Applied Thermal Engineering 80 (2015) 328–338

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research paper

Flow and heat transfer performances of helical baffle heat exchangers with different baffle configurations

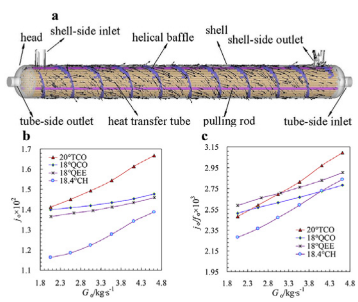
Cong Dong [a, b], Ya-Ping Chen [a, *], Jia-Feng Wu [a]

[a] School of Energy and Environment, Southeast University, Nanjing 210096, China
[b] School of Mechanical and Automotive Engineering, Zhejiang University of Science and Technology, Hangzhou 310023, China

HIGHLIGHTS

- Flow and thermal performances of four helical baffle heat exchangers are simulated.
- Special slices are constructed to obtain pressure and velocity nephograms.
- Local heat flux on tubes T1–T9 and tube layers N1–N4 is analyzed.
- Second flow and V-notch leakage are clearly depicted.
- 20°TCO scheme shows the strongest competition with an anti-shortcut structure.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 17 April 2014
Accepted 28 January 2015
Available online 7 February 2015

Keywords:
Helical baffle heat exchanger
Trisection configuration
Quadrant configuration
Continuous configuration
Circumferential overlap configuration
Secondary flow

ABSTRACT

The flow and heat transfer performances of four helical baffle heat exchangers were numerically simulated. The exchangers exhibited an approximate spiral pitch and different configurations, i.e., a trisection circumferential overlap baffle scheme with a baffle incline angle of 20° (20°TCO), a quadrant circumferential overlap baffle scheme with a baffle incline angle of 18° (18°QCO), a quadrant end-to-end baffle scheme with a baffle incline angle of 18° (18°QEE), and a continuous helical baffle scheme with a baffle helical angle of 18.4° (18.4°CH). Velocity vectors superimposed pressure nephogram for meridian slice M1, transverse slices f and f1, and superimposed velocity nephogram for unfolded concentric combination slices CS2 and CS3 are presented. The heat transfer enhancement mechanisms of secondary flow were analyzed. Curves describing the local average heat fluxes of heat transfer tubes T1–T9 within a 60° sector region and those of concentric heat transfer tube layers N1–N4 are presented. The results show that the 20°TCO scheme possesses the best market application value for its highest shell-side heat transfer factor j_o and average comprehensive index (j_o/f_o). The 18.4°CH scheme performs difficulty in manufacturing with continuous helical baffle but exhibits the worse performances in terms of j_o and (j_o/f_o).

1. Introduction

Shell-and-tube heat exchangers are robust in handling high-temperature and high-pressure media fluids and flexible in meeting almost any process requirement. Thus, these exchangers are widely used in, for instance, petroleum refining, chemical

* Corresponding author. Tel.: +86 13851729402.
E-mail address: ypgchen@sina.com (Y.-P. Chen).

http://dx.doi.org/10.1016/j.applthermaleng.2015.01.070
1359-4311/

engineering, power plants, and food processing, and most are of the segment baffle type, which has many advantages, such as simple structure, ease of manufacturing, convenient installation and advanced design. However, segment baffle type heat exchangers have many fatal drawbacks, including stagnant zones with lower heat transfer coefficients, higher pressure drops, and a propensity to induce vibration and fouling. These weaknesses could be solved by applying the innovative design of quadrant helical baffle heat exchangers.

Since the advent of quadrant helical baffle heat exchangers, many researchers have studied this novel type of heat exchanger, and most studies have focused on the optimum incline angle or helical angle of the sector baffles and the configurations of adjacent baffles. Lutcha et al. [1] predicted that the shell-side flow pattern in helical baffle heat exchangers is very close to that of plug flow. They also indicated that the optimum helical angle of the sector baffles is 40° and that the segment baffle scheme is the worst in terms of the behavior exhibited by the shell-side heat transfer coefficient versus pressure drop. Kral et al. [2] examined five helical baffle heat exchanger schemes and a segmental baffle scheme through water-to-water heat transfer performance experiments. Stehlik et al. [3] reviewed three helical baffle arrangements, finally they concludes that axial overlap baffles can counter to minimize the bypass stream at adjacent baffles and reduce the tube support spans. Andrews et al. [4] developed a three-dimensional CFD method based on the distributed resistance concept as well as volumetric porosity and surface permeability to simulate flow and heat transfer in helical baffle exchangers. The simulation results were compared with experimental value, which showed good agreement. Zhang et al. [5] experimentally measured the shell-side flow and heat transfer characteristics of a series of middle overlapped quadrant helical baffle heat exchangers and found that the best scheme is the one with an inclined angle of 30°. However, the four schemes of helical heat exchangers tested were of different tube lengths and cylinder diameters. Nevertheless, Nemati Taher et al. [6] numerically examined five helical baffle heat exchangers of 40° inclined angles with different baffle spaces and found the comprehensive index decreases with the increase in the axial overlap size.

