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Experiments on geometric effects of 90-degree vertical-upward elbow in air water two-phase flow

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ABSTRACT

This study investigates the geometric effects of a 90-degree vertical-upward elbow on local two-phase flow-parameters in an air–water system, and develops an experimental database for interfacial area transport modeling. The experimental facility is constructed from 5.08 cm inner diameter acrylic pipes and includes vertical and horizontal sections interconnected by a 90-degree vertical glass elbow. The elbow has a radius of curvature of 15.24 cm and is installed at $L/D = 63$ from the inlet. A four-sensor conductivity probe is used to measure time-averaged local two-phase flow parameters including: void fraction, bubble velocity, interfacial area concentration, and bubble frequency at ten axial locations along the test section. It is observed that the bubbles moving through the vertical-upward elbow are entrained by the secondary flow leading to a bimodal distribution in bubbly flow conditions. For the flow conditions investigated within the study, this bimodal distribution occurs regardless of the bubble distribution upstream of the elbow. It is found that the change in bubble distribution downstream of the elbow is strongly correlated to the dissipation of the elbow effects. Furthermore, the dissipation characteristics as well as the length of dissipation region for the vertical-upward elbow are found to be a strong function of the liquid-phase flow rate.

1. Introduction

Two-phase flow is widely observed in energy systems and finds applications in many industries including chemical, nuclear, oil and gas transport industries, etc. Within these systems, two-phase flow pass through a variety of flow restrictions such as elbows, valves, tees, nozzles and diffusers. The presence of flow restrictions significantly affects both global and local two-phase flow parameters including pressure drop, advection, phase distribution, and particle interaction mechanisms (Salcudean et al., 1983; Wang et al., 2004). Therefore, experimental studies are important towards enhancing the physical understanding of these flows and the development of dynamic models for two-phase flow through the flow restrictions.

Among the limited studies available concerning the effect of flow restrictions on interfacial structures, Kim et al. (2007) and Talley et al. (2009) investigated the effects of 90-degree and 45-degree horizontal elbows, respectively, on local two-phase flow parameters and their transport characteristics in air–water bubbly flow. These studies demonstrate that the elbows induce distortions in the local void fraction profiles, which dissipate further downstream of the elbow. Moreover, it was shown that depending on the flow condition, the elbows promote either bubble coalescence or bubble breakup leading to significant changes in the interfacial area concentration.

Currently, there is a lack of experimental database and knowledge of the mechanisms that govern the development of two-phase flow structures through flow restrictions. This may limit the capability of codes, which are used for thermal–hydraulic analysis of two-phase flow systems. In addition, the development and benchmarking of computational fluid dynamics codes (CFD) requires an experimental database of detailed local measurements (Lucas et al., 2010). In order to develop dynamic models applicable to two-phase flow through elbow restrictions, it is important to understand the geometric effects of elbows on both global and local two-phase flow parameters. Furthermore, it is important to identify and predict the region where two-phase flow demonstrates significant elbow-effects.

In view of the above, the objectives of the current study are: (1) to perform experiments and develop a database of local two-phase flow parameters in bubbly flow through a 90-degree vertical-upward elbow and (2) to characterize the effects of a 90-degree

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vertical-upward elbow on local two-phase flow parameters within the dissipation region of the elbow.

2. Experimental facility and test conditions

The schematic diagram of the test facility is shown in Fig. 1. The test section is constructed from 5.08 cm inner-diameter acrylic pipe segments that are arranged in a loop configuration. It has two vertical and three horizontal sections. The vertical and horizontal sections are interconnected by 90-degree glass elbows, which have a non-dimensional radius of curvature of $R_C/D = 3$. The current study is focused on investigating the effects of the 90-degree vertical-upward elbow (i.e. the elbow connecting vertical-upward-to-horizontal test section) on two-phase flow parameters. The vertical-upward elbow is indicated in Fig. 1 and a schematic diagram of the elbow is shown in Fig. 2(a). The lengths of vertical and horizontal sections are 3.35 m and 9.45 m yielding development lengths of 66 and 186 diameters, respectively. The test facility is designed such that all conceivable vertical-to-horizontal and horizontal-to-vertical flow configurations can be achieved by simple manipulation of valves. As such, vertical-upward or vertical-downward two-phase flow can be introduced via injection system (A) or injection system (B), respectively, as shown in Fig. 1. In the current study, injector (A) is used as the inlet and injector (B) serves as the exit.

Fig. 3 shows the schematic diagram of the two-phase flow injection system, which consists of a double annulus configuration. The outer annulus is formed by two concentric acrylic tubes. The main liquid flow rate is supplied to the outer annulus through three inlets oriented at 120° from each other to minimize inlet effects. The main liquid flow rate is varied during the experiments to create different flow conditions in the test section. The inner annulus is formed by the inner acrylic tube and a sintered stainless steel sparger, not shown in figure, which is installed at the center of the injector. The air to the test section is supplied through the sparger, which has an average pore size of 10 μm. The liquid flow rate in the inner annulus, referred to as the auxiliary flow rate is kept constant for all flow conditions. Bubbles are sheared off from the surface of the sparger by the auxiliary liquid flow rate. The bubble size at the inlet is maintained uniform at 2–3 mm for all flow conditions by supplying a constant auxiliary liquid flow rate of 0.62 m/s.

