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3D numerical simulation on the shell side heat transfer and pressure drop performances of twisted oval tube heat exchanger

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ABSTRACT

Twisted oval tube heat exchanger has been widely used in chemical industry field. In the present study, fluid flow and heat transfer characteristics in the shell side of this type of heat exchanger are studied numerically with Realized k–ε model. Influence of the geometrical parameters including twisted pitch length P and aspect ratio A/B on the performance of the shell side are analyzed. Results reflect that Nusselt number and friction factor both increase with the increasing of P and A/B. Their influence on the shell side overall heat transfer performance $h/\Delta P$ is also analyzed. It is concluded that the overall heat transfer performance of the shell side increase with the increasing of A/B. But on the aspect of the influence of P, it firstly increases with the increasing of P and then decreases with the increasing of P. Velocity and temperature distributions, stream traces and secondary flow distributions are presented to make the fluid flow and heat transfer characteristics in the shell side clear at the end of the present work. The magnitudes of the total velocity at the self-supporting points are found to be lower and the temperatures are found to be higher than their neighborhoods. Spiral flow can be found in the shell side especially for the cases with A = 14 mm, B = 5 mm. The intensity of the spiral flow becomes more and more drastic with the increasing of A/B and the decreasing of P. Analysis of the secondary shows that the magnitude of the secondary flow increases with the increasing of A/B and decreases with the increasing of P. Irregular secondary flow can also be found around the helixes which are formed by the twisting of the oval sections.

1. Introduction

It is very important to improve the efficiency of heat exchangers by using heat transfer enhancement techniques both inside and outside tubes. In recent years, great progress has been made in utilizing this technique. From the point of energy cost, promoting the efficiency of heat exchangers can be realized in two ways: promoting the heat transfer coefficient to decrease the heat transfer area, decreasing the pressure drop to save the cost of pump. Most of the heat transfer enhancement techniques aim at promoting the heat transfer coefficient such as the application of fin tube, corrugated tube. However, little attention has been paid on the decreasing of pressure drop. Twisted tube heat exchanger is a type of heat exchanger that aims at promoting the heat transfer coefficient of the tube side and also decreasing the pressure drop of the shell side. Applications of the twisted oval tube in chemical field can also be found in [1,2]. More and more attentions are paid on the performance of the twisted oval tube heat exchanger [2–4].

Tubes that play an important role in this heat transfer enhancement technology are made from smooth round tubes. They are formed into an oval section with a superimposed twist by some special techniques. Two ends of the tubes remain round on the consideration of assembling them with the tube sheet. Sketch of this kind of tube is illustrated in Fig. 1. Geometrical parameters of the twisted oval tube are twist pitch length(P) within which an oval section twists 360°, outer major axis (A) of the oval section and outer minor axis (B) of the oval section. a and b in Fig. 1 are inner major axis and inner minor axis, respectively.

When the tubes are arrayed in the same direction, they can be supported by the tubes themselves but not baffles or rods that a normal shell tube heat exchanger needs. With the tubes arrayed in 60° as described in Fig. 2, the supporting point will form when the oval section twists 60°. It means that there are six supporting points in a twisted pitch length. The flow channel can be divided into six subsections by these points as presented in Fig. 2. The first three subsections are totally the same with other three subsections after. Then a periodic flow channel can be found and the cycle length is half the twist pitch length (P/2). This special geometrical characteristic can form a longitude flow channel which will considerably reduce the pressure drop of the heat exchanger.

