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Research paper

Thermal performance in square-duct heat exchanger with quadruple V-finned twisted tapes

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HIGHLIGHTS

- The duct inserted with quadruple V-fined twisted tapes is offered.
- Effect of arrangements of quadruple twisted tapes on thermal behaviors is studied.
- Influence of incorporated V-fins on thermal performance is experimentally examined.
- The combined devices provide higher thermal performance than the twisted tapes alone.

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ABSTRACT

An investigation on heat transfer augmentation in a square duct with insertion of combined 30° V-fins and quadruple counter-twisted tapes is conducted experimentally. Air as the working fluid enters the test duct having a uniform wall heat-flux condition with Reynolds number ranging from 4000 to 30,000 in the present work. The combined vortex generators (called "V-finned counter-twisted tape") are obtained by incorporating V-fins into the edges of quadruple twisted-tapes having a similar twist ratio of 4. The effect of pertinent V-fin parameters such as four relative fin height, ($R_B = e/w = 0.16$, 0.21, 0.32 and 0.42) and relative fin pitch, ($R_P = P/w = 4$, 8, 12 and 16) at a single fin attack angle, $\alpha = 30°$ on thermal characteristics is examined. The experimental results reveal that the heat transfer and pressure drop in the form of respective Nusselt number and friction factor from the V-finned counter-twisted tape tend to increase with the rise of R_B but show the reversing trend with increasing R_P. The thermal performance of the V-finned counter-twisted tape is considerably higher than that of the quadruple twisted tapes alone. The V-finned counter-twisted tape with $R_B = 0.42$ and $R_P = 4$ yields the maximum Nusselt number and friction factor but the one with $R_B = 0.21$ and $R_P = 4$ provides the highest thermal performance of about 1.75 at lower Reynolds number.

1. Introduction

The heat transfer enhancement (HTE) techniques with swirl/vortex flows have been widely applied in many heat exchanger systems in order to enhance convective heat transfer coefficients by disrupting the boundary layer and increasing turbulence intensity in cooling/heating ducts of the systems. The HTE techniques can be divided into two groups: active and passive methods. The former needs external power sources such as vibration, suction and injection of fluid and electrostatic fields while the latter requires no external power source including coated/rough/extended surfaces, coil tubes, surface tension, additives for liquids/gases, and swirl/vortex flow devices. In general, the passive method is more popular, especially for swirl flow devices which are of most interest. Such devices include full-length twisted-tape or coil wire vortex generators for tubes and rib/fin/winglet/baffles for ducts/channels. The use of vortex generators does not only enhance a considerable heat transfer rate but also yield a substantial increase in pressure drop. Therefore, to obtain the best thermal performance from using the vortex generators, their optimum geometric parameters must be investigated.

For decades, several studies on the influence of the geometries of vortex generators on thermal behaviors in the heat exchanger ducts have been made. Promvonge et al. [1,2] reported the effect of inclined vortex rings and horseshoe baffles on heat transfer augmentation in a uniform heat-fluxed tube and also found that the

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Nomenclature

A	heat transfer area in duct, m^2
A_c	cross-sectional area, m^2
C_p	specific heat capacity, J/kgK
D_h	duct hydraulic diameter, m
e	fin height, m
f	friction factor
H	duct height, m
h	average heat transfer coefficient, W/m^2 K
k	thermal conductivity of air, W/mK
L	length of test duct, m
L_T	left or counter-clockwise twisted tape
$\dot{m}$	mass flow rate of air, kg/s
Nu	Nusselt number
P	fin pitch length, m
P_w	wetted perimeter, m
ΔP	pressure drop, Pa
Pr	Prandtl number
Q	heat transfer rate, W
Re	Reynolds number
R_B	relative fin height or blockage ratio, e/w
R_P	relative fin pitch or pitch ratio, P/w
R_T	right or clockwise twisted tape
T	temperature, K
t	fin thickness, m
U	mean velocity, m/s
w	tape width, m
y	twist length of tape, m

Greek letters

α	half angle of V-tip or attack angle of fin, degree (°)
η	thermal enhancement factor
ν	kinematics viscosity, m^2/s
ρ	density of air, kg/m^3

