

Comparative Study between Gas-Liquid and Liquid-Liquid Flow through Small Diameter Pipe

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Submitted: 18 Sep 2018; Accepted: 25 Sep 2018; Published: 05 Oct 2018

Abstract

In present study, the flow patterns of air – water and toluene – water have been investigated experimentally in vertical and horizontal milli channel. The flow regimes were investigated by a high speed video recorder in pipe with diameters of 2 mm. The comprehensive visualization of air - water, two - phase flow in a vertical and horizontal milli channel has been performed to realize the physics of such a two - phase flow. Different flow patterns of toluene – water flow were observed simultaneously in the milli channel at different values of toluene and water flow rates. Consequently, the flow pattern map was proposed for flow in the milli - channel, in terms of superficial velocities of liquid and gas phases.

Keywords: flow pattern, two - phase flow, superficial velocities, milli channel

Introduction

Growing interest on liquid - liquid and gas – liquid flow in various process industry and petrochemical industries is the driving force of the present study [1]. The phases can distribute themselves into various flow patterns or flow regimes depending on the fluid properties, the relative flow rates of the fluids, entrance geometry, pipe diameter and pipe inclination, during two-phase flow in pipe [2-4]. It is very difficult to understand the phenomena of two - phase flow without a clear understanding of the flow pattern maps. Flow pattern maps are usually predicted by visual and photographic evidences. Among these flow patterns, slug, annular and bubbly flow are occupied most of the area of the flow pattern map during gas – liquid and liquid – liquid flow [5]. Moreover, the density difference is less in liquid - liquid systems as compared to gas-liquid flows. As a result, there is a larger tendency of stratification and delayed initiation of dispersion in gas - liquid systems. Since wall-wetting properties and interfacial force become more important in liquid - liquid systems, the pipe material is often observed to play an important role on the interfacial distribution of the two phases [6-9]. Further, the viscosity ratio can vary over a wide range in the latter case thus adding to the complexity of the situation.

Flow of a mixture of two immiscible liquids is mostly encountered in various industrial processes, such as the petroleum industry where oil and water are often produced and transported together, the pharmaceutical industry where tubular reactors of small diameter are sometimes used for continuous production and the fine chemical industry where micro reactors have been used to intensify mass transfer limited reactions [7]. Optimal design of such facilities relies on substantial knowledge of the flow inside a pipe.

Experimental setup and procedure for air water two phase flow Extensive experiments have been performed to investigate of air water and toluene water two phase flow in a pipe of 2 mm diameter.

Experimental set up for gas – liquid flow

The experimental set - up used in this study is designed for flow of air – water mixtures in round horizontal and vertical tubes. A schematic diagram of the set up is shown in Figure 1. The setup comprises of fluid handling devices (pump, flow meters, storage tanks), test section (TS) and T - junction. Distilled water was pumped into the test loop by a water pump from an open tank. Both the liquid and gas streams flowed separately through a bank of rota meters before entering the gas-liquid mixer. The two-phase gas-liquid mixture then enters the test section.

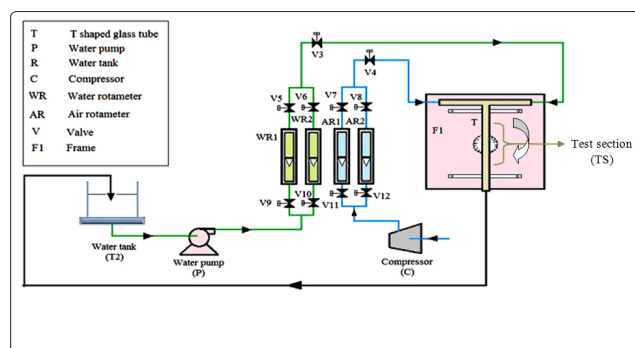


Figure 1: Schematic diagram of experimental setup for gas – liquid flow

Experimental set up for liquid – liquid flow

A schematic of the experimental set up is shown in Figure 2 for investigation of liquid – liquid flow. It comprises of a capillary glass tube of length 0.8 m and diameter 2 mm. A photograph of the micro-channel is given in Figure 2. The pumps have capacity

ranging from 0 to 3.33×10^{-6} m³/s. The inflows of the test fluids are metered using pre-calibrated rotameters (R1 and R2). The fluids enter the separator (S) after flowing through the test and exit sections. The flow patterns for different combinations of toluene and water superficial velocities are observed visually and photographed by a high-speed digital camera (DSCH9, Sony).

