International Journal of Heat and Mass Transfer 127 (2018) 598–606

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Numerical and experimental investigation of the heat exchanger with trapezoidal baffle

Xin Gu, Yuankun Luo, Xiaochao Xiong, Ke Wang, Yongqing Wang *

Key Laboratory of Process Heat Transfer and Energy Saving of Henan Province, Zhengzhou University, Zhengzhou 450002, China

ARTICLE INFO

Article history:
Received 26 August 2017
Received in revised form 3 July 2018
Accepted 8 July 2018

Keywords:
Shell and tube heat exchanger
Twisty flow
Heat transfer enhancement
Numerical simulation

ABSTRACT

Periodic whole cross-section computation models of shutter baffle heat exchanger and twisty flow heat exchanger were established respectively. The heat transfer coefficient, flow resistance and thermal performance in the shell side are numerically studied. Compared with that of the shutter baffle heat exchanger, the results show that the heat transfer coefficient of twisty flow heat exchanger is improved by 7.3–10.2%, pressure drop decreased by 18.5–21%, and the thermal performance factor TEF enhanced by 14.9–19.2%. The correctness and accuracy of simulation method and results are confirmed by experiments. In addition, the influence of inclination angle of trapezoidal baffle, baffles width, baffles pitch and number of baffles on the heat transfer performance are studied. The results show that the inclination angle of trapezoidal baffles and baffles pitch have a significant effect on heat transfer performance, the effect of baffle width has a secondary effect, and the number of baffles has a less significant effect. The results of this paper provide a new scheme for the structural improvement of the shell and tube heat exchanger, and provide the references for further performance optimization of the twisty flow heat exchanger.

0. Introduction

Shell-and-tube heat exchangers (STHXs) are widely used in power plant, chemical engineering, oil refining, environmental protection, and et al. [1,2]. In the aspect of structural optimization of STHXs, the ways for heat transfer enhancement and flow resistance reduction are mainly focused on the improvement and optimization of the structure of baffle in shell side. For example, using rod baffle, helical baffle, flower baffle, ladder-tape fold baffle, shutter baffle, et al. to replace the segmental baffle [3–5].

Ma et al. [6] studied the influence of the shape and structure parameters of rod baffle on the flow and heat transfer characteristics, and found that the rod baffle with rods of variable sections can improve the comprehensive performance by 13–14%. The helical baffle is made by continuous helical baffle firstly, while the manufacture is very difficult, especially for heat exchangers with a large diameter. Lutcha and Nemcansky [7] proposed a four elliptical sector-shaped joined end to end to from a helical pitch of STHXs with helical baffles(STHXsHB). They found that STHXsHB can increased heat exchanger effectiveness and heat transfer coefficient. Stehlik et al. [8,9] compared the STHXsHB with the STHXs with segmental baffles (STHXsSB). Results showed that the performance of STHXsHB was considerably enhanced, however STHXsHB has obvious triangular leakage zones between two adjacent plain baffles. Maakoul [10] used the numerical simulation method to compare the STHXsSB with the STHX with trefoil-hole (STHXsTH), and the result showed that trefoil-hole baffles enhance considerably the heat transfer, and this enhancement is done at the expense of a large pressure drop. You et al. [11] used the numerical and experimental methods to compare contours between STHXs with flower baffles (STHXsFB) and STHXsSB. It is found that they have different flow patterns, and the STHXsFB has a better overall thermal hydraulic performance than the STHXsSB. Wen et al. [12,13] proposed STHX with ladder-type fold baffle, and found that the shell-side heat transfer coefficient increased. Although the shell-side pressure drop also increases, the comprehensive performance of the improved heat exchanger is enhanced by 28.4–30.7%. Gu et al. [14,15] used the shutter baffle to replace the segmental baffle to decrease dead zone in the back of the segmental baffles and shell-side pressure drop. It is found that comprehensive thermal performance of heat exchangers increased significantly, while the heat transfer coefficient of STHXs with shutter baffles lower than STHXsSB.

In summary, the STHXs have characteristics of high flow resistance, high energy consumption and other structural defects, and should be continue to improve.

---

* Corresponding author.
E-mail address: wangyq@zzu.edu.cn (Y. Wang).

https://doi.org/10.1016/j.ijheatmasstransfer.2018.07.045
0017-9310/© 2018 Published by Elsevier Ltd.

