Investigation of Bubble Mechanisms of Cocurent Downward Flows through Packing

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1. Introduction

Two-phase flows through complex geometries such as rod bundle, contraction and expansion channels, and porous media are known to be extremely difficult to analyze due to interactions between gas and liquid phases. For a better design and understanding to gas-liquid interactions through complex geometries, investigations of bubble mechanisms are essential. The key interactions in bubbly flow regime are breakup and coalescence. For gas-liquid turbulent flows in a pipe, the mechanisms for bubble breakup and coalescence are attributed to bubble-to-bubble collision and bubble-to-turbulent eddies collisions [1,2,3,4,5]. In the cases of bubbly flows through complex geometries, bubble-to-wall collisions also need to be considered in bubble breakup and coalescence processes.

In this paper, bubble interactions through packing are investigated with a high-speed camera. First, bubble interactions are recorded and analyzed by using image processing techniques. Second, bubble interactions involving with geometry effects are identified. Finally, averaged behavior of bubbles are predicted and compared with experimental data.

2. Experimental facility

An adiabatic quasi two-dimensional channel with packing is designed to investigate bubble interactions with the aid of a high-speed camera shown in Fig.1 (a). The packing has diameter of 10 mm arranged in the equilateral triangular pattern shown in Fig.1 (b). The distance between the two adjacent packing is 12 mm, the thickness of the packing is 2.36 mm, the hydraulic diameter is 2.62 mm, and the porosity is 0.37. High-speed camera is recorded bubble images at 500 frames per second. The time interval between sequence of frames is 2 ms. As shown in Fig.2 the working fluids, ambient air and de-ionized water at room temperature, are supplied through a mixing head where air and water mix uniformly and are fed to the test section. This experimental facility is designed to simulate bubble breakup and coalescence dominated flows separately by adjusting appropriate flow rates.

3. Identifications of bubble interactions through packing

Two dominant coalescence mechanisms (compression and deceleration) and three dominant breakup mechanisms (shear, acceleration, and impact) were observed and discussed [6]. Compression coalescence and impact breakup are occurred while bubbles travel from upper pore to vertical channel. Deceleration coalescence is occurred while bubbles travel from vertical channel to lower pore. Shear breakup is occurred at lower pore. Acceleration breakup is occurred while a bubble travels from lower pore to horizontal channel.

Dominated bubble mechanisms corresponding to the average sized bubbles are compression and deceleration coalescence and shear breakup [7]. These mechanisms are shown in Fig.3.

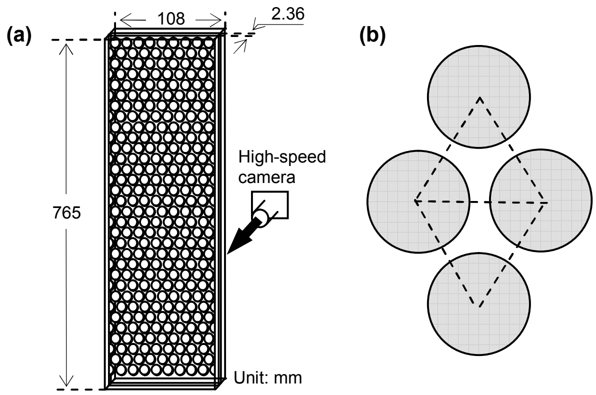

Fig.1. Schematic views: (a) test section and (b) packing arrangement

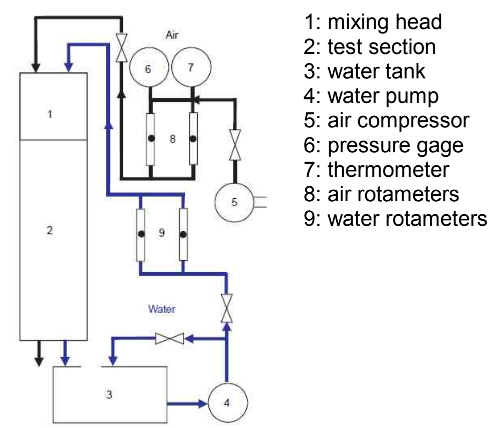

Fig.2. Schematic diagram of the experimental facility

4. Comparison

The choice of a commercial CFD solver is CFX-10.0 that utilizes population balance equations to describe bubble interactions of breakup and coalescence. The bubble interactions shown in Fig.3 are implemented into CFD analyses and averaged behaviors of bubbles are compared against experimental data in Fig.4 [7]. Fig.4 shows the median (averaged bubble size) variations for the dominant bubble breakup and coalescence flows. The best prediction has been made with the present model among other bubble interaction models. For the dominant bubble breakup flow, the predicted median is slightly higher than the experimental data. However, the predicted median is significantly higher than the experimental data for the dominant bubble coalescence flow.

