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Air-water two-phase bubbly flow across 90° vertical elbows Part II: Modeling

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ABSTRACT

Following Part (I) of the current study, which presents the experimental results of the elbow effects on two-phase flow parameters in bubbly flow, Part (II) develops models and correlations to predict the evolution of these parameters across and downstream of 90° vertical-upward and vertical-downward elbows. To quantify the length requires for the effects of the elbows to dissipate (or the dissipation length), the strength of elbows is defined as the variance of the local void fraction distribution. The axial development of the elbow-strength is modeled by an exponential function of the axial development length based on the experimental data. Then, the dissipation length of the elbow is determined by characterizing the evolution of the elbow-strength parameter. The elbow-strength parameter is also used to correlate the void-weighted bubble velocity and covariance terms in the interfacial area transport equation (IATE). The two-phase pressure drop across vertical elbows is modeled with a modified Lockhart-Martinelli correlation which considers the additional pressure drop induced by elbows. To evaluate the above developed models and correlations, they are implemented into the IATE applicable to the elbow-influenced region. The established IATE together with the available IATE of different flow orientations in straight channels are implemented to predict the interfacial area transport from the vertical-upward to horizontal to vertical-downward two-phase flow across elbows. It is found that the interfacial area concentration predictions are in good agreement with the experimental data with an average absolute percent difference of ±6% throughout the test section. The individual contributions to the interfacial area concentration transport due to each source and sink term in the IATE are discussed, demonstrating that the models and correlations developed for the two-phase flow parameters in elbow regions are reliable.

1. Introduction

In Part (I) of the current study [1], the experimental investigation of the effects of 90° vertical-upward and vertical-downward elbows on global and local two-phase flow parameters are discussed. It is demonstrated that elbows create secondary flow and cause bubble redistribution, which significantly affect the development of two-phase flow parameters. The effects happen across elbows and remain for a significant development length downstream. However, relatively limited studies are available to model these elbow effects on two-phase flow parameters.

Among studies available concerning modeling the effects of elbows or bends, most of them are limited to modeling of the two-phase pressure drop across elbows as listed in Table 2 in Part (I) of the current study. However, different correlations proposed by different researchers may differ significantly and be limited to specific flow restrictions under certain flow conditions. This indicates that the prediction of the two-phase pressure drop across elbows is still challenging and therefore requires further investigation.

In view of quantitatively modeling of the local two-phase parameters that are subject to the elbow effects, Yadav et al. [2,3] investigated the geometric effects of a 90° vertical-upward elbow on the advection of the bubble velocity, the void fraction distribution, and the interfacial area concentration transport across the elbow in air-water two-phase flow. The authors defined a parameter as a function of the local void fraction distribution to quantify the elbow-strength. A preliminary "dissipation length model" was then developed using the elbow-strength parameter to quantify the length of the region that is influenced by the elbow. Qiao and Kim [4] improved the model by including the initial

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increasing trend of elbow-strength with additional experimental data and assumed that it is also an exponential function of the development length in this region. However, the coefficients in their model are correlated with the liquid-phase Reynolds number which neglects the effects of the gas-phase. Therefore, the elbow dissipation length model may still have room to be improved. In addition, no model is available for studying the dissipation length and other two-phase flow parameters across the vertical-downward elbow.

Due to the above limitations, the current study continues the efforts of investigating the elbow effects on two-phase flow and developing correlations to model the effects of vertical elbows on two-phase flow parameters. To be specific, the objectives are: (1) to develop elbow dissipation length models that determine the regions subjected to the effects of 90° vertical-upward and vertical-downward elbows, (2) to establish correlations which can model the evolution of two-phase flow parameters in the elbow-influenced regions, and (3) to evaluate the developed models and correlations by implementing them into the interfacial area transport equation and predicting the interfacial area concentration in the elbow-influenced region.

2. Experimental facility and test conditions

The experimental facility and test conditions used to establish the experimental database for modeling the effects of vertical elbows are shown in Fig. 1, Tables 1 and 2, which have been discussed in detail in Part (I) of the current study. The experimental results for flow conditions which remain in bubbly flow at both the inlet and exit of the vertical elbows will be used to model the elbow effects.

