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Research Paper

Thermo-hydraulic design of single and multi-pass helical baffle heat exchangers

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HIGHLIGHTS

- Shortcut design approach for helical baffle exchangers.
- Design of single and multipass units.
- Correction factor determined using the thermal effectiveness-Ntu model.
- Complex internal flows modelled as a network of simple flow arrangements.

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ABSTRACT

A shortcut sizing approach for single and multipass heat exchangers with helical baffles is presented. An alternative approach for the determination of the correction factor of the logarithmic mean temperature difference as a function of the number of heat transfer units is introduced. Multipass arrangements give rise to complex internal heat flow paths; in this work, such flow paths are modelled using a simplified methodology that breaks up the complex flow and represents it as a network of simple arrangements such as counter flow and parallel flow. The network is solved to determine the outlet temperatures from where the correction factor is determined. The methodology is demonstrated on case studies from the open literature.

1. Introduction

Helical baffle heat exchangers offer and attractive option in terms of reduced surface area for the same heat duty and pressure drop compared to conventional exchangers. The helical flow patterns inside the shell promote high heat transfer coefficients and even reduced fouling thus making this type of technology suitable for use in foul-prone applications such as crude processing units. Since in single phase applications the fluid velocity is a fundamental design parameter, one of the geometrical variables available to modify its value is the number of passes. The existence of more than one pass on a stream gives rise to complex thermal arrangements which reduce the temperature driving forces across the unit. This effect is accounted for in design by means of a correction factor for the logarithmic mean temperature difference.

Helical baffle heat exchangers also called "helixchangers" exhibit a more uniform flow distribution on the shell side compared to conventional shell and tube exchangers for the same pressure drop [1]. They are also capable of reducing tube vibrations and fouling. Despite their higher manufacturing costs the benefits in terms of reduced maintenance and operating costs make them superior in the long term [2]. The main geometrical parameters that define this type of technology are: helical pitch (distance between two consecutive baffles); the helical angle (the angle formed between the helix and the vertical) and the shell diameter as shown in Fig. 1 [3].

The development of the helical baffle heat exchanger technology has evolved rapidly. From the construction point of view, they can broadly be classified in discontinuous and continuous baffles. The discontinuous baffle in turn can be subdivided into: single helical baffle and two layer or double helical baffle [4]. Further classification of the discontinuous baffle includes the shape in which it is manufactured and it includes: trisection, quadrant and sextant sector. Fig. 2 shows these constructions. Experimental and numerical simulations carried out by Salahuddin et al. [5] demonstrate that the discontinuous baffle exhibits better heat transfer performance for the same pressure drop. In terms of

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Nomenclature

A	heat exchanger surface area (m^2)
A_{sec}	cross sectional area (m^2)
B	helix pitch (m)
C	heat capacity rate ratio
CP_{min}	minimum heat capacity mass flow rate (W/°C)
CP_{max}	maximum heat capacity mass flow rate (W/°C)
C_p	heat capacity (J/kg °C)
D_{eq}	equivalent diameter (m)
D_s	shell internal diameter (m)
$d_{in,t}$	tube inner diameter (m)
$d_{out,t}$	tube outer diameter (m)
Ex	number of exchangers
F	correction factor of the logarithmic mean temperature difference
f_s	shell side friction factor
f_t	tube side friction factor
k	thermal conductivity (W/m °C)
L	exchanger length (m)
m	mass flow rate (kg/h)
N_p	number of passes
Ntu	number of heat transfer units
Ntu_{cc}	number of heat transfer units of the counter-current arrangement
Ntu_p	number of heat transfer units of the parallel arrangement
Ntu_T	total number of heat transfer units
Nu_s	shell side Nusselt number
Nu_t	tube side Nusselt number
NV	number of temperature variables
n	constant (1,2,3,4...) also number of helixes
Pr_s	shell side Prandtl number
Pr_t	tube side Prandtl number
Pr_w	Prandtl number at wall temperature
p	tube pitch (m)
Q	exchanger heat load (W)
Re_s	shell side Reynolds number
Re_t	tube side Reynolds number
S	number of streams
T	temperature (°C)
U	overall heat transfer coefficient (W/m^2°C)
Vs	shell side velocity (m/s)

Greek symbols

α	constant
β	helical angle (°)
ΔT	temperature difference (°C)
ΔT_{ln}	logarithmic mean temperature difference (°C)
ε	thermal effectiveness
ε_T	overall thermal effectiveness
ε_{cc}	thermal effectiveness of the counter-current arrangement
ε_p	thermal effectiveness of the parallel arrangement
μ	viscosity (kg/ms)
ρ	density (kg/m^3)
ξ	constant

construction the sextant sector construction shows higher performance since flow leakage inside the shell is reduced [6].

The geometrical parameter that has a larger impact on the thermo-hydraulic performance of helical baffle heat exchangers is the helical angle. Studies have reported that the highest heat transfer rate for a given pressure drop is obtained when the helical angle is 40° [7]. This work confirms the findings of Lei et al. [8].

Most recent experimental work that has resulted in the generation of empirical correlations for the determination of heat transfer and friction factor in helical baffle exchangers for a set of particular inclination angles is the work by Gao et al. [7]. This information proceeds from experimental data and includes the leak effects inside the shell and consequently can be used directly in design without the need of correction factors. A comprehensive review of the available correlations for heat transfer and pressure drop for helical baffle heat exchanger is the work by Wang et al. [9].

In terms of design methodologies for helical baffle heat exchangers, the main features of most published work are: use of ideal heat transfer correlations and the application of correction factors to account for the flow leakages inside the shell. Pioneering work in this area is the one published by Stehlik et al. [10]. Such

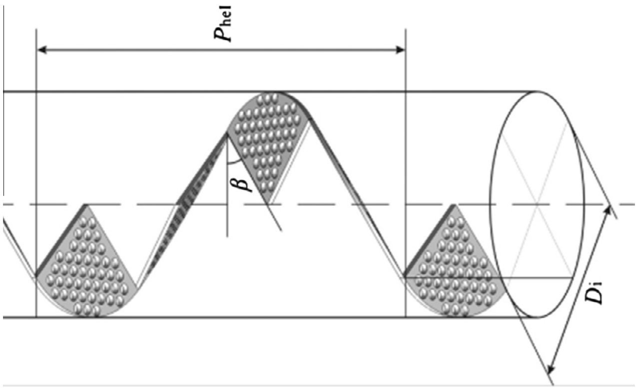

Fig. 1. Main geometrical features of a helical baffle exchanger [3].

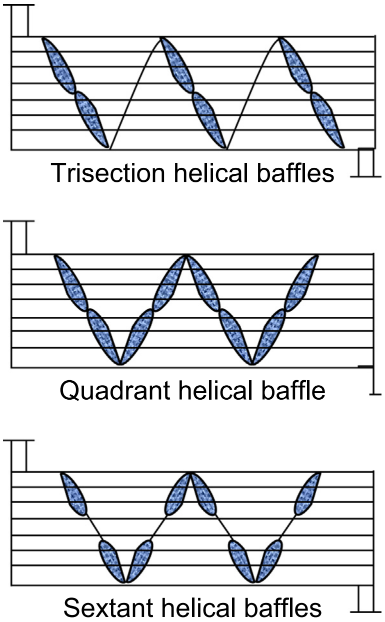

Fig. 2. Different construction features of discontinuous helical baffles.