A 45 kW Dean Model PH-2140 centrifugal pump is used to supply water from a 2300*L* accumulator tank to the facility. An 11.2 kW Quincy QGB15V rotary screw air compressor supplies air to the system. The air is supplied to two accumulator tanks with volumes of 1.51 m^3 and 0.45 m^3, which are connected in series. The tanks are used to minimize any pressure fluctuations in the air being supplied from compressor to the two-phase injector units. At the exit of the test section, a two-stage damper-separator system is installed to reduce the inertia of the exit flow and to minimize system pressure oscillations, which may arise due to the separator system.

The water flow-rate is measured by an electromagnetic flowmeter, which has an accuracy of ±0.5% of flow rate. The air flow-rate in the facility is measured by a set of rotameters, which have accuracies of ±3% of their full-scale readings. For the gas flow rates considered in the present study, a single rotameter was used with a full-scale reading is 7.86×10^{-4} m^3/s (100 standard cubic feet hour

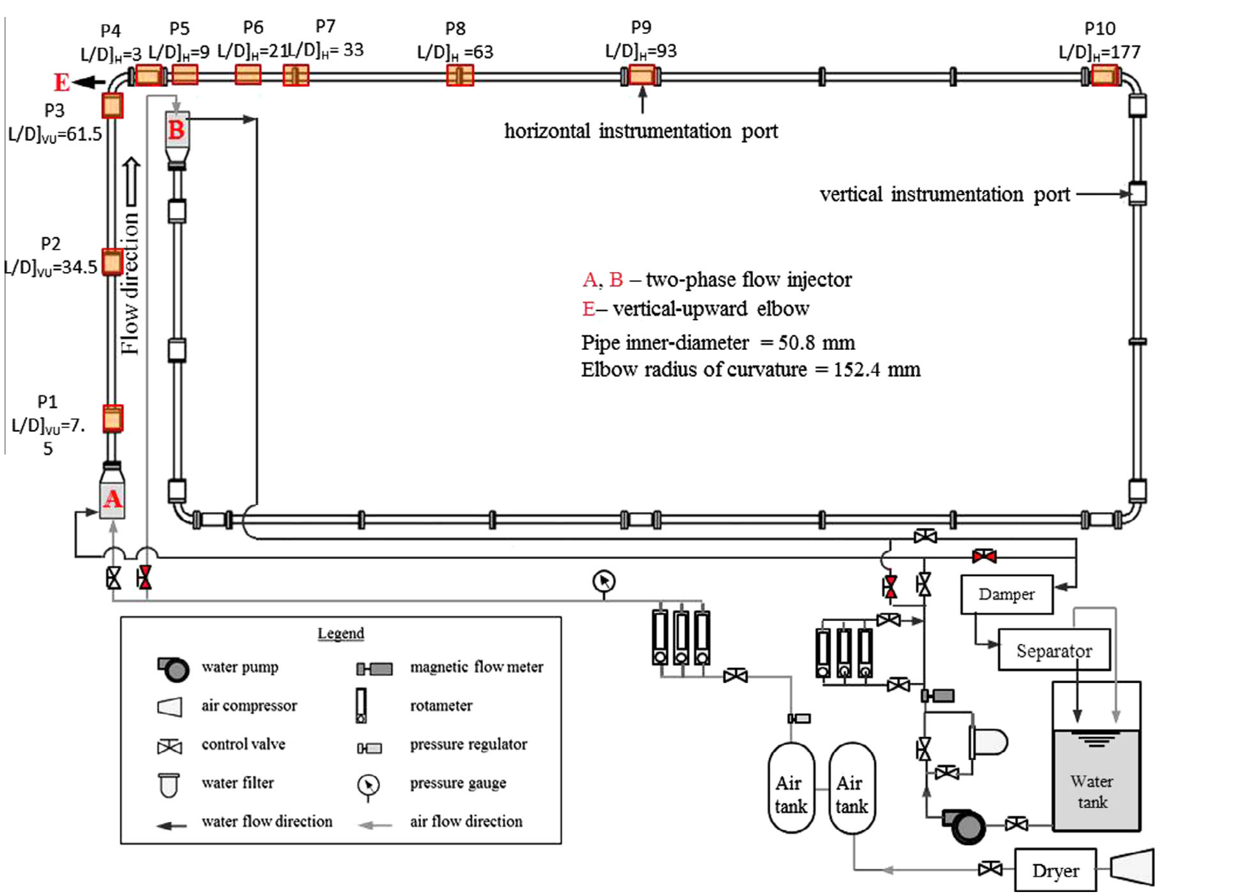

Fig. 1. Simplified schematic diagram of the test facility (not to the scale). For the current experiments, injector A is used as the inlet and injector B is used as the exit.