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Investigation on combined multiple shell-pass shell-and-tube heat exchanger with continuous helical baffles

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ABSTRACT

A combined serial two shell-pass shell-and-tube heat exchanger (CSTSP-STHX) with continuous helical baffles has been proposed to improve heat transfer performance. This CSTSP-STHX separates the shell side into two individual shell passes. The inner shell pass is conventional segmental baffled, and the outer shell pass is continuous helical baffled. The working fluid flows through the outer and inner shell passes in sequence. The thermo hydraulic performances of CSTSP-STHX are experimentally compared with the double shell-pass shell-and-tube heat exchanger with segmental baffles (SG-STHX). The results show that the CSTSP-STHX gets greater shell-side heat transfer coefficient and pressure drop, furthermore it also has better heat transfer coefficient under the same pressure drop than those of the SG-STHX. Finally it should be emphasized that the leakage on annulus separator has to be as possible as reduced. The present studies are beneficial for the design and practical operation of CSTSP-STHX.

1. Introduction

Conventional shell-and-tube heat exchangers with segmental baffles (SG-STHX) are still the most widely used in various industrial processes. However, the disadvantages become more and more obvious [1,2]: (1) high pressure drop on shell side; (2) low heat transfer efficiency and fouling in dead zones; (3) high risk of vibration failure on tube bundle.

In order to overcome the above-mentioned drawbacks of the conventional segmental baffles, helical baffles were proposed by Lutcha and Nemcansky [3] to obtain higher heat transfer coefficient, lower pressure drop, reduced fouling factor and possibility of tube bundle vibration [4,5]. Stehlik and Kral did lots of wonderful original research work on helical baffled shell-and-tube heat exchangers [6,7]. Then “HELIXCHANGER” [8] was commercial produced by ABB Heat Transfer. Many research studies have been conducted on shell-and-tube heat exchanger with discontinuous helical baffles (DCH-STHX). Typical experimental studies of this subject since the year of 2000 are listed in Refs. [9–14] about heat transfer performance and [15] about hydrodynamic. And typical progresses in simulations of DCH-STHX can be found in Refs. [16,17] about circumferential overlap trisection helical baffled heat exchanger [18–21], about middle-overlapped quarter helical baffled heat exchanger, and [22,23] about rapid design method for DCH-STHX. Mehdi [24,25] tried to use nanofluid in shell side of helical baffled heat exchanger to improve energy efficiency. It should be noted that the rapid development of CFD commercial code and computer hardware helps the direct 3D numerical simulation of complex flow phenomenon in heat exchangers and it is becoming more and more convenient and popular. But the discontinuous helical baffles have a fatal flaw which is named “triangle zones”. The triangle zones exist in each two adjacent oval-shaped plates, and fluid seriously leak from these triangle zones. Therefore, the flow in the shell side is not perfect helical flow or plug flow, resulting in a decrease in heat transfer coefficient.

Peng et al. [26] introduced the “single circle continuous helical baffle” manufacture method. Then they fabricated a shell-and-tube heat exchanger with continuous helical baffles (CH-STHX) and compared it with a SG-STHX, the experimental results indicated that the use of continuous helical baffles resulted in nearly 10% increase in heat transfer coefficient compared with that of conventional segmental baffles for the same shell-side pressure drop. Xie et al. [27–29] used Artificial Neural Network (ANN) and Genetic Algorithm (GA) to analyzed and predicted overall heat transfer rate of a CH-STHX based on limited experimental data. Recently Yang [30] proposed sealing strips for effectively reducing bypass stream

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Nomenclature

A_{cross}	cross-flow area per baffle spacing, m^2
A_o	heat transfer area based on outer diameter of tube, m^2
B	baffle spacing, m
c_1, c_2	constant in curve fitting
c_p	specific heat, J kg^{-1} K^{-1}
D_i	inside diameter of shell, m
D_1	tube bundle-circumscribed circle diameter, m
D_m	diameter of sleeve tube, m
d_i	tube inner diameter, m
d_o	tube outer diameter, m
f_t	Darcy friction factor for turbulence flow inside tube
f_s	shell-side friction factor
h	heat transfer coefficient, W m^{-2} K^{-1}
k	overall heat transfer coefficient, W m^{-2} K^{-1}
l	effective length of tube, m
m_1, m_2	constant in curve fitting
M	mass flow rate, kg s^{-1}
N_t	number of tubes
Nu	Nusselt number
Δp	pressure drop, kPa
Pr	Prandtl number
Pr_f	Prandtl number at reference temperature of fluid
q	volume flow rate, m^3 s^{-1}
Q	heat transfer rate, W
Q_{ave}	average heat transfer rate, W
Re	Reynolds number
ΔT_m	logarithmic mean temperature difference, K
T	temperature, K
t_p	Tube pitch, m
u	fluid velocity in shell side, m s^{-1}

