Energy Conversion and Management 113 (2016) 143–152

Contents lists available at ScienceDirect

Energy Conversion and Management

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

An efficient and low resistant circumferential overlap trisection helical baffle heat exchanger with folded baffles

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ARTICLE INFO

Article history:
Received 31 August 2015
Accepted 23 January 2016

Keywords:
Heat transfer enhancement
Helical baffle heat exchanger
Trisection helical baffles
Circumferential overlap
Folded baffles

ABSTRACT

An efficient and low resistant circumferential overlap trisection helical baffle shell-and-tube heat exchanger with folded baffles (cothHXf) is presented. It is a modified trisection helical baffle heat exchanger with folded helical baffles for setting rods-and-spanning sleeves. It not only inherits all the merits of circumferential overlap helical baffle scheme, but also adds many additional advantages, such as supporting the inclined baffles with the least rods, simplifying the manufacturing process of spanning tubes and effectively inhibiting the reverse leakage at triangular areas between adjacent baffles. The improved flow characteristic and heat transfer enhancement mechanism of this heat exchanger were numerically investigated in comparison with conventional segmental baffles shell-and-tube heat exchanger (segHX). The flow fields within triangular area of adjacent baffles and nearby regions were depicted. The impacts of the folded baffles on shell-side helical flow, secondary vortex flow, and leakage pattern were analyzed. The distribution configurations of fields of velocity, pressure, temperature and local heat flow rate were revealed. The results show that the heat transfer performance and comprehensive performance evaluation indexes of the cothHXf are much better than those of the segHX while the pressure drop of the cothHXf is much lower than that of the segHX. The numerical simulation results of vivid distributions of flow and thermal fields of the cothHXf can provide theoretical basis for an engineering design and popularized industrial application of the new type heat exchangers.

1. Introduction

Shell-and-tube heat exchangers are widely used in chemical industry. And the segment baffle shell-and-tube heat exchanger (segHX) is the most popular one. However, it holds the drawbacks of stagnant zones, higher pressure drop, propensity of inducing vibration and fouling. The helical baffle heat exchangers, firstly invented by Lutcha and Nemcansky [1] with quadrant helical baffle type and later developed to many modification forms, have many positive features such as eliminating stagnant flow regions, inhibiting tube bundle vibration damage and fouling as well as decreasing shell-side pressure drops, and have the potential to replace the segHX in the application of energy saving, conversion and utilization. Wang et al. [2,3] and Pan et al. [4] reviewed the research developments and applications of the heat transfer intensification technique of helical baffle heat exchangers in process industry of energy conversion and utilization.

Baffles are the core component of a helical baffle heat exchanger that decides its shell side heat transfer performance, although the structure of the baffle seems very simple. The optimal inclination angle or helical angle of helical baffle heat exchanger has been widely studied. Gao et al. [5] experimentally studied the flow resistance and heat transfer of five discontinuous helical heat exchangers, and confirmed that the heat exchanger with 40° helical angle presents the optimal comprehensive performance. Chen et al. [6] conducted performance tests on both oil–water and water–water heat transfer of five small inclined angle heat exchangers. And the 12° inclined angle scheme performs the best. The results show that it is no need to pursue large inclined angle for small flow rate at shell side.

Different analytical methods of performance of helical baffles heat exchanger were also presented. He et al. [7] applied second-law based thermodynamics analysis to evaluate two shell-and-tube heat exchangers. Their conclusion is that axial overlap helical baffle one is superior to the segmental baffles one. Saeedan and Bahiraei [8] adopted neural network of two-objective optimization to find optimum helical angle and axial overlap.

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http://dx.doi.org/10.1016/j.enconman.2016.01.055
0196-8904/

Nomenclature

A	heat transfer area based on the outer diameter of tube (m^2)
c	specific heat ($J\ kg^{-1}\ K^{-1}$)
d	tube diameter (m)
G	flow rate ($kg\ s^{-1}$)
h	heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
K	overall heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
k	turbulence kinetic energy ($m^2\ s^{-2}$)
p	pressure (kPa)
P	pump power (kW)
Pr	Prandtl number
Q	heat transfer rate (kW)
S_Φ	generalized source term
T	temperature (K)
U	velocity vector ($m\ s^{-1}$)
v	velocity ($m\ s^{-1}$)

Greek symbols

Γ_Φ	generalized diffusion coefficient
Δp	pressure drop (kPa)
Δt	temperature difference (K)
ε	turbulence kinetic energy dissipation rate ($m^2\ s^{-3}$)
ρ	density of fluid ($kg\ m^{-3}$)
λ	thermal conductivity ($W\ m^{-1}\ K^{-1}$)
μ	dynamic viscosity (Pa s)
Φ	universal variables

