization of all TT in contrast with those TT. Krishna et. al. [14] explored straight HE half left-ring HE embedded in a laminar stream locale experimentally in a circular tube. It is noted that heat transfer increments by diminishing spacer slots and accomplishes the maximum heat transfer for spacer gap of 2.0 in.

Wongcharee and Eiamsa-ard [15] used alternate clockwise and counter clockwise twisted-tapes in a circular tube to decide Nu_{rs} and f_{rs} and thermal hydraulic characteristics. It was reported that clockwise and anticlockwise Twisted-tapes yields a maximum augmentation of Nu_{rs} and f_{rs} in order of 2.980 and 3.160 times the smooth tube. Murugesan et al. [16] experimentally explored and revealed Nu_{rs} and f_{rs} and demonstrated a huge augmentation for a circular tube fixed with full length TT with trapezoidal-cut. Seemawute et al. [17] found that in a HE tube fitted with the PTA, PT and TT demonstrated a huge improvement in the Nu_{rs} namely 184%, 102% and 57% of that of the PT.

Murugesan et. al. [18] examined the V-cut TT and reported that the mean Nu_{rs} and f_{rs} increment with reducing Twist and width ratios and increases with increasing depth ratios (DR). Ibrahim [19] experimentally determined Nu_{rs} and f_{rs} performance of horizontal double pipes of flat tubes having full-length helical screw. The parameters considered were different Twist ratio and different spacer length. Thianpong et al. [20] experimentally explored and inferred that Nu_{rs} and f_{rs} are higher for dimpled tube fitted with the TT, than the dimple tube alone and PT. A decrease in PR and y/w yields to a higher Nu_{rs} and f_{rs}. Saha [21] researched Nu_{rs} and f_{rs} of a rectangular and HE tube with a mix of internal axial corrugations on surfaces of duct and insert in the form of Twisted-tape with and without oblique teeth. The axial corrugations combined with twisted-tapes of all types with oblique teeth performs superior to no oblique teeth combined with axial corrugations.

Chiu and Jang [22] examined the longitudinal strip inserts (without hole) and detailed that Nu_{rs} and f_{rs} were 7.0–16% and 100–170% higher than the PTs. Nu_{rs} and the pressure drop was 13–28% and 140–220%, respectively. Guo et al. [23] numerically analyzed the tubes with short width TTs and reported that Nu_{rs} and f_{rs} diminish by cutting off the tape edge. Whereas, tubes with centre-cleared TTs, the heat transfer is increased for a appropriate central clearance ratio. Garcia et al. [24] utilized the helical-wire-coils inside a round tube to decide the thermo-hydraulic behaviour in laminar, transition and turbulent stream. Water and water–propylene glycol blends was utilized at various temperatures and the outcomes demonstrates that in turbulent locale wire coils increase friction factor and heat transfer up 9.0 and 4.0 times in contrast to the smooth tube. Promvonge [25] experimentally found the effect of wire coils with TTs as an insert in a circular tube on $Nu_{rs}$and f_{rs}. It was reported that combination of wire coils with TTs increases Nu_{rs} to folds as compared to wire coil/TT alone.

Gunes et al.[26] investigated the heat transfer and pressure drop for a coiled wire insert in a turbulent flow regime. It was observed that Nu_{rs} increases with the increase of Re_n and wire thickness and decrease in pitch ratio. At $a/D = 0.0892$ and $P/D = 1$ at Re