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An investigation of two-phase flow pressure drop in helical rectangular channel☆

Guo-dong Xia *, Xian-fei Liu

Key Laboratory of Enhanced Heat Transfer and Energy Conservation, Ministry of Education, College of Environmental and Energy Engineering, Beijing University of Technology, Beijing 100124, China

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ABSTRACT

Numerical simulations have been carried out to evaluate the two-phase frictional pressure drop for air-water two-phase flow in horizontal helical rectangular channels by varying configurations, inlet velocity and inlet sectional liquid holdup. The investigations performed using eight coils, five different inlet velocity and four different inlet sectional liquid holdups. The effects of curvature, torsion, fluid velocity and inlet sectional liquid holdup on two-phase frictional pressure drop have been illustrated. It is found that the two-phase frictional pressure drop relates strongly to the superficial velocities of air or water, and that the curvature and torsion have some effect on the pressure drop for higher Reynolds number flows in large-scale helical rectangular channel; the inlet sectional liquid holdup only increases the magnitude of pressure drop in helical channel and has no effect on the development of pressure drop. The correlation developed predicts the two-phase frictional pressure drop in helical rectangular channel with acceptable statistical accuracy.

1. Introduction

Helical channels are well known types of curved tubes which have been used in a wide variety of applications, for example, heat recovery processes, air conditioning and refrigeration systems, chemical reactors, nuclear reactors, steam generators and other heat transfer equipments [1–3]. When the two-phase flow enters the helical portion, the heavier fluid is subjected to a larger centrifugal force which causes the liquid to move away from the center of the helical channel, while the gas tends to move along the inner side of the channel. As the development of the fluid flow in the helical channel, the fully developed flow is established and the pressure on the outer side of the cross-section is much higher than that inner side for the helical channel. This process is a continuous function of coil geometry. Despite varying applications, the literature on two-phase flow through helical coiled tubes is rather scanty.

Two-phase flow characteristics and pressure drop are more complex and important for engineering applications. For helically coiled tubes, numerous theoretical and experimental works have been reported on flow characteristics. Guo et al. [4] studied the pressure drops of steam–water two-phase flows in two helical coiled tubes with four different helix axial inclinations. The results showed that the system pressure and mass quality had a significant effect on the two-phase pressure drop. Zhao et al. [5] studied the pressure characteristics of steam–water two-phase flow through a small horizontal helical pipe of steam generator. Their results showed that the frictional pressure drop multiplier of two-phase flow was a function of the mass flow rate and the pressure and the heat flux didn't affect the frictional pressure drop multiplier. Some new correlations for frictional pressure drop multiplier of two-phase flow inside small helical pipe were proposed. Chen and Guo [6] presented pressure drop in oil–air–water three-phase-flow through helical pipes. The frictional pressure drop of oil–air–water three-phase flow was measured. The effects of flow rates and liquid properties on pressure drop were examined. Correlations for the predictions of pressure drop were also obtained. Taylar et al. [7] gave a research on the hydraulic performance of small bending radius helical coiled pipes used in HTR-10 steam generator experimental facility. The two-phase flow frictional drop was proved to be used for HTR-10 steam generator design. Xin et al. [8,9] investigated the air–water two-phase flow in vertical helical pipes and annular helicoidal pipes. The results showed that the pressure drop of the two-phase flow in the vertical helical pipes and annular helicoidal pipes depended on both the Lockhart–Martinelli parameter and the flow rates. Awwad et al. [10] performed experimental investigations for air–water two-phase flow in horizontal helicoidal pipes of varying configurations. Correlation for the two-phase flow in the horizontal helicoidal pipes has been established based on the present experimental data. Biswas and Das carried out experiments to evaluate the frictional pressure drop for air and non-Newtonian liquid two-phase flow through the helical pipe in both the horizontal and vertical orientation [11,12]. The effects of the gas and liquid flow rate, coil diameter, and liquid

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* Corresponding author.
E-mail address: xgd@bjut.edu.cn (G. Xia).

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Nomenclature

a	Length of the horizontal direction, **m**
b	Length of the vertical direction, **m**
c	Section perimeter, **m**
De	Dean number
G	Mass flow rate, $\mathbf{kg\ m^{-2}\ s^{-1}}$
H	Pitch, **m**
L	Length of the helical channel, **m**
m	Quality, $\mathbf{kg\ s^{-1}}$
R	Coil radius, **m**
r	Equivalent radius of section, **m**
Re	Reynolds number
Re	Reynolds number
$\triangle p$	Pressure drop, **Pa**
ϕ	The angle measured from the inlet plane of the coil
x	The horizontal direction coordinates
y	The vertical direction coordinates

Greek letters

a	density, $\mathbf{kg\ m^{-3}}$
μ	Viscosity, $\mathbf{kg\ m^{-1}\ s^{-1}}$
δ	Curvature
λ	Torsion
υ	Superficial velocity, $\mathbf{m\ s^{-1}}$
ξ	Correction factor

