Energy Conversion and Management 133 (2017) 76–86

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Numerical design and investigation of heat transfer enhancement and performance for an annulus with continuous helical baffles in a double-pipe heat exchanger

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ARTICLE INFO

Article history:
Received 4 October 2016
Received in revised form 8 November 2016
Accepted 2 December 2016

Keywords:
Continuous helical baffles
Water to water heat exchanger
Heat transfer enhancement
Double pipe
Friction
Numerical

ABSTRACT

In this paper, the design and thermo-hydraulic performance of a double pipe heat exchanger with helical baffles in the annulus side, are investigated numerically. Three-dimensional computational fluid dynamics (CFD) model, using the software FLUENT, have been performed to investigate the annulus side fluid flow, heat transfer coefficient and pressure drop for different configurations. A numerical analysis is conducted for different values of Reynolds number and baffle spacing (0.025–0.1 m). The numerical model was first validated for a simple double pipe heat exchanger by comparison with empirical correlations. The model was then used to investigate the helical baffles effects. The results obtained for a helically baffled annulus side provide enhanced heat transfer performance and high-pressure drop compared to the simple double-pipe exchangers. Thermal performance and high-pressure drop is an increasing function of baffle spacing and *Re*. In addition, empirical correlations expressing the results were developed based on curve fitting.

1. Introduction

Double pipe heat exchangers have an important role in various engineering processes. A simple double-pipe exchanger consists of two pairs of concentric pipes, the two fluids that are transferring heat flow in the inner and outer pipes, respectively. The fluids usually flow through the exchanger in opposite directions (counter-current flow). Double-pipe exchangers are commonly used in applications involving relatively low flow rates and high temperatures or pressures, for which they are well suited. Other advantages include low installation cost, ease of maintenance, and flexibility were stated by Shah and Sekulic [1].

Recently, various studies have been done on the heat transfer enhancement of heat exchangers, Yang et al. [2] Akpinar [3], Ma et al. [4], which can result in energy-saving, time-saving, raising thermal rating and extend the working life of the equipment. This is done by incorporating various passive geometrical features to enhance the heat transfer characteristics. These improvements decrease the thermal resistance at the expense of a higher pressure, as reported by Jian et al. [5] Bhadouriya et al. [6].

A description of representative physical situations that appear in the literature now follows. Pourahmad and Pesteei [7] experimentally studied a double pipe heat exchanger equipped with wavy strip turbulators, inserted in the inner pipe, their results showed considerable enhancement on heat transfer characteristics. Ibrahim [8] studied the augmentation of laminar flow and heat transfer in flat tubes by means of helical screw-tape inserts with various twist ratios and spacer length inserts. Effect of porous baffles and flow pulsation on a double pipe heat exchanger performance was studied by Targui and Kahalerras [9], the authors suggest that the inclusion of oscillating components in the inner pipe enhances the heat transfer. A study of using typical and perforated discontinuous helical turbulators was conducted by Sheikholeslami et al. [10], experiments were carried out for various open area ratios and pitch ratios. Results show that the thermal performance is an increasing function of open area ratio while it is a decreasing function of pitch ratio.

It should be noted that nowadays and with the rapid development of computational fluid dynamics (CFD), various numerical inspections of double-pipe heat exchangers are based on CFD

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http://dx.doi.org/10.1016/j.enconman.2016.12.002

Nomenclature

Latin symbols

A_{cross}	cross-flow area at the annulus side, m^2
B	baffle spacing, mm
c_p	specific heat capacity, J/(kg K)
c_i	coefficients in $k-\varepsilon$ model
D_s	internal annulus diameter, m
D_o	external tube diameter, m
D_h	hydraulic diameter, m
h	average heat transfer coefficient, W/(m^2 K)
k	turbulent fluctuation kinetic energy, m^2/s^2
L	tube total effective length, m
f	friction factor
$\dot{m}$	mass flow rate, kg/s
Pr	Prandtl number
Δp	pressure drop, Pa
Q	heat transfer rate, W
Re	Reynolds number
Nu	Nusselt number
T_{in}	hot water inlet temperature, °C
t_{in}	cold water inlet temperature, °C
u	average velocity, m/s
x, y, z	Cartesian coordinate