Subscripts

t	tube side
s	shell side
sim	simulation
exp	experiment
f	fluid
w	wall
m	logarithmic mean

Abbreviations

BV	adjacent baffles with blocked V-notches structure
CO	adjacent baffles with circumferential overlap structure
EE	adjacent baffles with end-to-end structure
MO	adjacent baffles with middle axial overlap structure
BS	one cycle of the heat exchanger

A set of novel types of helical baffle heat exchangers have been proposed by changing baffle shapes or connection configurations to enhance the performance. Stehlik and Wadekar [9] suggested adopting axial overlap with greater helical angled baffles to increase the heat transfer coefficient. Zhang et al. [10–13] studied various schemes of axial overlap helical baffle heat exchangers and presented the correlation formulae and method for design and evaluation. Nemati Taher et al. [14] conducted the simulation on the axial overlap helical baffle heat exchangers and the results indicate that for the same mass flow rate, the heat transfer per unit area decreases with the increase of baffle spaces; however, for the same pressure drop, the most extended baffle space obtains higher heat transfer. Yang et al. [15] carried out a numerical investigation on the Nusselt number of helical baffle heat exchanger by altering the number and width of the sealing strips on shell side and the results show that the sealing strips can effectively improve the heat transfer performance.

In recent years, the engineering application results presented by Zeyninejad Movassag et al. [16], Tasouji Azar et al. [17] and Zhang et al. [18] show that the axial overlap helical baffle heat exchangers perform better comprehensive performance of unit pressure heat transfer coefficient but lower heat transfer coefficient than those of the segmental baffles ones. Liu et al. [19] studied exhaust gas recirculation helical baffle cooler with spiral corrugate tubes and compared with segmental baffles cooler with smooth tubes, and found that the former gets better performance over the latter.

Wang et al. [20] and Lei et al. [21] studied continuous helical baffle heat exchangers and demonstrated that the continuous helical baffle heat exchangers have better heat transfer performance than that of segmental baffles ones. Zhang et al. [22–26] investigated the heat transfer characteristics of integral heat transfer enhancement techniques at both shell and tube sides (low-fin tubes, rib-shaped fin tubes and petal-shaped finned tubes) of helical baffle heat exchangers and discussed the mechanisms of heat transfer intensification. The results indicate that the performances of the helical baffle heat exchangers with these enhanced tubes are higher than that of the bare tube ones. Some complex helical baffle structures were developed such as multiple shell-pass continuous helical baffle heat exchangers by Lei et al. [27], Chen et al. [28] and Wang et al. [29–31] which seem too difficult to be applied.

The leakage at triangle area is regarded as major deficiency of the non-continuous helical baffle heat exchangers, and improving the conjunction configuration is the hot issue to improve the performance of helical baffle heat exchangers. Several novel heat exchangers were put forward, such as the sextant helical baffle heat exchanger was proposed by Du et al. [32], the fold baffles helical baffle heat exchanger was designed by Wang et al. [33] and the improved fold baffles helical named ladder-type fold baffle was proposed by [34,35]. Chen et al. [36] invented trisection helical baffle heat exchanger with circumferential overlap structure (cothSTHX), the circumferential overlap structure is a perfect design to restrict triangle leakage and promote the heat transfer performance. Dong et al. [37] numerically compared four baffle shape or connection configurations of trisection helical baffle heat exchangers. The results show that the circumferential overlap (CO) scheme, with one row tubes damper the leakage flow at V-notch of adjacent baffles, has better performance than the conventional end-to-end (EE) scheme, and it has the highest shell-side heat transfer coefficient and comprehensive indexes; the blocked V-notches (BV) scheme has the highest pressure drop and the worst comprehensive indexes; and the middle axial overlap (MO) scheme has the lowest values of both shell-side heat transfer coefficient and pressure drop and the second highest comprehensive indexes. The average values of comprehensive index $h_o/\Delta p_o$ of CO scheme in the calculated range is respectively 16.5%, 27.3% and 13.5% higher than that of the EE, BV and MO schemes. Dong et al. [38–41] also made a lot of experimental and numerical simulation research for different helical baffle heat exchangers.

In this paper, the mathematical models of the cothHXf with baffle angle of 28.5° and the segHX are established by GAMBIT 2.4.6 version and numerically simulated by ANSYS FLUENT 16.2 version. The heat transfer coefficient and resistant of circumferential overlap structure were analyzed to provide methodic assistance for design and application of the new type helical baffle heat exchanger.