3. Modeling of the effects of 90° vertical elbows

The effects of 90° vertical elbows on two-phase flow parameters have been discussed in Part (I) of the current study. The modeling of these parameters will be discussed in this section. First, the length of the region influenced by elbows, the dissipation length, will be modeled by predicting the axial development of the α distribution. Then the modeling of the bubble velocity and covariance (a parameter arising in the modeling of bubble interactions due to the change of the α distribution) in the elbow region will be discussed. Finally, the two-phase pressure drop across vertical elbows will be modeled with a modified Lockhart-Martinelli correlation which considers the additional pressure drop induced by vertical elbows.

3.1. Elbow dissipation length

As discussed, elbows can affect the two-phase flow downstream. Similar to the entrance length defined to consider the inlet effects, the elbow dissipation length can be defined to quantify the region affected by the elbow downstream. The methodology is to define an elbow-strength parameter based on the two-phase flow parameters. The elbow dissipation length can be then determined by setting a threshold value on the elbow-strength parameter. For single-phase flow, the intensity of the secondary flow induced by the elbow has been used to quantify the elbow-strength [5,6]. For two-phase flow, however, a parameter related to both phases is expected to be defined to quantify the elbow-strength. The void fraction, the most basic two-phase flow parameter, which quantifies the volume ratio of the gas phase and the mixture, by nature is a good option. With detailed local measurements, the variance

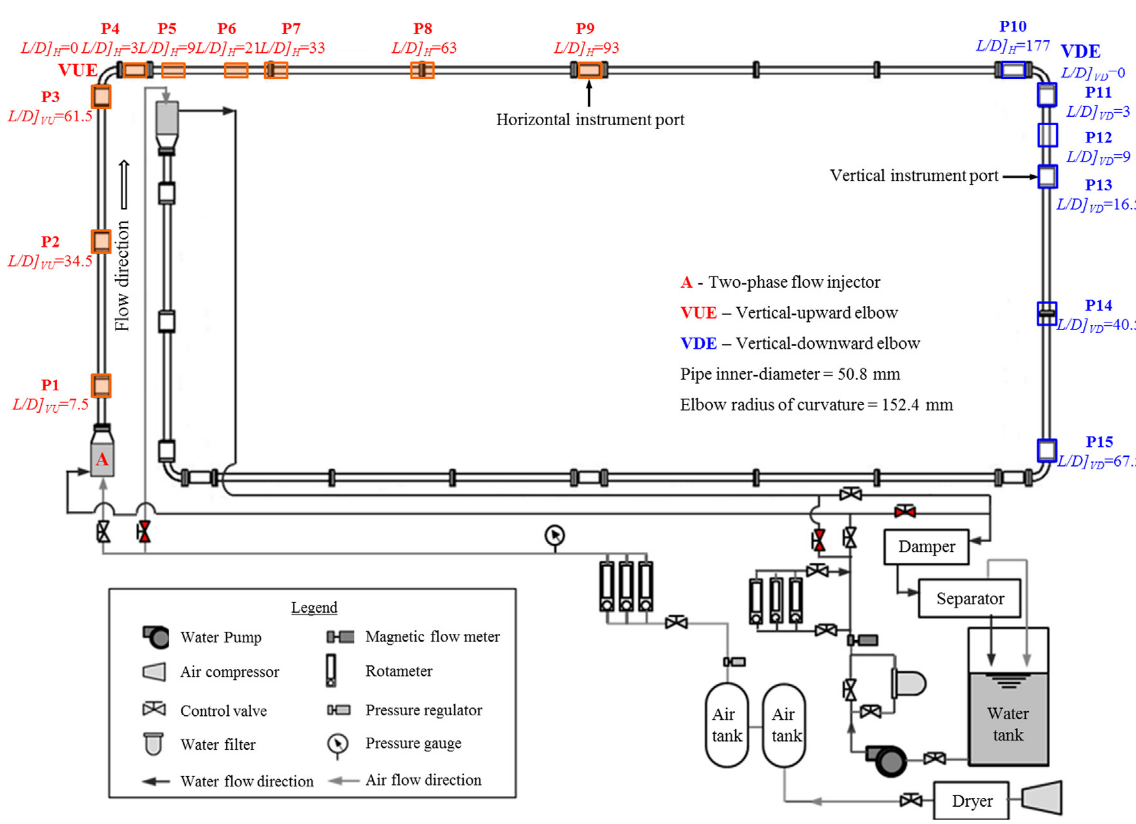

Fig. 1. Simplified schematic diagram of the test facility.

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