Greek symbols

Γ	generalized diffusion coefficient
ε	turbulent kinetic energy dissipation rate, m^2/s^3
λ	thermal conductivity, W/(m K)
μ	dynamic viscosity, kg/(m s)
ν	kinematic viscosity, m^2/s
ρ	density, kg/m^3
σ_k	Prandtl number for k
σ_ϵ	Prandtl number for ϵ

Subscripts

in	inlet
out	outlet
a	annulus side
t	tube side
turb	turbulent

methods [11,12]. These methods have been a necessary supplement to experiments and theory. Moreover, it offers an economic alternative. Gorman et al. [13] presented a numerical investigation of the thermal and fluid flow design of a double-pipe heat exchanger in which the wall of the inner pipe is helically corrugated. Comparisons with simple smooth-walled double-pipe heat exchangers showed a factor of three increases in heat transfer and a factor of two to four larger pressure drop. Hashemian et al. [14] investigated a conical tube instead of the cylindrical tube as a novel improved geometry for double pipe heat exchangers in. The model was solved numerically, the results show 55% and 40% increment in effectiveness and heat transfer improvement number at the optimum conditions. Saeedan et al. [15] presented a numerical study on the thermal performance of a helically baffled double-pipe heat exchanger combined with a 3D fined tube operated with nanofluids, the effects of Reynolds number and volume concentration on heat transfer and pressure drop were evaluated. Sheikholeslami and Ganji [16] presented experimental results for a double pipe heat exchanger with perforated turbulators used in annulus region, with physical phenomena are shown by means of numerical analysis, results revealed that thermal performance is enhanced with increasing open area ratio. Ahmed et al. [17] studied the thermal performance and entropy generation for a bundle of wing shaped-tubes was conducted. Results indicate the higher heat transfer performance is obtained with installing fins with heights from 2 to 12 mm. Ahmed et al. [18] presented a review of published works on the characteristics of heat transfer and flow in finned tube heat exchangers. The review considers plain, louvered, slit, wavy, annular, longitudinal, and serrated fins. Further thermal enhancement methods are studied in [19–28].

In this work, a numerical study for a water-to-water double-pipe heat exchanger with continuous helical baffles at the annulus side is conducted Fig. 1a. In the literature, helical baffles are almost exclusively used in shell and tube heat exchangers to enhance heat transfer performance and reduce pressure drop, and no publications studying their thermo-hydraulic performance for the annulus of a double-pipe heat exchanger could be found. As shown in Fig. 1b, the flow pattern in the annulus side is rotational (blue color), and the fluid is forced to flow in and ideal helical pattern. The flow in the inner tube (red color) is kept the same as in conventional double-pipe heat exchangers. First, the heat exchanger parts: tube side, annulus side and helical baffles are modeled for different cases with variable baffle spacing. The numerical model was validated against empirical correlations for the simple double-pipe heat exchanger. After the model validation, the numerical model is used to compute and compare the thermo-hydraulic performance for a double-pipe heat exchanger with a helically baffles annulus side. The effects of hydraulic, geometric and thermal characteristics are considered in the evaluations.

2. Numerical model

2.1. Physical models

The aim of this research is to compare different configurations of helical baffles in the annulus side of a double-pipe heat exchanger. The addition of these geometrical features changes the pressure and velocity distribution along the annulus side of the heat exchanger and thus the amounts of heat transfer rate and pressure drop changes. The configurations of helically baffled double-pipe heat exchanger are shown in Fig. 2, the baffle spacing B varies from 0.1 to 0.025 m (top to bottom order). In aforesaid configurations, the effect of geometric, flow and thermal parameters are numerically investigated. Although the geometry of present type of heat exchanger is simple, its numerical thermo-hydraulic study is complex due to the complexity of flow regime in the annulus side.

The warm water flows on the tube side, while the cool water flows in the annulus side in a counter-current configuration. Another point should be highlighted that the length and diameters of the modeled heat exchangers are kept the same with each other, which is to ensure all of the values of geometry parameters are consistent except the baffle spacing. The material of the heat exchangers parts is stainless steel and its thermal conductivity is $\lambda = 15.2$ W/(m K). More geometry details are listed in Table 1.

2.2. Governing equations

Water is considered as a Newtonian and incompressible fluid with constant thermo-physical properties. Furthermore, the fluid