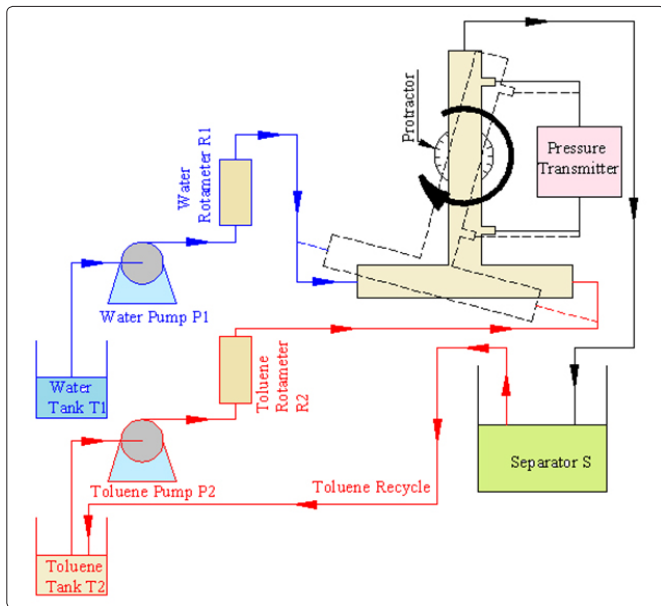


Figure 2: Schematic diagram of experimental setup for liquid – liquid flow

Upward flow in vertical pipe

A number of different flow patterns are observed during upward flow of air and water in 2 mm tube diameter. A schematic of flow pattern and their range of existence are given in the flow pattern map Figure 3 (a). The map shows that at lower to moderate phase superficial velocity ($U_{sa} = 0.025 - 0.2$ m/s and $U_{sw} = 0.025 - 8$ m/s), air slugs propagate through the continuous water phase. The air slugs assume a Taylor bubble like shape and hence this flow pattern is termed as the “slug flow pattern”. At very high water ($U_{sw} > 0.1$ m/s) velocity and low air flow rate ($U_{sa} < 0.09$ m/s) slug to bubbly transition regime has been observed [10]. The pattern exhibits bubbly flow characteristics with further increase in water velocity at low air flow rates. As the air velocity is increased (> 6.32 m/s) at low to moderate water velocity ($0.06\text{m/s} < U_{sw} < 0.18\text{m/s}$) the pattern exhibits annular flow. A schematic of flow pattern and their range of existence are given in the flow pattern map Figure 3 (a) for liquid – liquid flow. It can be observed from this figure that at low to moderate superficial velocity of toluene results in slug flow pattern [11 - 14]. At high superficial velocity (0.5 m/s to 0.9 m/s) of toluene with low velocity of water (0.1 m/s to 0.4 m/s) annular flow was observed.

