Applied Thermal Engineering 67 (2014) 122–130

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Experimental investigation on heat transfer enhancement of a heat exchanger with helical baffles through blockage of triangle leakage zones

Simin Wang [a], Jian Wen [b,*], Huizhu Yang [b], Yulan Xue [b], Hanfei Tuo [c]

[a] School of Chemical Engineering and Technology, Xi'an Jiaotong University, Xi'an 710049, China
[b] School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an 710049, China
[c] Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA

HIGHLIGHTS

- Fold baffles were firstly proposed to block the triangle leakage zones in STHXsHB.
- The flow field and heat transfer performance were investigated.
- The integrative performance of STHXsHB is greatly enhanced by the improved fold baffles.

ARTICLE INFO

Article history:
Received 13 March 2013
Accepted 9 March 2014
Available online 18 March 2014

Keywords:
Heat exchanger with helical baffles
Fold baffle
Triangle leakage zone

ABSTRACT

The configuration of a heat exchanger with helical baffles is improved by the application of fold baffles to block the triangle leakage zones between two adjacent plain baffles. The flow patterns of shell side in the heat exchanger was numerically studied and the results showed that the helical pitch of streamlines decreases and the velocity vectors both in radial and axial directions increase obviously for the configuration improvement. The heat transfer experiments were also performed to evaluate the performance of the improved heat exchanger with fold baffles. The experimental results showed that the shell-side heat transfer coefficient α_0 and overall heat transfer coefficient K are improved by 17.7%–34.2% and 7.9%–9.7%, respectively. The increased thermal flux exceeds the pumping power penalty due to with increased shell-side pressure drop $\triangle$P. And the values of thermal performance factor $\eta_{integrative}$ are all above 1.0, which demonstrates that the better integrative performance that takes into account heat transfer coefficient and pressure drop is obtained through the configuration optimization of baffles. The conclusions are benefit to the optimizing design of heat exchanger with helical baffles for energy conservation.

1. Introductions

Shell-and-tube heat exchangers (STHXs) are important heat and mass exchange apparatus in oil refining, chemical engineering, environmental protection, electric power generation, and et al., since it has the robust construction geometry, easy maintenance and possible upgrades. Segmental baffles are most commonly used in conventional STHXs to support tubes and enhance shell-side heat transfer via creating zigzag flow and turbulence. The major drawbacks of the conventional STHXs with segmental baffles (STHXsSB) are high pressure drop in shell side, fouling resistance caused by dead zone and high risk of flow-induced vibration failure [1–5]. Thus, higher pumping power is often needed to offset the higher pressure drop under the same thermal load. Therefore, it is essential to develop a new type of STHXs with improved baffles and reduce pressure drop while maintaining and even increasing shell-side heat transfer performance.

To overcome the above-mentioned drawbacks of the conventional segmental baffle, STHXs with helical baffles (STHXsHB) were firstly proposed by Lutcha and Nemcansky [6]. The helical baffles in STHXs are shaped approximately as helicoids in order to urge the shell-side fluid to flow in approximately continuous helical flow. They investigated the flow patterns produced by such baffle geometry with different helix angles and found that helical baffles

* Corresponding author. Tel.: +86 13201606129 (mobile); fax: +86 29 82668725.
E-mail address: jianwen@mail.xjtu.edu.cn (J. Wen).

http://dx.doi.org/10.1016/j.applthermaleng.2014.03.017
1359-4311/

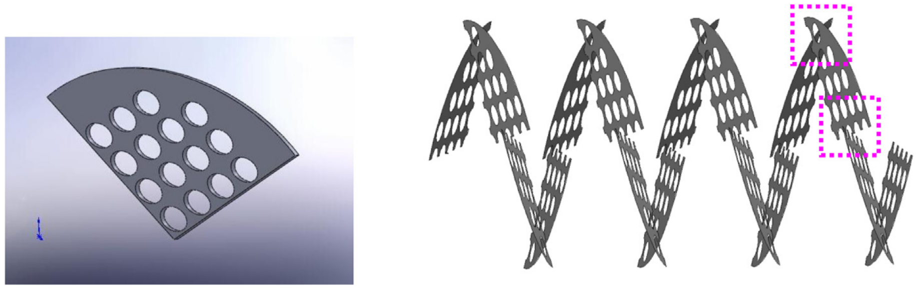

Fig. 1. Configuration of plain baffle.

could force the shell-side fluid to approach plug flow, which increased the average temperature driving force. The flow patterns induced by the baffles also intensified the shell-side heat transfer remarkably. Stehlik et al. have compared heat transfer characteristics between helically baffled and segmentally baffled heat exchangers. Results of single-phase heat transfer and pressure drop tests performed on heat exchanger with helical baffles show considerable advantage in shell side [7].