Nomenclature

A	heat transfer area mm^2
B	baffle pitch mm
D	diameter of inner shell mm
d	diameter of tube mm
f	shell-side flow resistance coefficient
h	shell-side heat transfer coefficient $W{\cdot}(m^{-2}\,K^{-1})$
M	shell-side flow rate $kg\,s^{-1}$
Nu	shell-side Nusselt number
Δp	shell-side pressure drop Pa/m
t	temperature K
t_p	tube pith mm
S_{Φ}	generalized source term
W	baffle width mm
θ	inclination angle of baffle (°)
κ	turbulence kinetic energy $(m^2\,s^{-3})$
x,y,z	Coordinate(m)

Re	Reynolds number,ρumdt/μ
u	horizontal component velocity $m\,s^{-1}$
v	vertical component velocity $m\,s^{-1}$
w	axial component velocity $m\,s^{-1}$

Greek symbols

c_p	specific heat J $(kg^{-1}\,K^{-1})$
ε	turbulence kinetic energy dissipation rate$(m^2\,s^{-3})$
ρ	density $kg\,m^{-3}$
μ	dynamic viscosity of viscosity $m^2\,s^{-1}$
λ	thermal conductivity $W{\cdot}(m^{-1}\,K^{-1})$

Subscripts

s	shell side
t	tube side
w	wall

Based on the analysis of the heat transfer performance of the STHXs with different baffles, a kind of shell and tube heat exchanger with trapezoidal baffle is proposed. The structure of trapezoidal baffle is shown in Fig. 1.

The trapezoidal baffle is made of an elliptical plate without two kinds of certain proportion cutting. two or more trapezoidal baffles arranged parallelly as a group, two groups of adjacent trapezoidal baffle orthogonal arrangements as a unit along with tube length direction. When the fluid flows in the shell side, it can induce the fluid flows in the radial and axial periodic alternating flow pattern. The fluid presents is twist-flow in the main flow field in the shell side, which has a significant performance of the heat transfer enhancement and the fluid flow resistance reducing.

1. Numerical simulation of flow field in heat exchanger

1.1. Physical model

Geometric structure in shell side of the STHXs are usually periodic along the fluid flow direction. The whole flow region in shell side can be divided into entrance section, fully developed periodic section and exit section. Generally, most of the flow and heat transfer region belongs to the fully developed periodic section, and flow and heat transfer performance in this section represents basically the whole performance of the shell side. The fully developed periodic section is often selected as the study object [16,17]. With some appropriate simplifications on the geometric structure in shell side, the periodic whole cross-sectional computation model is established. Periodic models of shutter baffle heat exchanger and twisty flow heat exchanger are shown in Fig. 2. The model structure parameters are listed in Table 1.

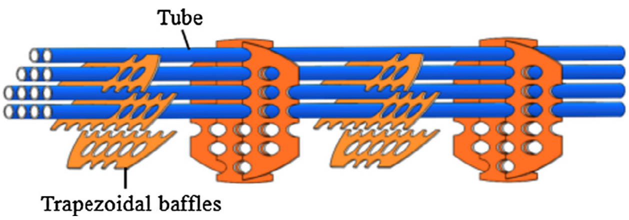


Fig. 1. Trapezoidal baffle of twisty flow heat exchanger.

1.2. Basic control equations

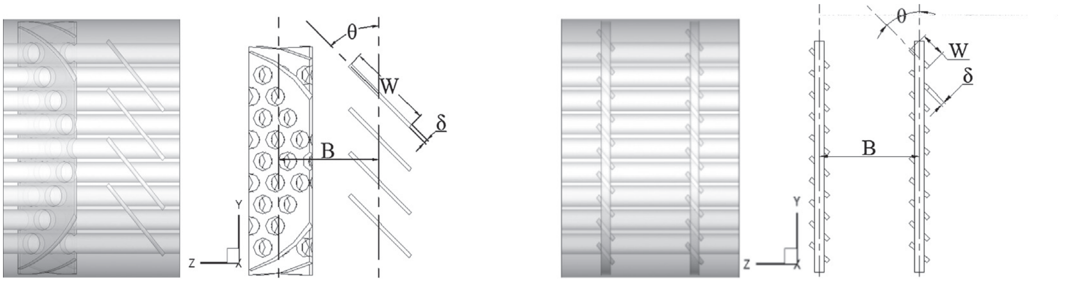
The governing equations for continuity, momentum, energy, k and ε in the computational domain can be expressed as follows:

Continuity equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0; \tag{1}$$

Momentum equation:

$$\begin{aligned}
&\frac{\partial u}{\partial t}+div\ (uU)=div\ (ugrandu)-\frac{1}{\rho}\frac{\partial p}{\partial z};\\
&\frac{\partial u}{\partial t}+div\ (vU)=div\ (vgrandv)-\frac{1}{\rho}\frac{\partial p}{\partial y};\\
&\frac{\partial u}{\partial t}+div\ (wU)=div\ (wgrandw)-\frac{1}{\rho}\frac{\partial p}{\partial z};
\end{aligned} \tag{2}$$



(a)Geometrical model of twisty flow STHX and trapezoidal baffles. (b)Geometrical model of shutter baffles STHX and shutter baffles.

Fig. 2. Geometrical model and schematic diagram of STHX.