International Journal of Heat and Mass Transfer 88 (2015) 481–491

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Numerical study on heat transfer enhancement characteristics of tube inserted with centrally hollow narrow twisted tapes

Pengxiao Li [a], Zhichun Liu [a,*], Wei Liu [a], Gang Chen [b]

[a] School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
[b] State Key Laboratory of Coal Combustion, Huazhong University of Science and Technology, Wuhan 430074, China

ARTICLE INFO

Article history:
Received 1 February 2015
Received in revised form 28 April 2015
Accepted 29 April 2015
Available online 15 May 2015

Keywords:
Cross hollow twisted tape
Unilateral twisted tape
Laminar flow
Heat transfer performance
Friction factor

ABSTRACT

In this study, a new tube insert, named centrally hollow narrow twisted tape, is developed and its effect on the heat transfer enhancement performance of a tube under laminar flow conditions is numerically simulated. The model defines two study variables—hollow width and clearance—and then incorporates the concept of a unilateral twisted tape; the effect of the number of unilateral twisted tapes on the tube heat transfer performance is then examined. The results show that the tube with cross hollow twisted tape inserts has the best overall heat transfer performance for different hollow widths of the tape. Compared with the conventional twisted tape, the optimum overall heat transfer performance of the new type of tape increases by 28.1%. Clearance, which is defined as the width between the tube and twisted tape, also affects the heat transfer performance. The smaller the clearance, the better is the overall heat transfer performance. For different Reynolds numbers, the number of unilateral twisted tapes that gives the optimum overall heat transfer performance is different. If the Reynolds number increases over 600, the tube can achieve the best overall heat transfer performance when the number of unilateral twisted tapes is 4. Empirical formulas for *Nu* and *f* are obtained based on calculation results. The results show that under laminar flow conditions, the cross hollow twisted tape is a very promising high-performance tube insert.

1. Introduction

Heat exchangers play an important role in various fields such as chemical engineering, metallurgy, electric power, refrigeration, and air-conditioning and are widely used in these fields. Good heat transfer performance is very crucial for the use of heat exchangers in these fields because it is related to the energy-saving benefit. With industrial development, shell and tube heat exchangers have been very commonly applied in various industries. Therefore, it is important to improve the performance of heat exchangers by heat transfer enhancement technology, which will produce good energy savings. Making enhancement in the tube side is one of the main ways to improve the performance of heat exchangers.

Variable approaches have been studied and utilized for heat transfer enhancement in tube side, such as finned tubes [1], surface-shaped tubes [2,3], and inserts within tubes [4–7]. Compared with other inserts, the twisted tape insert has some advantages: (1) It can be easily installed or replaced for cleaning purposes. (2) The cost of manufacturing and modifying the tube with a twisted tape insert is low. (3) It can be shaped easily. (4) It can substantially increase the heat transfer capacity [8]. However, twisted tape inserts also have an obvious drawback. The use of twisted tapes considerably increases the flow resistance in the tube, which limits the overall performance improvement. The principle of heat transfer enhancement in a tube with twisted tapes is as follows [9–11]. (1) The tapes generate swirls, which strengthen the disturbance of the flow boundary layer in the tube. Because of the radial velocity of the vortex, the mixing of fluids in the near-wall region and central region is enhanced, which leads to a thinner flow boundary layer and better heat transfer capability. (2) Twisted tapes generate spiral flow lines. Therefore, heat transfer increases because of a longer flow path.

Saha et al. [12] designed an experiment to simulate the enhanced heat transfer process of a tube with coaxial fins and center-cleared twisted tapes. This compound heat transfer enhancement method had a better heat transfer performance than the method employing a tube with only coaxial fins or only twisted tapes. The larger the hollow width of the tapes, the smaller was the Nusselt number (*Nu*), but the flow resistance also reduced simultaneously. Eiamsa-ard et al. [13] studied the effect of the clearance between the tube and twisted tape on the heat transfer capability.

* Corresponding author.
E-mail address: zcliu@hust.edu.cn (Z. Liu).

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2015.04.103
0017-9310/

Nomenclature

w	width of the twisted tape, mm
y	180° twist pitch of the twisted tape, mm
y/w	twisted ratio
D	inner diameter of the tube, mm
L	the length of a period of the tube, mm
C	hollow width of the cross hollow twisted tape, mm
S	clearance of the twisted tape, mm
n	number of unilateral twisted tapes
c_p	specific heat at constant pressure of water, J/kg K
Re	Reynolds number
Nu	Nusselt number
f	friction factor
u	flow velocity, m/s
u_i	the velocity component in the three-dimensional space, m/s
h	heat transfer coefficient, W/m^2 K
p	pressure of water, Pa
t	temperature of water, K
PEC	comprehensive heat transfer performance coefficient
Nu_0	Nusselt number of a plain tube
f_0	friction factor of a plain tube
c	hollow ratio = C/D
s	clearance ratio = S/D
Greek symbols	
δ	thickness of the twisted tape, mm
ρ	density of water, kg/m^3
μ	dynamic viscosity of water, kg/m s
λ	thermal conductivity of water, W/m K
β	synergy angle (°)
θ	synergy angle (°)