Subscripts

avg	average
max	maximum
g	gas phase
l	liquid phase
lo	corresponding to entire flow as liquid
T	two-phase flow

properties on two-phase frictional pressure drop have been illustrated. The analysis of the two-phase flow frictional pressure drop data was largely not in agreement with the Lockhart–Martinelli or the modified Lockhart–Martinelli correlation due to the non-Newtonian characteristics of the liquid. Santini et al. [13] investigated the pressure drops of the two-phase flow in a helically coiled steam generator. A frictional two-phase flow pressure drop correlation based on an energy balance of the two-phase mixture was proposed. Murai et al. [14] investigated the average pressure drop of the air–water two-phase flow in the helical pipe to elucidate the effects of centrifugal acceleration on the flow structure distribution. Mohammed and Narrein [15,16] performed the hydraulic characteristics of nanofluid flow in a helically coiled tube heat exchanger. The effects of using different geometrical parameters and rotation with the combination of various nanofluid on fluid flow characteristics in a helically coiled tube heat exchanger (HCTHE) are numerically investigated.

Compared with the numerous investigations of single-phase flow, gas–liquid two-phase flow characteristics through the helical coil tubes, only limited information regarding the pressure drop for gas–liquid two-phase flow is available in the open literature. Almost all research work has focused on the gas–liquid two-phase flow in the circular helical channels; the pressure drop characteristics of gas–liquid in the helical rectangular channel with higher Reynolds number are seldom involved. The problem of determining the pressure losses in helical coil is important in the design and analysis of the fluid machinery. The objective of this paper is to numerically study the pressure drop and evolution characteristics in the helical rectangular channel. The multi-component multiphase flow pressure loss in the complex three-dimensional curve channel of the expander is an important factor that affects the efficiency of the single screw expander. Because the previous researches are mainly focused on the processing and performance of the prototype, the multi-component multiphase flow pressure loss in the complex three-dimensional curve channel needs to be further studied. Effects of the relevant parameters on the pressure drop and evolution characteristics in the helical rectangular channel are discussed. These works in the present paper give much guiding significance for the structural design and optimization of the screw in single screw expander prototype.

2. Theoretical and numerical methodology

2.1. Characteristics of helical rectangular channel

A schematic of the helical rectangular channel with its main geometrical parameters is shown in Fig. 1. In this analysis, the helical rectangular channel is perceived to be horizontally oriented. The side length of the horizontal direction is a. The length in the vertical direction is b. The coil radius (measured from the centre of the pipe to the axis) is represented by R. The distance between two adjacent turns is called pitch H. The side of the pipe wall which is nearest to the coil axis is termed inner side I and the outmost side is termed as outer side O. The dimensionless parameter curvature and torsion are defined as $\delta = r/R$, $\lambda = H/2\pi R$. The centrifugal acceleration is defined as υ^2/R. The Reynolds number $\mathrm{Re} = \rho \upsilon d/\mu$. The Dean number is used to characterize the flow in helical pipe. That is defined as $\mathrm{De} = \mathrm{Re}\delta^{0.5}$ [15].

2.2. Review of pressure drop correlations in the helical tubes for the two-phase flow

Some correlations for the two-phase frictional pressure drop in the helical pipes have been found in the open literature. The studies of the two-phase flow in the helically coiled tubes mostly use the correlations based on the Lockhart–Martinelli parameter.

Awwad [10] investigated the air–water two-phase flow in the horizontal helicoidal pipes; the correlations of the frictional pressure

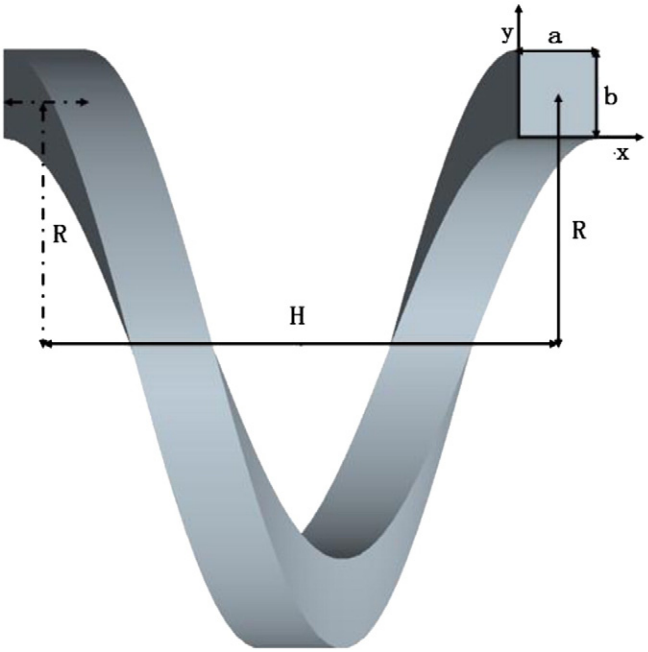

Fig. 1. Schematic of a helical pipe with its main geometrical parameter.