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Thermal characteristics in a heat exchanger tube fitted with dual twisted tape elements in tandem☆

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ABSTRACT

The paper presents a comparative investigation of enhanced heat transfer and pressure loss by insertion of single twisted tape, full-length dual and regularly-spaced dual twisted tapes as swirl generators, in a round tube under axially uniform wall heat flux (*UHF*) conditions. The investigation encompassed the Reynolds number based on the inlet tube diameter (D) ranging from 4000 to 19,000. The experiments are performed using single twisted tapes and full-length dual twisted tapes with three different twist ratios ($y/w=3.0$, 4.0 and 5.0) and also regularly-spaced dual twisted tapes with three different space ratios ($s/D=0.75$, 1.5 and 2.25). The effects of major parameters on heat transfer and friction factor are discussed and the results from both single and dual twisted tape inserts are compared with those from the plain tube. The result shows that the heat transfer of the tube with dual twisted tapes is higher than that of the plain tube with/without single twisted tape insert. For both single twisted tape and full-length dual twisted tapes, Nusselt number (Nu) and friction factor (f) tend to increase with decreasing twist ratio (y/w). The average Nusselt number and friction factor in the tube fitted with the full-length dual twisted tapes at $y/w=3.0$, 4.0 and 5.0, are respectively 146%, 135% and 128%; and 2.56, 2.17 and 1.95 times of those in the plain tube. For the regularly-spaced dual twisted tapes, the heat transfer rate is decreased with increasing space ratio (s/D). The average Nusselt numbers in the tube fitted with the regularly-spaced dual twisted tapes (s/D) of 0.75, 1.5 and 2.25 are respectively, 140%, 137% and 133% of that in the plain tube. With the similar trend mentioned above, all dual twisted tapes with free spacing yield lower heat transfer enhancement in comparison with the full-length dual twisted tapes ($s/D=0.0$).

1. Introduction

Twisted tape inserts extensively appear in heat exchanger systems for redeveloping the thermal boundary layer, inducing swirl flow and therefore enhancing the heat transfer performance. To date, twisted tapes can be used in compact heat exchangers because of its low cost, ease of maintenance and manufacture. Tubes with twisted tape insert have been also used in several thermal system applications; for example, heat recovery processes, air conditioning and refrigeration systems, and chemical reactors. Many researches on heat transfer enhancement for such kinds of configurations have been carried out for the past decades. Twisted tape was early introduced as heat transfer enhancement device in form of typical twisted tape [1,2]. However, at some operating conditions, the typical twisted tape generated friction loss within the heat exchanger of unsatisfactory level, gave rise to higher pumping power, resulting in performance factor at the same pumping power below unity. Numerously latter works paid attentions to bring down the friction loss by introduction of free space to the twisted tape with different geometries, which included short length twisted tapes [3–5], regularly-spaced twisted tape [6,7], loose-fit twisted tape [8], and perforated/notched twisted tape [9]. As found, the modified twisted tapes could bring friction loss down effectively with unavoidable reduction of heat transfer rate, thus only some of them could provide better thermal performance factors compared to those of typical twisted tape. On the other hand, modification of twisted tape was made by focusing on the increase of heat transfer rate rather than the reduction of friction loss, for example, the jagged [9], broken [10] and serrated [11] twisted tapes. The tapes in this group were designed to offer stronger swirl flow and better mixing than the typical one. However, the enhanced heat transfer by the use of the twisted tapes in the group was certainly accompanied by the rise of friction factor. In general, the performance factors of twisted tapes in this group were higher than those of the former group, for instance the broken and serrated twisted tapes [10,11] provided the performance factors as high as 1.4. Another technique for heat transfer augmentation is compound technique in which, twisted tape and the other augmentation devices such as finned tube [12], spirally corrugated tube [13] and conical-ring

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Nomenclature

A	heat transfer surface area, m^2
C_p	specific heat of fluid, J kg^{-1} K^{-1}
D	inside diameter of 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 test section, m
M	mass flow rate, kg s^{-1}
Nu	Nusselt number $= hD/k$
P	pressure of flow in test 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, °C
$\tilde{T}$	mean temperature, °C
s	free-spacing length, m
U	average velocity, m s^{-1}
V	voltage, V
$\dot{V}$	volume flow rate, m^3 s^{-1}
w	tape width, m
y	pitch length of twisted tape, m

Greek letter

ρ	fluid density, kg m^{-3}
δ	tape thickness, m
μ	fluid dynamic viscosity, kg s^{-1} m^{-1}
η	heat transfer enhancement efficiency

Subscripts

a	air
b	bulk
c	convection
i	inlet
o	outlet
p	plain tube
pp	pumping power
s	swirl generator
w	wall

turbulators [14] were utilized simultaneously. Further improvement of thermal performance for the tube with modified twisted tape was also reported, such as the use of loose-fit twisted tape together with microfin tube [8]. An enhancement of the compound devices was usually found better than those of the individual devices. Recently, the twin and triple twisted tapes were applied [15,16] to generate twin and triple swirl flows in a circular tube. This led to better performance compared to the single twisted tape, due to the bursting swirls developed in the clearances between the twisted tapes.