Up to now, most of helical baffles used in STHXs are noncontinuous approximate helicoids due to difficulty in manufacture. Generally, noncontinuous helical baffles are made by four elliptical sector-shaped plates joined end to end. The interspace between the two adjacent sector-shaped plates, called triangle zone, leads to great fluid leakage. Therefore, the flow in the shell side is not exactly the perfect helical flow, which in turn degrades the heat transfer. Many investigations were performed on STHXsHB, but most of them were focused on the effect of helical pitch, helix angle and connection type of baffles on the performance of the heat exchangers [8–14]. Some improved configurations were also achieved to enhance the performance of STHXsHB, but few of them referred to the decrease of leakage flow [15–17]. It is clear that the blockage of the triangle region can improve the performance. However, very few relevant research works have been reported in open literature [18]. Only Peng et al. [19] and Wang et al. [20] carried out numerical and experimental study of STHXs with continuous helical baffles. Results showed an almost 10% increment in heat transfer coefflcient compared with conventional segmental baffles at the same shell-side pressure drop. It is very difficult in manufacture and installation of the above mentioned continuous helical baffles in STHXs, especially with larger shell diameter. Therefore, the objective of this study is to improve baffle configuration of STHXsHB in order to block the triangle zones and to investigate the heat transfer and pressure drop performance.

In this paper, a new type of fold baffle is proposed to block the triangle leakage zones in shell side of STHXsHB. The shell-side flow patterns of the improved STHX with fold baffles and the original STHX with plain baffles were compared numerically. And in order to validate the advantages of STHXsHB with fold baffles, the comprehensive performance was also experimentally investigated.

2. Mathematical modeling of flow field

2.1. Physical model

In the improved helically baffled heat exchanger, fold baffles are substituted for plain baffles to be installed in the shell side. The two straight edges of the sector-shaped plain baffle are folded in order to be overlapped in installation to block the original triangle leakage zones. The configurations of the two kinds of baffles are shown in Figs. 1 and 2, respectively.

As shown in Fig. 3, a series of plain baffles are installed in shell side to form an original tube bundle and to create approximate spiral flow. To reach the spiral flow in the shell side, the helical baffles are required to have the consistent baffle spacing, the same helix angle α and so on. The improved tube bundle with fold baffles is shown in Fig. 4. The triangle gap between two adjacent baffles is blocked by the fold baffles. The shell-side flow patterns of STHXsHB with two different baffle configurations were numerically studied later.

2.2. Governing equations and boundary conditions

The renormalization group (RNG) $k-\varepsilon$ model of Yakhot and Orszag is adopted in the simulation because the model provides improved predictions of near-wall flows [21,22]. The RNG $k-\varepsilon$ model was derived by a statistical technique called renormalization method, which is widely used in industrial flow and heat transfer because of its economy and accuracy. The governing equations for continuity, momentum, energy, k and ε in the computational domain can be expressed as follows:

Continuity:

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{1}$$

Momentum:

$$\frac{\partial}{\partial x_i}(\rho u_i u_k) = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_k}{\partial x_i}\right) - \frac{\partial P}{\partial x_k} \tag{2}$$

Energy:

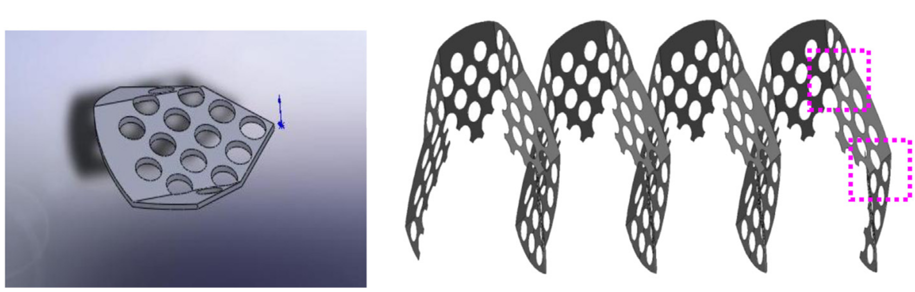

Fig. 2. Configuration of fold baffle.