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Comprehensive effects of baffle configuration on the performance of heat exchanger with helical baffles

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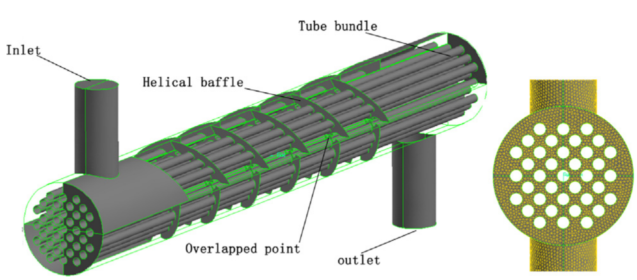
HIGHLIGHTS

- Flow and thermal performances of six helical baffle heat exchangers are analyzed.
- The distribution of h_s in whole shell-side is demonstrated.
- The flow characteristics of two connection method of baffles are compared.
- The optimal helix angle is analyzed by synergy principle.

GRAPHICAL ABSTRACT



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ABSTRACT

In this paper, non-continuous helical baffles heat exchangers with different helix angles and different connection methods, i.e. including continuous connection method and middle-overlapped method, between two adjacent sections have been simulated by using commercial software of GAMBIT and FLUENT. To explore the comprehensive effects of helix angles and connection way of baffles on the performance of heat exchangers, three kinds of helix angles (20°, 30°, 40°) were chosen. Six heat exchanger models were established to cover the chosen helix angles and two connection methods. To minimize the influence of unrelated factors on analysis results, same geometrical parameters and thermo-physical conditions were used. Therefore the six models with the same geometrical model were simulated with different volume flow rates. Analysis results showed that: the larger helix angle contributes to lower heat transfer rate and lower pressure drop; among all simulated models, heat exchanger with 40° helix angle have the highest heat transfer coefficient per unit pressure drop. Continuous connection method contributes to small local resistance and pressure drop and it has better performance than middle-overlapped method when consuming same pumping power.

1. Introduction

Heat exchangers contribute to many industrial areas significantly, such as petroleum refining, chemical engineering, food processing, and nuclear power plant etc. Among all types of heat exchangers, shell-and-tube heat exchangers (STHXs) are the most widely used. According to Master et al. (2006) more than 35–40% of heat exchangers are shell-and-tube type due to their robust geometry construction, easy maintenance and possible upgrades. In the past decades, a series of improvements had been adopted to obtain a better performance of STHXs with segment baffles. However the major drawbacks still remain (Stehlík and Wadekar, 2002): (1) It causes a large shell-side pressure drop; (2) The zigzag flow results in a dead zone behind each segment baffle, leading to an increase of fouling resistance and decrease of heat transfer rate; (3) The cross flow causes high risk of vibration failure on tube bundle.

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Nomenclature

A_o	heat exchanger area based on the outer diameter of tube
B	baffle pitch (mm)
c_{ps}	specific heat (J/kg K)
d_o	outer diameter of tube (mm)
D_i	inside diameter of shell (mm)
D	diameter of tube bundle-circumscribed circle (mm)
h_s	heat transfer coefficient (W/m^2 K)
k	turbulent kinetic energy
l	effective length of tube (mm)
M_s	mass flow rate (kg/s)
n	tube number
N_u	N_u number
N_P	work efficiency of the pressure gradient
Q_s	heat transfer rate (J)
q	volume flow rate (m^3/s)
R_e	R_e number
S	cross-flow area at the shell centerline (mm^2)
∇t_m	logarithmic mean temperature difference (K)
t_w	average temperature of tube (K)
t_p	tube pitch (mm)
u	mean velocity of the shell-side (m/s)

Greek symbols

β	helix angle
α	overlapped space
ε	turbulent energy dissipation
ρ	fluid density (kg/m^3)
μ	fluid dynamic viscosity (Pa s)
λ	thermal conductivity (W/m K)
θ_T	intersection angle between velocity and temperature gradient
θ_p	intersection angle between velocity and pressure gradient

Subscripts:

in	inlet
out	outlet
s	shell side
t	tube side
w	wall

As a consequence, the segment baffles cause a reduction in the net heat transfer and STHXs furnished with segment baffles can hardly meet recent demands of high thermal efficiency.