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Nomenclature

A	outer major axis, m
A_s	flow area, m^2
a	inner major axis, m
B	outer minor axis, m
b	inner minor axis, m
C_p	isobaric specific heat, J/(kg K)
d_e	hydraulic diameter, m
d_r	smooth round tube diameter, m
f	friction factor
F	heat transfer area, m^2
G	mass flow rate, kg/s
h	heat transfer coefficient, W/m^2 K
H	side length of the hexagonal shell, m
I	Turbulence intensity
j	heat transfer factor
k	turbulence kinetic energy
K	overall heat transfer coefficient, W/m^2 K
L	length of the shell side flow channel, m
l	length from the inlet of the tube, m
l_δ	turbulent length scale, m
m	constants for j and f factor correlations
n	constants for j and f factor correlations
Nu	Nusselt number
Pr	Prantl number
P	twisted pitch length, m
p	pressure, Pa
q	heat flux, W/m^2
Q	heat transfer rate, W
Re	Reynolds number.
T	temperature, K
u, v, w	physical velocity components, m/s
x, y, z	coordinate directions

Greek symbols

β	tube layout angle
ΔP	pressure drop, Pa
ΔT	temperature difference between inlet and outlet, K
ΔT_m	Logarithmic mean temperature difference, K
λ	thermal conductivity, W/(m K)
μ	dynamic viscosity, Pa s
ρ	density, kg/m^3

subscripts

f	friction factor
h	Heat transfer coefficient
i, j	tensor symbol
in	inlet
o	outlet/outer side
s	shell side
t	tube side
w	Wall of the flow channel
ε	turbulence kinetic energy dissipating rate

Experimental studies have been conducted for the purpose of obtaining the heat transfer and pressure drop performance of the twisted tube. In the early stage, Asmantas et al. [5] tested the performance of twisted tube to get the heat transfer and pressure drop correlations. Tests on consideration of the effects of Pr, geometrical parameters on the performance of the twisted tube have also been accomplished in turbulent state [6–8]. Gao et al. [9] also studied the phenomenon of nucleate boiling when the twisted tube technique is combined with porous media. Longitude velocity distribution and secondary flow distribution in the laminar state were studied theoretically by many researchers. Based on the forming of Poiseuille flow, Todd [10] studied the influence of geometrical parameters on the fluid flow. Perturbation method such as coordinate perturbation and parameter perturbation were also applied on the analysis of the flow in a twisted tube [11,12].

Since Bolinder [13] derived governing equation in a helical coordinate with tensor analysis technique, studies on curved pipes with different cross section have been more and more, such as the studies on helical square duct [14], and rotating helical duct [15] and the reliability of solving the governing equations of these pipes with perturbation method has also been analyzed. On the aspect of solving the governing equations, Zhang and Zhang [16] solved the governing equations with perturbation method and investigated the secondary flow in a small twisted tube. With the perturbation method, the first order perturbation component of the secondary flow has been derived.

With the development of numerical method, analysis about the influence of flow field on temperature field in twisted oval tube can also be found. From the point of obtaining the heat transfer and pressure drop correlations Meng et al. [17] studied the flow in a twisted tube numerically at Re = 500–1500. Bishara et al. [18] simulated the laminar flow in a twisted tube. Details of their conclusion can be found in Bishara et al. [19] and Bishara's [20] research. Tan et al. [21] also simulated the heat transfer and fluid flow characteristics in twisted oval tubes recently.

On the aspect of shell side heat transfer and flow, many researches focused on the turbulent intensity [22], boundary layer depth [23] and heat diffusion coefficient [24]. Numerical models for predicting the shell side heat transfer and pressure drop performance of the twisted oval tube heat exchanger has also been published in the past few decades [25]. Based on the shell side heat and fluid flow characteristics of the twisted oval tube heat exchanger,

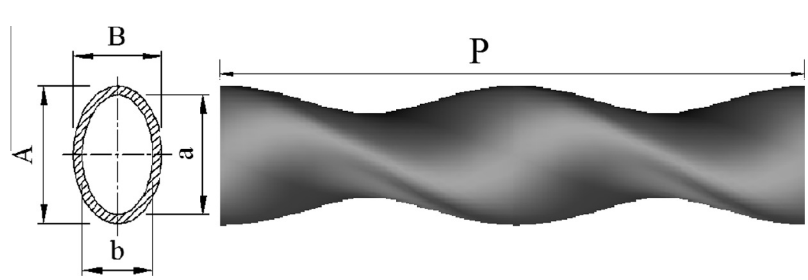

Fig. 1. Sketch of the twisted oval tube.