International Journal of Heat and Mass Transfer 84 (2015) 990–997

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Experimental investigation on performance comparison for shell-and-tube heat exchangers with different baffles

Jian Wen [a], Huizhu Yang [a], Simin Wang [b,*], Yulan Xue [a], Xin Tong [a]

[a] School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an 710049, China
[b] School of Chemical Engineering and Technology, Xi'an Jiaotong University, Xi'an 710049, China

ARTICLE INFO

Article history:
Received 17 July 2014
Received in revised form 29 October 2014
Accepted 26 December 2014
Available online 5 February 2015

Keywords:
Heat exchanger
Helical baffles
Ladder-type fold baffles
Triangular leakage zone
Heat transfer enhancement

ABSTRACT

An improved structure of ladder-type fold baffle is proposed to block the triangular leakage zones in original heat exchangers with helical baffles. The numerical results showed that the distribution of shell-side velocity and temperature in improved heat exchanger are more uniform and axial short circuit flow is eliminated. The experimental results showed that the shell-side heat transfer coefficient α_0 and overall heat transfer coefficient K are improved by 22.3–32.6% and 18.1–22.5%, respectively. The increment in shall-side pressure drop is about 0.911–9.084 kPa, while the corresponding pumping power penalty is about 2–80 W. The thermal performance factor *TEF* enhances by 18.6–23.2%, which demonstrates that the ladder-type fold baffles can effectively improve the heat transfer performance of heat exchangers with helical baffles. The results of this paper are of great significance in the optimal design of the heat exchanger.

1. Introduction

Shell-and-tube heat exchangers (STHXs) are widely used in power plant, chemical engineering, environment engineering, and waste heat recovery due to their robust geometry construction, reliable operation, easy maintenance and possible upgrades [1]. The segmental baffles are often used in STHXs, which forces the shell-side fluid to go through in a zigzag manner. But there are some inherent drawbacks, such as a large shell-side pressure drop and dead zones in the back of segmental baffles, leading to a serious fouling and high risk of vibration failure on tube bundle, etc. [2–6]. Therefore, a new type of STHX is required to solve the problem of heat exchangers with segmental baffles (STHXsSB) mentioned above. STHX with helical baffles (STHXsHB) was firstly proposed by Lutcha and Nemcanskypro in 1990 [7]. They found that the shell-side spiral flow of STHXsHB is closer to plug flow which can lead to an increase in heat transfer temperature difference. Furthermore, the shell-side spiral flow will cause radial velocity gradient, therefore thinning boundary layer and increasing heat transfer coefficient. Bashir et al. [1] found that STHXsHB are able to reduce shell-side fouling. Stehlik et al. [8] and Butterworth [9] have reported that STHXsHB can reduce the flow-induced vibration. Stehlik et al. [8] used experiment methods to compare the STHXsHB with the STHXsSB. Results showed that the performance of STHXsHB was considerably enhanced. Kral et al. [10] compared the performance among five STHXsHB with different helical angles and one STHXsSB. The result showed that the heat transfer coefficient of STHXsHB was higher than that of the STHXsSB, and the helix angle of 40° was the best.

Ideally, the helical baffle is made by continuous helical baffles, while the manufacture is very difficult, especially for heat exchangers with large diameter. The conventional STHXsHB are usually made by four elliptical sector-shaped plain baffles joined end to end to form a helical pitch. Each baffle occupies one-quarter of the cross section of the heat exchanger and is angled to the axis of the heat exchanger. However, there are obvious triangular leakage zones between two adjacent plain baffles, which cause a short-circuit leakage in the shell side. The leakages shunt main spiral medium flow and decrease the medium flow velocity, which in turn degrades the heat transfer performance of STHXsHB [11,12]. The triangular leakage of STHXsHB would change the flow pattern in the shell-side fluid from a spiral flow to an axial flow, which will reduce the flow distance of the medium and thus weaken the heat transfer. A lot of researchers devoted themselves to the heat transfer enhancement in STHXsHB, but most of efforts were focused on the effect of helical pitch, helix angle and connection type of baffles [5,7,8,10,13]. Only few attempted to the decrease of leakage flow [11,14–17]. Peng et al. [14] used the continuous helical baffle to block triangular gaps and found that continuous helical baffle increased the heat transfer coefficient

---

* Corresponding author.