Helical baffles proposed and developed by Lutcha and Nemcansky (1990) helps in alleviating the principal shortcomings of the conventional design. The helical baffle is usually classified into two types, i.e. continuous and discontinuous. Fluid flows through the tube bundles in an ideal helical manner in a continuous helical baffle STHXs, but this type of baffle is difficult to manufacture. Up to now helical baffles actually used in STHXs are discontinuous types (Wang et al., 2010), in which fluid flows in a pseudo-helical manner. Four triangular-shaped plates out of an elliptical plate are arranged in a pseudo-helical baffle system, forming one cycle of a helical path. Each baffle occupies one quadrant of the heat exchanger's shell cross section and is angled to the axis of the heat exchanger (β shown in Fig. 1 is the helix angle). Adjacent baffles touch at the perimeter of each sector, forming an end-to-end continuous connection. Another connection between two adjacent sectors is the middle-overlapped connection as shown in Fig. 1. The overlapped space between two adjacent sectors is presented by:

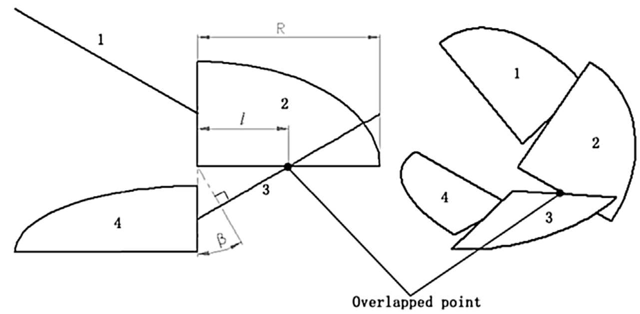

Fig. 1. Definition of overlapped space.

$$\alpha = \frac{l}{R}, \tag{1}$$

where l is the distance from overlapped point to the axis of heat exchanger as shown in Fig. 1 and R is the inner radius of the shell.

In recent years, many researches have been done to investigate the effects of helical baffle configuration on the performance of STHXs. Nemati Taher et al. (2012) made a comparison between different baffles space and found that the most extended baffles space contributed to higher heat transfer rate, and the pressure gradient decreased with the increase of baffles space. Other researchers (Jafari Nasr and Shafeghat, 2008; Kral et al., 1996; Lei et al., 2008) studied the effect of helix angles by simulation and experiment. Their results suggested that STHXs with helical baffles had higher heat transfer coefficient than STHXs with segmental baffle at the same consumption of pumping power. Zhang et al. (2009) studied the helix angle experimentally and found that an angle of 40° has better performance than the other. However, heat exchangers used in the experiment are all middle-overlapped connected which can't show the performance of other baffles configuration like continuous connection baffles. Besides, parameters like baffle numbers (n) in one cycle was studied by Du et al. (2014). It turns out that sextant sector plates reduce the leakage flow in the triangle area effectively and it reduced pressure drop of shell-side compared to quadrant and trisection sector plates. Other researchers proposed new baffle configuration to improve heat transfer rate. Yang et al. (2015) proposed a combined single shell-pass shell-and-tube heat exchanger with two-layer continuous helical baffles and it can improve heat transfer by enhancing turbulence and local mixing on the shell side of heat exchanger. Dong et al. (2014) studied heat transfer characteristics in four trisection helical baffle heat exchangers with different adjacent baffle connections, results showed that the local heat transfer coefficient on the center tube is much higher than that on the peripheral tubes and the circumferential overlap connection are the highest among the four baffles connections. Wang et al. (2014) eliminated the leakage zones between two adjacent plain baffles through fold baffles, and it increased heat transfer coefficient by 8.7% averagely. Much attention has been paid to the effect of helix angle on the performance of STHXs, while few literatures address the importance of overlapped space. It controls the leakage flow between adjacent baffles, which affects heat transfer rate and flow resistance dramatically in larger flow rate. Besides, helix pitch is also related to overlapped space by the following equation Li et al. (2007):

$$B = \alpha n D_s \sin\frac{\pi}{n}\tan\beta \tag{2}$$

where α is overlapped space between two adjacent sectors defined in Eq. (1), n is the number of baffles in one cycle, D_s is the shell inner diameter and β is the helix angle.

It is clear that helix angle is a vital parameter in optimization design of helical heat exchangers and small helix angle leads to