Clement C. Tang
e-mail: clement.tang@engr.und.edu

Sanjib Tiwari
e-mail: sanjib.tiwari@my.und.edu

Mechanical Engineering Department,
University of North Dakota,
Grand Forks, ND 58202

Afshin J. Ghajar
School of Mechanical and Aerospace Engineering,
Oklahoma State University,
Stillwater, OK 74078
e-mail: afshin.ghajar@okstate.edu

Effect of Void Fraction on Pressure Drop in Upward Vertical Two-Phase Gas-Liquid Pipe Flow

Experimental data for the void fraction and two-phase frictional pressure drop from various sources has been compiled and analyzed. The experimental data revealed that at the lower range of superficial gas velocity and void fraction, the variations of the two-phase frictional pressure drop with superficial gas velocity and void fraction are relatively flat. However, as the superficial gas velocity and void fraction increase to higher values, the frictional pressure drop became significantly sensitive to the two parameters. In a situation when the two-phase pressure drop is sensitive to the variation of the void fraction, it is then that the proper and accurate characterization of the void fraction becomes significant. From the experimental data, regions where the pressure drop is sensitive to the variation of the void fraction are identified and evaluated. [DOI: 10.1115/1.4007762]

Introduction

Two-phase gas-liquid flow occurs when both the gas and liquid phases exist in the flow as different components (e.g., air-water, helium-water, etc.), or in the event when the flow of a fluid is experiencing a phase change as a result of evaporation or condensation. Such a flow can commonly be found in the nuclear, petroleum, and process industries. The complex nature of two-phase gas-liquid flow is the consequence of the flow being influenced by several flow parameters. Both void fraction and pressure drop are among the major flow parameters that affect the behavior of two-phase flow. Thus, in the effort to gain a better understanding of the complexities involved in two-phase flow, the fundamental understanding of void fraction and pressure drop becomes essential.

The proper and accurate characterization of void fraction is of considerable importance in two-phase flow systems. For example, in nuclear reactor technology, void fraction is significant in estimating the reactivity of a boiling water reactor that uses light water as the neutron moderator and coolant. Void fraction is an important physical parameter for assessing other two-phase flow parameters (e.g., two-phase density and gas and liquid velocities). In addition, the void fraction is a parameter that is necessary for determining the two-phase pressure drop. The two-phase pressure drop is a parameter that is significant in designing two-phase flow systems.

Over the past few decades, there have been a number of investigations on void fraction and pressure drop due to their significance in affecting two-phase flow behavior. To date, the literature reports many correlations for predicting the two-phase flow pressure drop in various pipe orientations and flow conditions. Among the earliest is the correlation introduced by Lockhart and Martinelli [1] and a more recent model for pressure drop that covers from the macro- to microscale channels was introduced by Cioncolini et al. [2,3]. Similarly, for the void fraction correlation, the literature reports a large number of correlations for void fraction predictions. Extensive evaluations on the performances of the void fraction correlations available in the literature have been conducted recently [4–7]. However, many of the investigations focused on the void fraction and pressure drop separately and the effect of void fraction on pressure drop has not yet been thoroughly explored.

In the present study, experimentally measured void fraction and frictional pressure drop results for an upward vertical two-phase flow are compiled and analyzed. From the experimental data, the effect of void fraction on frictional pressure drop is evaluated. Regions where the frictional pressure drop is sensitive to void fraction are identified.

Background

The total pressure difference for two-phase flow in a pipe is the sum of the hydrostatic pressure difference, the momentum pressure difference, and the frictional pressure difference

$$\Delta p_t = \Delta p_h + \Delta p_{\mathrm{mom}} + \Delta p_f \tag{1}$$

The two-phase hydrostatic pressure difference can be expressed as

$$\Delta p_h = [\alpha\rho_g + (1-\alpha)\rho_l]gL\sin\theta \tag{2}$$

Throughout this study, the momentum pressure difference is zero, since the flow quality remains constant in the test section from the inlet to the exit. When expressed in the form of a pressure gradient, the frictional pressure gradient for an upward vertical two-phase flow becomes

$$(\Delta p/L)_f = (\Delta p/L)_t - [\alpha\rho_g + (1-\alpha)\rho_l]g \tag{3}$$

In a two-phase flow, one of the parameters used for describing the flow condition is the superficial velocity. The expressions for the superficial gas and liquid velocities are

$$u_{sg} = \frac{\dot{m}_g}{A\rho_g} \tag{4}$$

and

$$u_{sl} = \frac{\dot{m}_l}{A\rho_l} \tag{5}$$

Contributed by the Nuclear Division of ASME for publication in the Journal of Engineering for Gas Turbines and Power. Manuscript received September 13, 2012; final manuscript received September 19, 2012; published online January 8, 2013. Editor: Dilip R. Ballal.