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Experimental study on effect of heat transfer enhancement for single-phase forced convective flow with twisted tape inserts

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ABSTRACT

In this paper, experimental investigation on heat transfer and friction characteristics of dual-pipe heat exchanger for single-phase forced convective flow with alternation of clockwise and counterclockwise twisted tape (ACCT tape) and typical twisted tape (TT tape) inserted in the inner tube has been carried out. And effects of different lengths of twisted tapes on heat transfer enhancement were studied through a circular tube using water as testing fluid in turbulent conditions with a range of Reynolds number between 3000 and 9000. In the dual-pipe heat exchanger, hot water was cooled in the inner tube and cold water was as cooling fluid between the inner tube and the outer tube. The results showed that the ACCT tapes performed better on heat transfer enhancement than the typical twisted tapes and the best effect appeared with the full-length ($l = 2400$ mm) ACCT tape insert in comparison with the twisted tapes of other lengths. The maximum values of PEC (performance evaluation criteria) with the full-length ACCT tape insert reached 1.42 in experimental flowing conditions. Empirical correlations for Nusselt number and friction factors were established and found to fit the experimental data with a deviation within 8%.

1. Introduction

Heat transfer enhancement technology has been developed and widely applied in many industries such as automotive, locomotive, aerospace, etc. As a simple and effective passive heat transfer enhancement technique, twisted tape can change flow track of fluid, reduce thickness of the boundary layer, and then increase convective heat transfer coefficient. At the same time, inserting twisted tapes in tubes increases frictional resistance of heat exchanger.

Thus, a lot of researchers engaged themselves in researches about this area and a large number of experimental and numerical studies on the effect of twisted tapes on heat transfer and friction factor in a circular tube or rectangular tube were carried out [1–5].

Saha and Dutta made a comparison about the effects of heat transfer enhancement in laminar flow between full-length typical twisted tapes, twisted tapes with uniform intervals and twisted tapes with smoothly varying (gradually decreasing) pitch [6]. Their research showed that not all modified twisted tapes performed better on heat transfer than typical twisted tapes.

Chakroun and Fahed experimentally studied the effect of the twisted-tape width on the heat transfer and friction factor performance with laminar flow in circular tubes [7]. The results showed that the width of the twisted tape has little effect on friction factor but more pronounced effect on heat transfer.

Hasanpour et al. did experimental investigations on heat transfer and pressure drop of double pipe heat exchanger in turbulent regimes, in which the inner copper tube is inserted with typical, pierced, V-cut and U-cut twisted tapes of three different twist ratios of 3, 5 and 7 [8]. All of the modified twisted tapes led to higher Nusselt number and friction factor and different cuts led to different effects of heat transfer.

In addition, many scholars have tried to combine twisted tapes with other inserts, such as twining coils around twisted tapes [9,10], inserting a rod at the center of twisted tapes [11], etc. Some scholars combined nano-fluid [12–14] or tubes of special geometries with twisted tapes [15–17]. The results showed that most of these means led to good effects on heat transfer enhancement [24,25].

A summary of previous researches on heat transfer enhancement showed that there were no data on heat transfer and friction factor in circular tubes fitted with alternation of clockwise and counterclockwise twisted tape in turbulent flowing regions. In this paper, a new type of twisted tape, which was twisted with alternation of clockwise and counterclockwise periodically and semicircular cuts uniformly distributed on both sides (ACCT tape) was adopted. So the purpose of this paper is divided into two aspects: (i) to study heat transfer and friction characteristics in turbulent

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Nomenclature

l	length of twisted tape, m
L	tube length of the experimental section, m
D_i	diameter of inner tube, mm
T_h^{in}	inlet temperature of hot water, K
T_h^{out}	outlet temperature of hot water, K
T_h	bulk temperature of hot water, K
T_c^{in}	inlet temperature of cold water, K
T_c^{out}	outlet temperature of cold water, K
T_c	bulk temperature of cold water, K
T_w	tube wall temperature of inner tube, K
U_h	mean velocity of hot water, m/s
ΔP	pressure drop, Pa
V_h	volume flow rate of hot water, m^3/s
V_c	volume flow rate of cold water, m^3/s
W_h	mass flow of hot water, kg/s
W_c	mass flow of cold water, kg/s
ρ_{in}	density of hot water at inlet temperature, kg/m^3
ρ_h	density of hot water at bulk temperature, kg/m^3
C_{ph}	specific heat capacity of hot water, J/(kg K)
C_{pc}	specific heat capacity of cold water, J /(kg K)
v	kinematic viscosity of hot water, m^2/s
λ_h	thermal conductivity of hot water, W/(m K)
A	the area of inner tube, m^2
δ	deviation of heat transfer rates, W
h_i	heat transfer coefficient, $W/(m^2 K)$
Q_h	heat transfer rate released by hot water, W
Q_c	heat transfer rate absorbed by cold water, W
Q	mean heat transfer rate, W
Re	Reynolds number
Nu	Nusselt number
f	friction factor
PEC	performance evaluation criteria

conditions through a circular tube fitted with ACCT tapes of various lengths, typical twisted tapes of various lengths, (ii) to provide reliable correlations based on the data gathered during this experiment for both Nusselt number and friction factor. The parameters involved in experiment and calculation are as follows:

2. Experimental apparatus

The experimental setup consisted of a dual-pipe heat exchanger and a water flow system with its accessories. As shown in Fig. 1, the hot water circuit was arranged as: a hot water storage tank that provided with multiple electrical heaters with rheostat, a 0.37 kW centrifugal pump, a turbine flow meter, a piping system with suitable valves, and an inner tube of heat exchanger. All hot pipes and storage tank were made of stainless steel and insulated with suitable insulation thickness. The cold water circuit consisted of a 0.37 kW centrifugal pump, a turbine flow meter, a piping system with suitable valves. The two flowmeters, whose measurement error is within 1%, are used to measure the volume flow rate of hot water and cold water respectively.

For the dual-pipe heat exchanger, the inner tube was made of copper with a thickness of 2 mm, inner diameter of 16 mm and length of 2470 mm, while the outer tube was made of stainless steel with a thickness of 3 mm, inner diameter of 32 mm and length of 2400 mm. The inlet temperature of hot water in the inner tube was kept at 50 °C with a temperature controller while the inlet temperature of cold water between the inner tube and the outer tube was at room temperature (16–18 °C). Twisted tapes used in experiment were the ACCT tapes and the typical twisted tapes twisted with one direction. As shown in Figs. 2and 3, the ACCT tape was twisted with alternation of clockwise and counterclockwise tape periodically and semicircular cuts uniformly distributed on both sides with a thickness of 1 mm, pitch (p) of 42 mm, width (w) of 14 mm and twist ratio (p/w) equal to 3. Typical twisted tape was twisted with a thickness of 1 mm, pitch of 42 mm, width of 14 mm and twist ratio (p/w) equal to 3. Four twisted tapes with different lengths (L = 2400, 1800, 1200 and 600 mm) of ACCT tape and typical twisted tape were used in experiment respectively. The sketch of arrangement of twisted tapes in tube was shown in Fig. 4 and picture of ACCT tapes was shown in Fig. 5.

Eight T-type calibrated thermocouples, which were distributed regularly and fixed in the hole on the outer wall surface of the inner tube with a depth of 1.0 mm, were used to measure the tube wall temperature. And the signals were processed and displayed by the paperless recorder with a measurement error of 0.1 °C. Data of the inlet and outlet temperature of cold and hot water were measured by thermal resistances with a measurement error of 0.1 °C. The pressure drop between the inlet and the outlet of the inner tube was measured using pressure taps and a U-tube manometer which used kerosene as measurement medium with a measurement error of 0.1 mm. Data of water flow rates, pressure drop and temperatures were recorded in steady-state conditions.

Experimental uncertainties of Reynolds numbers, Nusselt numbers and friction factors were calculated with ANSI/ASME standard [18]. The maximum uncertainties of Nusselt number, Reynolds number and friction factor were found to be 5%, 8% and 10% respectively.

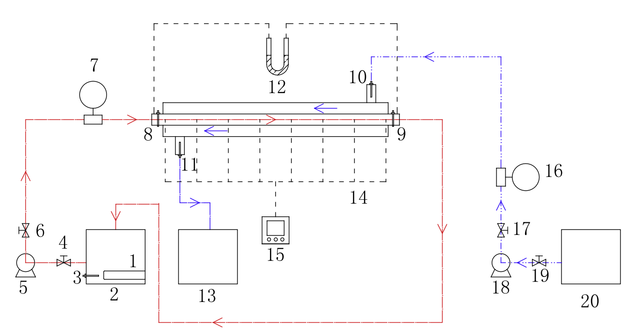

Fig. 1. Layout of the experimental system. 1. Heater; 2. Hot water tank; 3. RTD-hot water in tank; 4. Ball valve; 5. Hot water pump; 6. Hot water control valve; 7. Flowmeter; 8. RTD-hot water inlet; 9. RTD-hot water outlet; 10. RTD-cold water inlet; 11. RTD-cold water outlet; 12. U-tube manometer; 13. Cold water recoverer; 14. Thermocouples; 15. Data logger; 16. Flowmeter; 17. Cold water control valve; 18. Cold water pump; 19. Ball valve; 20. Cold water tank.

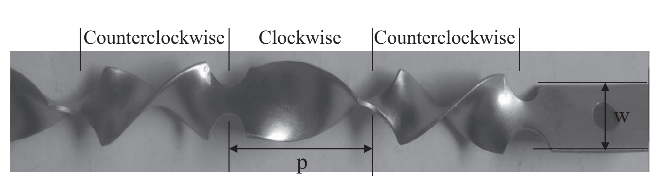

Fig. 2. The ACCT tape.

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