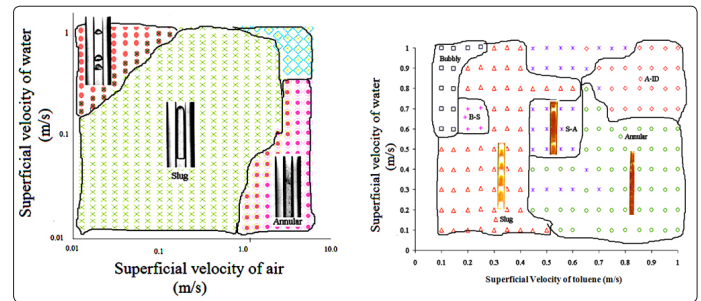


Figure 3: Flow pattern map for 2 mm diameter pipe

- (a) air – water up flow
- (b) toluene – water up flow

Horizontal flow in pipe

A schematic of flow pattern and their range of existence are given in the flow pattern map of Figure 4(a). The Figure shows that at lower phase flow rate slug flow has been observed in 2 mm diameter pipe. This pattern extends for the range of 0.02 m/s to 9 m/s of air velocity and 0.02 m/s to 0.1 m/s of water velocity with further increase in water velocity, the pattern exhibits bubbly flow. Figure 4 (b) shows the flow pattern map for liquid – liquid two phase flow. At low to moderate velocity of water and toluene (0.01 m/s to 1 m/s) slug flow regime was observed. At very high velocity (> 1.5 m/s) of toluene with low velocity (up to 2 m/s) of water annular flow was observed [15]. A survey of the past literature shows that annular flow is the natural flow pattern for gas – liquid down flow [15 - 20].

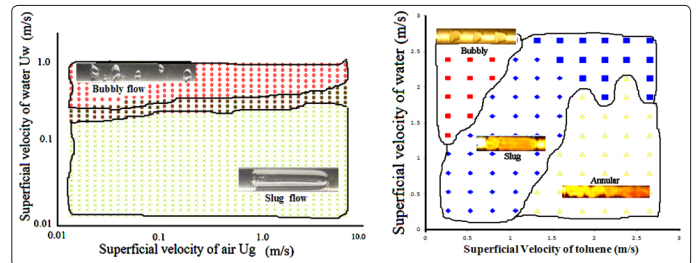


Figure 4: Flow pattern map for 2 mm diameter pipe

- (a) air – water horizontal flow
- (b) toluene – water horizontal flow

Down in vertical pipe

The map (Figure 5(a)) shows the pattern at low water velocity and low to moderate air flow rates is annular. As the water velocity is increased further, bullet shaped Taylor bubbles is form this flow pattern is termed as the “slug flow pattern”. Figure 5(b) shows the flow pattern map for liquid – liquid two phase flow towards down direction. Bubbly flow was observed at high superficial velocity (1.5 m/s to 2.5 m/s) of water and low velocity of toluene (0.1 m/s to 1 m/s). Bubbly flow as shown in Figure 5(b) is characterized by spherical or non-spherical bubbles which may be of a size equivalent or less than that of the channel diameter [17]. At low to moderate velocity of toluene and water slug flow was observed. With increasing velocity of toluene from 1 m/s to 2.5 m/s at low to moderate velocity of water, annular flow was observed.

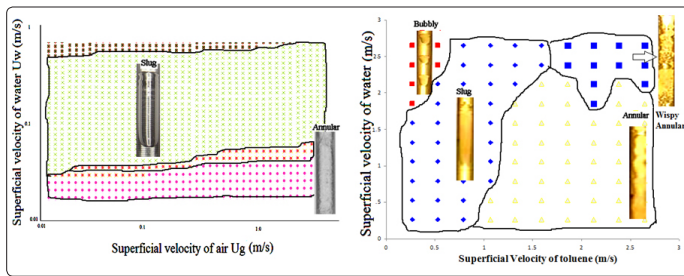


Figure 5: Flow pattern map for 2 mm diameter pipe (a) air – water down flow (b) toluene – water down flow

Conclusions

The flow pattern maps of liquid – liquid two phase flow were constructed for two components, water and toluene. Three flow regimes were found namely, bubbly, slug and annular for liquid–liquid two phase flow. At high superficial velocity (0.5 m/s to 0.9 m/s) of toluene with low velocity of water (0.1 m/s to 0.4 m/s) annular flow was observed during up flow through vertical pipe. At low to moderate velocity of water and toluene (0.01 m/s to 1 m/s) slug flow regime was observed during horizontal liquid – liquid two phase flow. Annular flow pattern was not observed in the horizontal tubes even at high - gas velocities. During up gas – liquid flow, at very high water ($U_{sw} > 0.1$ m/s) velocity and low air flow rate ($U_{sa} < 0.09$ m/s) slug to bubbly transition regime has been observed. The pattern exhibits bubbly flow characteristics with further increase in water velocity at low air flow rates.

Acknowledgement

Funded by CVRCE, Bhubaneswar

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