Because the quadrant baffle scheme is more suitable for use with square tube layouts, Chen et al. [7] proposed circumferential overlap trisection helical baffle heat exchangers for the most commonly used equilateral triangle tube layout, and the anti-shortcut baffle structure by widening the straight edges of the sector baffles with one row of tubes in the triangular area of adjacent baffles can effectively improve the heat transfer performance. Several water–water heat transfer performance tests [8] demonstrated that the circumferential overlap trisection scheme with an inclined angle of 20° is better than the segmental baffle scheme in terms of both the shell-side heat transfer coefficient and the shell-side heat transfer coefficient per unit pressure drop for four single thread schemes with baffle inclined angles of 20°, 24°, 28°, and 32° and a dual thread scheme with a baffle inclined angle of 32°.

With respect to continuous helical baffle heat exchangers, Peng et al. [9] and Wang et al. [10] experimentally studied continuous helical baffle heat exchangers compared with the non-continuous helical baffle schemes and segmental ones, and showed that the performance gain of the continuous helical baffle heat exchangers are rather limited. Zeng et al. [11] experimentally studied two continuous helical baffle heat exchangers with middle and tangential inlet/outlet, and found these two schemes performed worse than both schemes of the quadrant helix baffles and segment baffles in terms of comprehensive index.

As the question what kind of baffle conjunction structure of helical baffle heat exchangers performs better, thus the question still remains [12–20]. Which schemes perform better, the continuous helical baffle scheme or the non-continuous scheme? The trisection baffle scheme or the quadrant baffle scheme? In this study, four helical baffle heat exchangers, such as 20°TCO, 18°QCO, 18°QEE (adjacent baffles touch at the perimeter) and 18.4°CH were compared. The heat exchangers exhibited an identical equilateral triangle tube layout and approximate spiral pitch with different baffle shapes and assembly configurations.

2. Computation model

2.1. Physical model

The sample of whole geometric model for 20°TCO scheme with shell-side flow field and four kinds of baffle configurations are shown in Fig. 1. The detailed geometric parameters of four helical baffle heat exchangers are listed in Table 1. The computational domain of the helical baffle heat exchanger is simplified with only 34 heat transfer tubes, 3 rods, 10 groups of helical baffle cycle, one shell, and inlet or outlet nozzles for both shell and tube sides, as shown in Fig. 1(a). The 3D schematics of four studied baffle configurations for 20°TCO, 18°QCO, 18°QEE and 18.4°CH schemes are shown in Fig. 1(b)–(e), respectively.

The TCO scheme is a design with an equilateral triangle tube layout exhibiting an anti-shortcut structure, and the straight edges of each sector baffle cut between tube rows, whereas those of both the QCO and QEE schemes are lined with partial holes, which makes the manufacture of the baffles complicated. The difficulty in manufacturing continuous helical baffles is clear, not only in forming the curve shaped of the baffles but also in drilling the holes.

2.2. Control equations [6,21–25]

The computational domain of studied four helical baffle heat exchangers are numerical simulated by using commercial CFD code of software FLUENT. The conservation equations for mass, momentum and energy are stated as Equations (1)–(3).

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 equations:

$$x-\text{momentum}\ \frac{\partial(\rho u)}{\partial t}+\operatorname{div}(\rho u U)=-\frac{\partial p}{\partial x}+\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{yx}}{\partial y}+\frac{\partial \tau_{zx}}{\partial z}+F_x \tag{2a}$$

$$y-\text{momentum}\ \frac{\partial(\rho v)}{\partial t}+\operatorname{div}(\rho v U)=-\frac{\partial p}{\partial y}+\frac{\partial \tau_{xy}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}+\frac{\partial \tau_{zy}}{\partial z}+F_y \tag{2b}$$

$$z-\text{momentum}\ \frac{\partial(\rho w)}{\partial t}+\operatorname{div}(\rho w U)=-\frac{\partial p}{\partial z}+\frac{\partial \tau_{xz}}{\partial x}+\frac{\partial \tau_{yz}}{\partial y}+\frac{\partial \tau_{zz}}{\partial z}+F_z \tag{2c}$$

Energy equation:

$$\frac{\partial(\rho T)}{\partial t}+\operatorname{div}(\rho U T)=\operatorname{div}\left(\frac{\lambda}{C_p} gradT\right)+S_T \tag{3}$$

The RNG $k-\varepsilon$ turbulent viscosity model is applied to simulate fluid flow and heat transfer for helical baffle heat exchangers. The