Subscripts

b	bulk
0	smooth duct
conv	convection
i	inlet
o	outlet
pp	pumping power
s	duct surface

larger R_B provided higher heat transfer and pressure drop than the smaller while the larger R_P gave the reversing trend pattern. Lee et al. [3] experimentally studied heat transfer behaviors in a stationary rectangular divergent channel with parallel angled ribs. Promvonge et al. [4] numerically investigated the turbulent flow and heat transfer characteristics in a square duct with V-shaped discrete ribs. Experimental works on thermal characteristics in a solar air heater channel fitted with rib-groove turbulators and delta winglet vortex generator were reported in Refs. [5–8]. Sriromreun et al. [9] examined the influence of Z-baffle turbulators on heat transfer augmentation in a rectangular duct. Numerical works on heat transfer and pressure drop characteristics of turbulent nanofluids flow in a rib/rib–groove channel could be found in Refs. [10,11].

Promvonge et al. [12,13] studied the heat transfer enhancement in turbulent flow over 30° angle-finned tapes inserted diagonally in a square duct. They showed that the finned-tape with smaller fin pitch provided considerably higher heat transfer and pressure drop than the smooth duct alone and was superior to the wire-coil/twisted-tape. Peng et al. [14] reported convection heat transfer in a channel fitted with various ribs and V-shaped ribs and found that the 45° V-shaped continuous ribs yielded the best thermal/hydraulic performance. Chompookham et al. [15] proposed the application of combined ribs and winglets in a channel and indicated that the Nusselt number and friction factor from the ribs together with the winglets were considerably higher than those from the ribs or winglets alone. Saha [16] provided experimental data of heat transfer and pressure drop of turbulent flow in rectangular and square ducts with internal transverse rib turbulators on two opposite duct walls and with wire-coil inserts. SriHarsha et al. [17] and Gupta et al. [18] conducted a measurement on the local heat transfer distribution and pressure drop in a ribbed square channel and showed that the 60° V-broken rib yielded heat transfer higher than the 90° continuous and profiled ribs. Chang et al. [19,20] investigated heat transfer enhancement in a channel fitted with the compound roughness of staggered V-ribs and deepened scales.

With a view to the increase of heat transfer rate rather than the decrease of pressure drop, lots of modified twisted-tapes were developed, for instance, the perforated/serrated twisted tapes and so on. Studies on the influence of helical twisted-tapes on heat transfer and friction loss characteristics in tubes were conducted by Nanan et al. [21,22] and Eiamsa-ard et al. [23]. They pointed out that the thermal performance of those tapes was increased around 10–15% above the classic twisted-tapes. Naik et al. [24] examined on thermal performance of twisted-tape and wire-coil inserts in turbulent flow using CuO/water nanofluid and indicated that thermal performance associated with nanofluid in a tube with wire-coil inserts was higher than that with twisted-tape inserts. Kanizawa et al. [25] presented experimental data of pressure drop and heat transfer coefficient for two-phases flows in tubes containing twisted-tapes. Bhuiya et al. [26–28] reported the effect of the double counter-twisted tapes/perforated twisted-tape/triple twisted-tapes on heat transfer and fluid friction characteristic in a heat exchanger tube. They found that both heat transfer rate and friction factor of the inserted tube were significantly higher than those of the plain tube.

Eiamsa-ard et al. [29] investigated the HTE in a tube using twisted tapes with alternate axes at different alternate lengths. A study on the thermal behaviors in a tube with delta-winglet and peripherally-cut twisted-tapes was carried out by Eiamsa-ard et al. [30,31]. They proposed that the maximum thermal performance was for the delta-winglet twisted tape while the peripherally-cut one performs better than the typical one. Murugesan et al. [32] presented heat transfer and flow friction characteristics of a double pipe heat exchanger fitted with square-cut twisted tapes and plain twisted tapes. Several modified twisted tapes inserted in a tube to enhance heat transfer were introduced by Rahimi et al. [33] and indicated that the highest thermal performance was obtained for the jagged twisted tape. Promvonge [34] reported heat transfer and turbulent flow friction characteristics in a tube inserted with wire coils in conjunction with twisted tapes and found that the combined wire coil and twisted tape yielded double increase in heat transfer over the wire-coil/twisted-tape alone. Promvonge and Eiamsa-ard [35–37] investigated the thermal characteristics in a tube fitted with serrated twisted tape; conical-ring and twisted-tape; and alternate clockwise and counter-clockwise twisted-tape swirl turbulators. Recently, Promvonge et al. [38] conducted a