Greek symbols

β	inclination angle
ε	heat balance deviation
λ	conductivity factor, W m^{-1} K^{-1}
ρ	density, kg m^{-3}
ν	kinematics viscosity, m^2 s^{-1}

Subscripts

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

Abbreviation

CSTSP-STHX	combined serial two shell-pass STHX with continuous helical baffles
SG-STHX	STHX with segmental baffles
STHX	shell-and-tube heat exchanger

between shell wall and tube bundle in the CH-STHX. For convenient to engineering practice, Wang et al. [31] developed a thermal design method for the CH-STHX named maximal velocity ratio design method which can ensure the new design CH-STHX has greater heat transfer coefficient than that of the original SG-STHX. The helical baffle surface becomes relatively steep at portions close to the central axis when pitch is large, especially in STHXs with large shell diameters. In such situations, continuous helical baffles are quite difficult to manufacture. To solve this problem, a central sleeve tube (see Fig. 1) has to be employed to fit the helical structure inside the shell. On the one hand, tubes can not be arranged at the place where the central tube is located, and thus heat transfer area of the heat exchanger will be decreased; on the other hand, part of heat exchanger volume is occupied by the central tube and cannot be used for heat exchange, which will result in the decreasing of compactness. Therefore, the already mentioned problems stopped popularization of continuous helical baffled STHXs [32]. Song [33] reported that the helix flow would get weak in the central axis zone and the fluid almost went through in a straight line path resulting in decreasing heat transfer performance, as shown in Fig. 2.

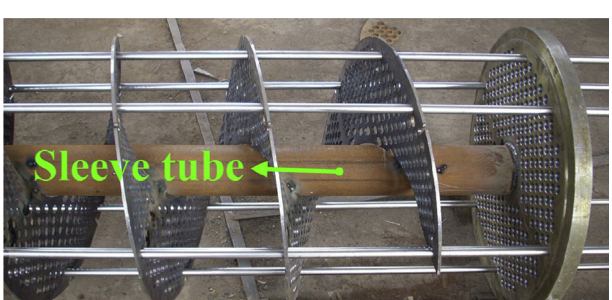

Fig. 1. Central sleeve tube of a continuous helical baffled STHX [30].

Due to the above reasons, Wang and Yang [34–36] proposed the combined serial two shell-pass shell-and-tube heat exchangers with continuous helical baffles (CSTSP-STHX) as shown in Fig. 3 to both simplify the manufacture process and make full use of the advantages of continuous helical baffles. This CSTSP-STHX separates the shell side into two individual shell passes. The inner shell pass is conventional segmental baffled, and the outer shell pass is continuous helical baffled. The working fluid flows through the outer and inner shell passes in sequence. As to each individual shell pass, the cross-sectional flow area is reduced, the velocity of fluid is increased and the heat transfer performance can have a great improvement.

In this study, the thermal hydraulic performances of the CSTSP-STHX have been compared with those of the double shell-pass segmental baffled heat exchangers (SG-STHX) by experiment to validate the advantages of the CSTSP-STHX.

2. Configuration of the novel CSTSP-STHX

The physical model of CSTSP-STHX is presented in Fig. 4a, and the double shell-pass SG-STHX is presented in Fig. 4b as comparison subject. As described above, the CSTSP-STHX has two shell passes which are the outer shell pass constructed by continuous helical baffles and the inner shell pass constructed by segmental

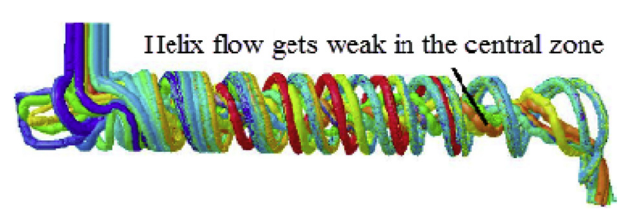

Fig. 2. Shell-pass flow path line of continuous helical baffled heat exchangers [31].