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2014.12.071
0017-9310/

Notation

Latin symbols

S	the distance of bend to the center, mm
R	radius, mm
u	fluid velocity in shell side, m s^{-1}
Re	Reynolds number, $\rho u_m d_t/\mu$
m	mass flow rate, kg s^{-1}
A_m	the minimum transverse area, m^2
B	baffle pitch, mm, $\sqrt{2}D_s \tan\beta$
D_s	diameter of inner shell, mm
D_{otl}	diameter of the tube bundle-circumscribed circle, mm
d_o	outer diameter of tube, mm
d_i	inner diameter of tube, mm
t_p	tube pith, mm
α_0	shell side heat transfer coefficient, W·(m^{-2} K^{-1})
K	overall heat transfer coefficient, W·(m^{-2} K^{-1})
A	heat transfer area, m^2, $N\pi d_t L_s$
Δt_m	logarithmic mean temperature difference, K, $\frac{\Delta t_{\max}-\Delta t_{\min}}{\ln(\Delta t_{\max}/\Delta t_{\min})}$
N	number of tubes
L_s	length of tube, mm
t	temperature, K
Nu	Nussle number, hd/λ
ΔP	pressure drop, kPa
f	flow resistance coefficient

Greek symbols

α	bend angle, °
c_p	specific heat J·(kg^{-1} k^{-1})
μ	dynamic viscosity of viscosity, m^2 s^{-1}
ρ	density, kg m^{-3}
λ	thermal conductivity, W·(m^{-1} k^{-1})
β	helix angle,°
Φ	heat exchanger quantity, W
ψ	correct factor for the logarithmic mean temperature difference

Subscripts

s	shell side
t	tube side
w	wall

by about 10%. However, such continuous helical baffles are difficult in manufacture, especially for the heat exchanger with large diameter. Wang et al. [15] proposed the triangular plates to stuff the triangular gaps. The experimental results demonstrated that the heat transfer coefficient was almost unchanged, while the shell-side pressure drop increased significantly. Song et al. [16] designed an anti-shortcut baffle structure that widened the straight edges of the plain baffles to accommodate one or two rows of tube pitch. Experimental results showed that the structure could decrease the triangular leakage and improve the heat transfer performance. Wang et al. [11] used the fold baffle to replace the plane baffle to block the shell-side triangular leakage of STHXsHB. It was found that the overall heat transfer coefficient of heat exchanger increased. Wen et al. [17] proposed the fold helical baffles to block the triangular leakage. The numerical results found that the structure can effective improve the performance of STHXsHB.

Shell-side triangular leakage zones in STHXsHB need to be addressed properly for further improvement of the performance. In this paper, a novel ladder-type fold baffle is proposed to block the triangular leakage zones. There are only two ladder-type fold baffles required to form a helical pitch in the improved design, while four elliptical sector-shaped plain baffles are required for the original STHXsHB. Therefore the improved design is convenient in localization and installation. The shell-side flow patterns of the improved STHX with ladder-type fold baffles and the original STHX with plain baffles were compared numerically. In addition, an experimental investigation was also performed to study heat transfer performance of the improved STHXsHB.

2. The configuration of the improved baffles

As shown in Fig. 1a, the original elliptical sector-shaped plain baffles is cut off a standard ellipse, symmetrically with respect to the minor axis. The cut off angle of the baffle sector should be larger than 90° and varies with the helix angle β. While the projection angle of the baffle onto the normal cross-section of the heat exchanger is 90°. As shown in Fig. 1b, the novel ladder-type fold baffle is formed from folding a flat panel twice, which consists of three planes. The plane A and plane C are perpendicular to the axis of the tube bundle. The folding angles between the different planes are the same, denoted as α. The folding ratio φ is the ratio of the distance S to the projection radius R ($\varphi = S/R$). The baffle height ω is ratio of the baffle height H to the projection diameter D ($\omega = H/D$).

Fig. 2 demonstrates the installation of the baffles in the tube bundle of heat exchangers. It can be clearly observed that there are two triangular leakage zones forming an X-shape between the two adjacent original plain baffles. However, the straight edges of the two adjacent ladder-type fold baffles are overlapped to accommodate several rows of tube pitch and two fold planes are made by bending both sides of the baffle, making the two adjacent ladder-type fold baffles connected closely.

3. Periodical modeling of heat exchangers

A validated CFD method can provide detailed information in heat exchangers and the rapid development of CFD commercial code is making the numerical simulation of the complex heat exchanger becomes possible. However, it is time consuming by the present computer resource to simulate the whole STHXsHB. Periodic flow often occurs when the physical geometry is periodically repeating [18]. Zhang found that the fluid flow in the shell side of STHXsHB can reach fully developed region very quickly and one cycle of STHXsHB is enough to investigate its performance [19]. Therefore the periodic model with two cycles will be used to study the shell-side performance of STHXsHB.

3.1. Physical geometry and mesh generation

The geometrical parameters of the STHXsHB are the same with experimental model. Tube bundle consists of 40 tubes with the diameter of 19 mm and is fixed with 12 tie rod. The shell-side length is 230 mm with two cycles. The geometrical model of STHXsHB with adder-type fold baffles is shown in Fig. 3.

The computational domain was meshed with unstructured tetrahedral grids using ICEM CFD because of the complexity of the configurations. To accurately simulate the near-wall region, the prism meshes were generated in the tubes regions. A series of grid independence tests have been conducted. The grid numbers for the improved STHXsHB and the original were 6,482,355 and 6,299,216, respectively. The local front view of grid is shown in Fig. 4.