Since the balance of bubble breakup and coalescence is found at the larger bubble size than the experimental data, appropriate median variations can be obtained by adjusting the breakup coefficient. In turbulent dispersed flows, breakup coefficient is a constant found experimentally to be equal to 0.25 by Martinez-Bazan et al. [3,4]. In our packing geometry, the critical bubble size can be found approximately 0.35. The median variations as a function of axial location estimated with the present model with the adjusted breakup coefficient are shown in Fig.3. The uncertainties of medians for the bubble breakup and coalescence dominated flows are ± 0.215 and ± 0.202 mm, respectively. The medians estimated with the present model fall within the uncertainties of medians.

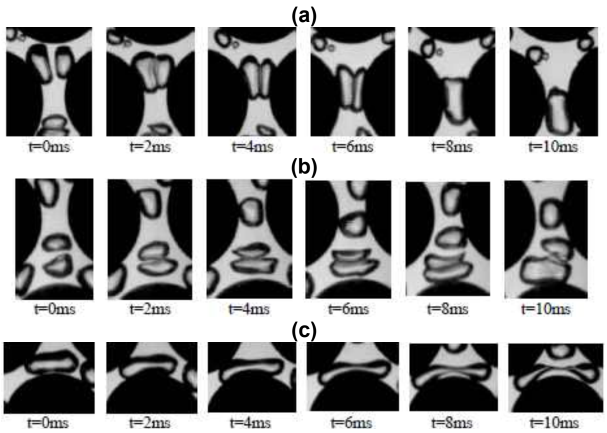

Fig.3. Bubble mechanisms: (a) compression coalescence, (b) deceleration coalescence, and (c) shear breakup

5. Discussion

A mechanistic model of bubble breakup and coalescence has been developed based on the experimental observations. Two dominant coalescence mechanisms (compression and deceleration) and three dominant breakup mechanisms (shear, acceleration, and impact) are observed and discussed. The bubble mechanisms corresponding to the average sized bubble are compression and deceleration coalescence and shear breakup. The averaged behaviors of bubbles along the axial direction are estimated under the two inlet flow conditions: bubble breakup and coalescence dominated flows. The bubble size medians predicted by existing models and the present model have been compared. The predictions made with the present model are comparable for the bubble breakup and coalescence dominated flows.

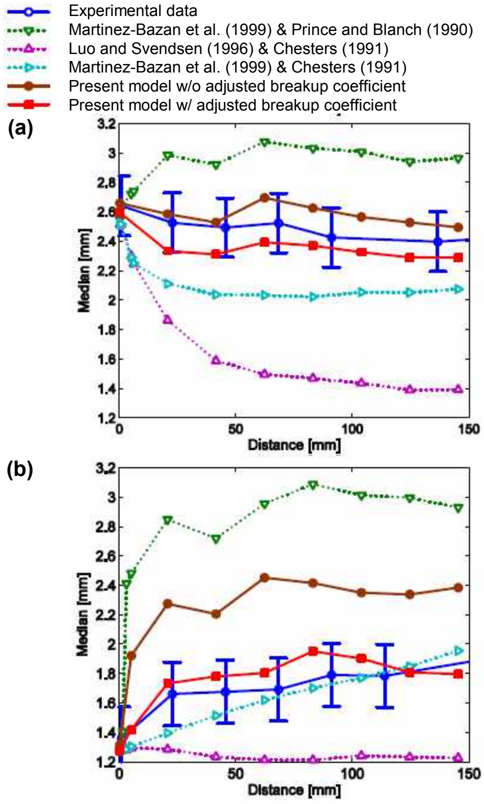

Fig.4. Axial averaged behaviors of bubbles: (a) bubble breakup dominated flow and (b) bubble coalescence dominated flow

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