The results showed that when the clearance rates were 0.0, 0.1, 0.2, and 0.3, the heat transfer rate increased by 73.6%, 46.6%, 17.5%, and 20.1%, respectively, compared to the tube without twisted tape inserts. Therefore, we conclude that the clearance between tubes and twisted tapes can reduce resistance, but it will also reduce the heat transfer performance of the tubes. Eiamsa-ard and Promvonge [14] found that an optimal free-spacing ratio of 0.5 for a regularly spaced helical tape yielded the best *Nu*, which was 50% higher than that obtained using a plain tube. They [15] also studied the heat transfer enhancement of a tube fitted with a serrated twisted tape. The results showed that the heat transfer rate of the tube fitted with a serrated twisted tape was up to 27% better than that of a plain tube. Guo et al. [16] investigated the overall performance of a tube with cross twisted tapes having widths of 18 and 10 mm. The results showed that the tube with a wide cross twisted tape enhanced heat transfer better for laminar flow whereas a narrow cross twisted tape enhanced heat transfer better for turbulent flow by increasing the disturbance of the core flow region. Guo et al. [8] also studied the heat transfer behavior in a tube with a center-cleared twisted tape, short-width twisted tape, and conventional twisted tape separately for laminar flow. They found that the short-width twisted tape reduced not only the resistance but also the heat transfer coefficient, because of the weakening of the disturbance in the flow boundary layer. Therefore, reducing the width of the twisted tape weakens the overall performance of the tube. For a hollow ratio of 0.3, the tube with the center-cleared twisted tape had the best overall performance, which was 1.07–1.20 times that of the tube with the conventional twisted tape. Zhang [17] investigated the heat transfer performance of a tube with helical screw-tape without core-rod inserts and found that the overall performance was clearly enhanced. The value of the comprehensive heat transfer performance coefficient (*PEC*) varied between 1.58 and 2.35. Zhang [18] also found that the tube with multiple regularly spaced twisted tapes had better overall performance. The value of the *PEC* in this case varied between 1.64 and 2.46.

The performance of enhancing technology can be analyzed and evaluated from different perspectives. Tao and other researchers used the field synergy theory to evaluate the performance of improved heat transfer technology, and they inferred that the theory can be used to design inserts that provide better heat transfer performance. Guo et al. [22] used numerical calculations to demonstrate the feasibility and importance of the field synergy theory in the analysis of the mechanism of heat transfer enhancement. Another perspective to evaluate the performance of improved heat transfer technology is to determine the amount of energy dissipation. Liu et al. optimized the flow field within a tube to enhance heat transfer by minimizing heat consumption [23], whereas Jia et al. achieved this by minimizing entransy dissipation [24].

Results from the above studies indicate that a large flow resistance limits the overall heat transfer performance of a tube with a twisted tape, hindering it from being widely used in practice. Therefore, in this study, we aim to design an optimization program with a better overall heat transfer performance. We construct a tube model with a cross hollow twisted tape, aiming at reducing the flow resistance caused by the inserts. Compared with the center-cleared twisted tape, the cross hollow twisted tape can produce more intense disturbance in the boundary layer. In addition, it can effectively reduce the flow resistance by reducing the contact area between the twisted tape and fluid. Therefore, the proposed model can provide a better heat transfer coefficient and low resistance coefficient. Finally, we introduce the concept of a unilateral twisted tape and study the effect of the number of unilateral twisted tapes on the heat transfer behavior.

2. Physical model

The geometric models of a conventional twisted tape, unilateral twisted tape, and cross hollow twisted tape are shown in Fig. 1. The parameters of the model are listed in Table 1. For cross hollow twisted tape, L is equal to 180° twist pitch (y), while for unilateral

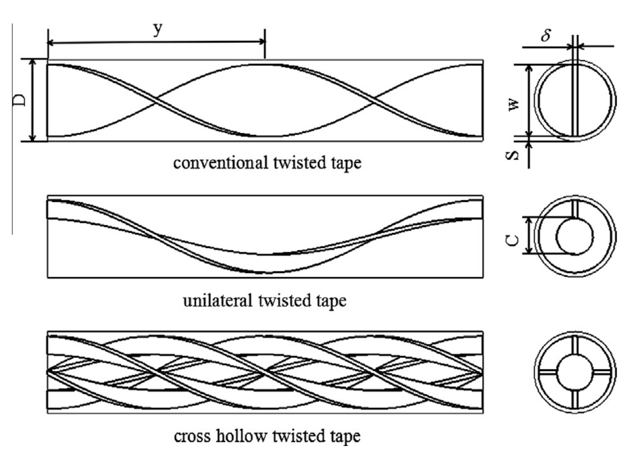

Fig. 1. Tube fitted with conventional, unilateral, and cross hollow twisted tapes.