According to the above literature, the light from the advantages of the regularly-spaced twisted tape and twin twisted tapes motivates us to develop a new type of twisted tape using combined geometries of these two twisted tapes. Therefore, the goal of the present investigation is to generate heat transfer and flow friction data of air heating in a round tube fitted with the newly designed twisted tape called “regularly-spaced dual twisted tapes”. For comparison, experiments using full-length dual twisted tapes (tapes without free spacing) and typical single twisted tape under similar conditions are also performed.

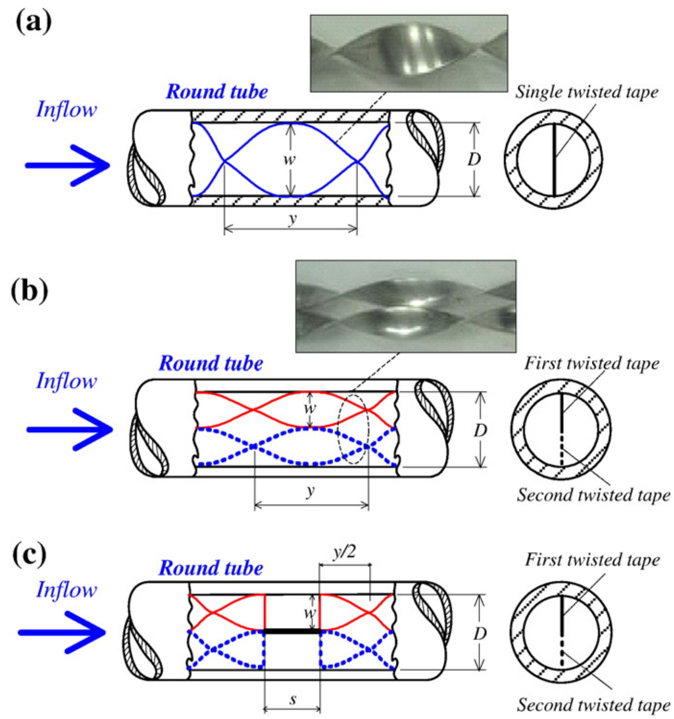

Fig. 1. Test tube with twisted tape inserts: (a) single twisted tape, (b) full-length dual twisted tapes and (c) regularly-spaced dual twisted tapes.

2. Experimental strategy

2.1. Tube with dual twisted tape inserts

Fig. 1 shows the tube fitted with three different types of twisted tape inserts (typical single tape, full-length dual tapes or (dual tapes without free spacing) and regularly-spaced dual tapes) which were used in the present work. The copper test tube has inside and outside diameters of 47 mm and 50 mm, a length of (L) 1250 mm and thickness (t) of 1.5 mm. All tapes used in the present work are made of aluminum alloy with thickness (δ) of 0.8 mm. The typical single twisted tape has a width of 46 mm while both types of the dual tapes have that of 23 mm. Three different twist lengths (y) were introduced; 138, 184 and 230 mm for the single tape and 69, 92, and 115 mm for the full-length dual tapes which corresponded to the same set of twist ratios ($y/w = 3.0$, 4.0 and 5.0). The regularly-spaced dual twisted tapes were prepared with four different space ratios,

Table 1
Detail of twisted tape inserts.

	Single twisted tape	Full-length/regularly-spaced dual twisted tapes
Parameter		
(a) Reynolds number, (Re)	4000 to 19,000	Similar
(b) Tape width, (w)	46 mm	23 mm
(c) Tape pitch length, (y)	138, 184, and 230 mm	69, 92 and 115 mm
(d) Twist ratio, (y/w)	3, 4, and 5	3, 4, and 5 (for full-length dual tapes) 3 (for regularly-spaced dual tapes)
(e) Space length, (s)	non	35.25, 70.5 and 105.75
(f) Space ratio, (s/D)	non	0.75, 1.5 and 2.25
(g) Tape thickness,	0.8 mm	Similar