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Effects of the gap size on the flow pattern maps in a mini-gap annular channel

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ABSTRACT

An experimental study has been performed to examine the effects of gap size on the flow pattern maps of air–water two-phase flow inside a mini-gap annular channel with inclination angles (θ) of 0°, 30°, and 60°. The tests are conducted for three different sizes of the inner diameters (D_i) of the concentric annular test section—namely 8, 10, and 11 mm—while the outer diameter is equal to 12.5 mm. The flow pattern maps are presented for various types of flow including plug flow, slug flow, annular/slug flow, annular flow, bubbly/plug flow, bubbly/slug–plug flow, churn flow, and dispersed bubbly flow, regarding the alteration of gap sizes and inclination angles. According to the experimental conclusions, the angle of inclination and the various gap sizes are influential in the transition of flow regimes.

1. Introduction

Two-phase gas–liquid flow in an annulus has many applications, such as cooling of electronic devices, nuclear and chemical reactors, and petroleum transportation [1]. Undoubtedly, knowing the flow patterns is necessary for designing a thermal engineering system, because the flow patterns affect the system's pressure loss and heat transfer rate. A considerable number of studies about two-phase liquid-gas flow in pipes have been performed [2–7]. However, there are relatively few studies about two-phase flow in an annulus. Below are briefly reviewed some of the studies concerning the two-phase gas–liquid flow inside an annulus.

Julia and Hibiki [1] presented a new model for flow regime transition of two-phase flow of air–water in a vertical annulus. They considered bubbly, slug or cap–slug, churn, and annular flow regimes.

Ekberg et al. [8] investigated the flow patterns of two-phase flow between two horizontal narrow concentric cylinders. The flow patterns were churn, slug/plug, stratified, stratified–slug, annular–slug, bubbly–plug, and dispersed bubbly.

Dillon et al. [9] tested the effects of channel vibration and wall gas injection on pressure drop of two-phase flow of air–water mixture in a narrow horizontal annulus where inner and outer diameters of the annulus were 7.93 mm and 9.53 mm, respectively.

Wongwises and Pipathattakul [10] investigated the effects of different angles of a narrow annular channel on flow patterns, pressure drop, and void fraction of water–air mixture. The flow patterns in their experiments were plug flow, slug flow, annular/slug flow, annular flow, bubbly/plug flow, bubbly/slug–plug flow, churn flow, and dispersed bubbly flow.

Metin and Ozbayoglu [11] presented correlations of friction factors for two-phase flow in a horizontal eccentric annulus where two sizes of annulus were investigated. Flow patterns in this work were stratified and intermittent.

Julia et al. [12] studied the axial development of four flow regimes—bubbly, cap–slug, churn, and annular—in adiabatic air–water two-phase upward flow in a vertical annulus. Subsequently, Julia et al. [13] examined radial and axial development for the same flows as in Julia et al. [12].

Recently, Ozar et al. [14] experimentally studied two-phase flow of steam–water in a vertical annular channel where the flow patterns were bubbly, cap–slug, and churn-turbulent.

As mentioned above, the two-phase flow in annulus has been studied by some researchers. To the best of our knowledge,

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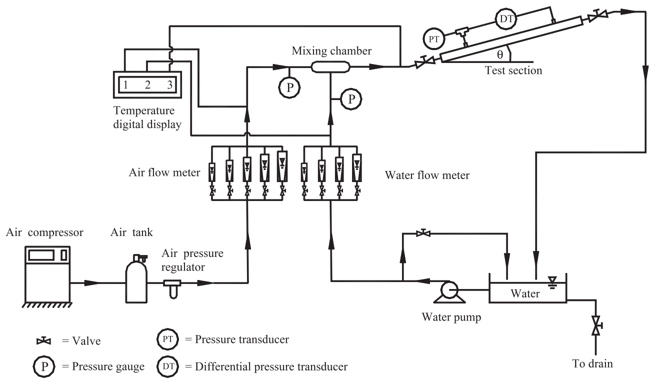

Fig. 1. Schematic diagram of the experimental setup (Wongwises and Pipathattakul [10], with permission from Elsevier).

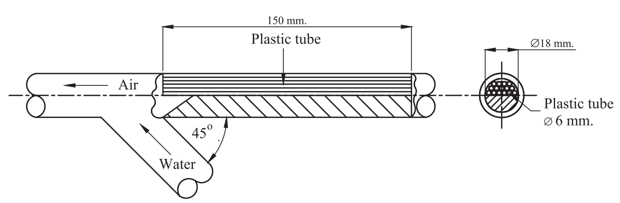

Fig. 2. Schematic diagram of the mixing section (Wongwises and Pipathattakul [10], with permission from Elsevier).

however, the effects of gap size on the flow pattern maps in an annular mini-channel remain unstudied. In the present study, the main concern is to investigate the effects of gap size of an inclined annulus on flow pattern maps. The researchers consider various types of flow, including plug flow, slug flow, annular/slug flow, annular flow, bubbly/plug flow, bubbly/slug–plug flow, churn flow, and dispersed bubbly flow. For this work the experimental setup of Wongwises and Pipathattakul [10] is improved to examine the effect of gap size.

