



Experimental study on vertical downward air-water two-phase flow in a large diameter pipe



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ABSTRACT

Downward two-phase flows in large diameter pipes are important in various industrial applications, especially for the safety analysis in nuclear reactors. To address the issue that few data of downward flow in large diameter pipes is available for model evaluation, experiments of air-water downward flow in a pipe with inner diameter of 203.2 mm have been performed. Area-averaged void fraction and pressure measurement, as well as flow visualization, have been conducted at several axial locations. The flow conditions for superficial gas velocity range from 0.05 m/s to 3.00 m/s and for superficial liquid velocity range from 0.1 m/s to 1.5 m/s, which cover cap-bubbly flow, churn-turbulent flow and annular/filling film flow. The flow structure at several axial locations and the transition from churn-turbulent flow to annular/filling film flow have been discussed. Current available drift-flux models developed for downward flow in regular pipes as well as for upward flow in large pipes are evaluated using newly collected data. For churn-turbulent flow, the data indicates a larger drift velocity than the model prediction. Corresponding drift-flux constitutive equations are suggested which can reduce the prediction error from 34.37% to 11.79%.

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1. Introduction

Two-phase flow in large diameter pipes is often encountered in various industrial applications. In chemical and petroleum industries, the large bubble column, chemical reactor and pump systems are commonly used. In the nuclear industry, two-phase flow often occurs in large channels. Thus, the fundamental knowledge of two-phase flow in large diameter pipes is especially important for the nuclear safety. A large diameter pipe is defined as a pipe whose diameter is larger than the maximum cap bubble size, which is proposed by Kataoka and Ishii [1] as

$$D_{cr} = \frac{D_h}{\sqrt{g/\Delta\rho}} > 40 \quad (1)$$

where the D_h is the hydraulic diameter of channel, g is the surface tension, $\Delta\rho$ is the density difference between the liquid and gas phases. Once the flow channel diameter is larger than this critical size, the slug bubble bridging the entire channel can no longer exist due to the Taylor instability, which

results in the disintegration of large cap bubbles and induces three-dimensional recirculatory behaviors [2]. Therefore, the bubble behavior, void fraction and velocity profiles in large pipes can be very different from those in small pipes, in which slug bubbles can be sustained. These changes cause different physical mechanisms of gas and liquid transport, implying the models developed for small-diameter pipes may be no longer applicable for large diameter channels [1]. The capability to accurately predict the two-phase flow in large channel system is extremely important for nuclear safety.

The drift-flux model [3,4] and the two-fluid model [5] are two most commonly used models to formulate a general transient two-phase flow problem. Compared with the rigorous two-fluid model, the drift-flux model is an approximate formulation but can provide acceptable prediction accuracy with much less computational efforts. In addition, the one-dimensional two-fluid model requires a drift-flux relation as a constitutive equation to calculate the area-averaged relative velocity for the interfacial drag, and the advanced computer codes typically used in the nuclear system analysis, such as RELAP and TRACE, are based on one-dimensional form of the two-fluid model. Therefore, a complete set of drift-flux models covering various flow systems and geometries is necessary for the accurate prediction of these codes.

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