2. Experimental set-up and procedure

The schematic view of the experimental set-up is shown in Fig. 1. The experimental setup includes four main sections: a water supply, an air supply, a mixing chamber (Fig. 2), and the test section (Fig. 3). Air and water are delivered to the mixing chamber by an air compressor and a water pump, respectively. Before they enter the mixing chamber, the mass flow rate of air and water are measured by rotameters with accuracy of ±2%. After mixing, water and air are pumped towards a mixing chamber before entering the test section. Air and water pressures are measured at the inlet of the mixer by precision Bourdon tube pressure gauges, while the temperatures are measured with thermocouples of T-Type with an accuracy of ±0.1 °C. The mixture of air and water enters the test section, which can be mounted at different angles. The test section consists of two concentric transparent tubes made of acrylic glass. The outer tube has a diameter of 12.5 mm, while three different tubes, with sizes of 8, 10, and 11 mm, are used as the inner tube. The length of the annular is 880 mm. The pressure at the inlet of the test section is measured with a pressure transducer with accuracy of ±20 mbar. A differential pressure transducer was installed in the test section within the length of 420 mm, to measure the pressure drop across the test section. After and before the test section, two valves are installed. When the mixture flows through the test section, the valves are closed simultaneously and the flow patterns are recorded with a high-speed camera. Tests are conducted at three sizes of gap and different angles of test section inclination. More details of the experimental set up are given in Wongwises and Pipathattakul [10].

3. Results and discussion

Before presenting the flow pattern maps, some definitions will be presented about different types of flow for better understanding of the graphs. Here follows a brief description of different types of flows [10]:

(a) *Plug flow (P):* The bubbles are formed on the upper side of the tube at a relatively low air velocity, and the size of the bubbles is large.
(b) *Slug flow (S):* The interface between water and air is unstable and wavy. The waves formed in the tube block the whole tube section and then will be removed by the air, which flows in high velocities.
(c) *Annular flow (A):* The water is in contact with the walls while the air flows in the central section of the annulus.
(d) *Annular/slug flow (A/S):* Formation is similar to annular flow, except for some frequent appearances of water slug.
(e) *Bubbly/plug flow (B/P):* With increasing the air velocity, the bubbles are combined together so that they form as a bullet. These bullets flow parallel with the liquid flow, which contains smaller bubbles.
(f) *Bubbly/slug–plug flow (B/S–P):* It is similar to the bubbly/plug flow but larger bubbles are formed because of the higher mass flow rate of air.
(g) *Churn flow (C):* The bubbles in slug flow break down which leads to an oscillatory motion. This happens when the air velocity is high, compared with liquid velocity.
(h) *Dispersed bubbly flow (Db):* Liquid flow is continuous and contains small bubbles.
(i) *Slug/bubbly flow (S/B):* The liquid slug contains a dispersing of small bubbles.

Figs. 4 and 5 show two-phase flow data and flow pattern maps for a test section having $D_i = 10$ mm, $D_o = 12.5$ mm, $\theta = 0°$ and $D_i = 11$ mm, $D_o = 12.5$ mm, $\theta = 60°$, respectively. The solid lines in

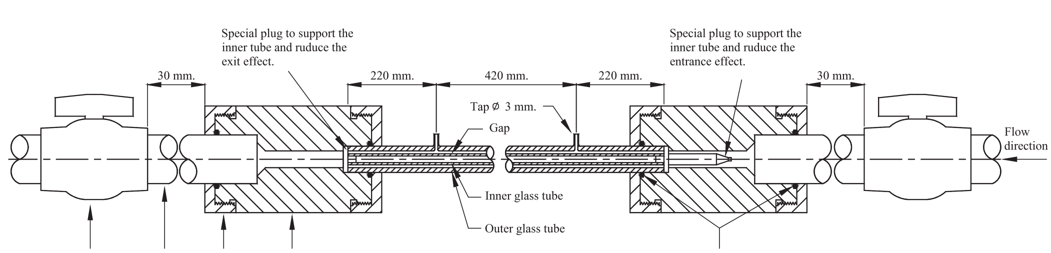

Fig. 3. Schematic diagram of the test section (Wongwises and Pipathattakul [10], with permission from Elsevier).