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Air-Water Two-Phase Flow through Small Diameter Pipes

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Abstract

In this study, the flow patterns of air - water, two-phase flows have been investigated experimentally in a vertical and horizontal milli channel. The flow regimes were observed by a high speed video recorder in pipes with diameters of 2 mm, 5.5 mm and 8.5 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 air-water flow were observed simultaneously in the milli channel at different values of air 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

The phases can distribute themselves into different flow patterns or flow regimes depending on the relative flow rates of the fluids, tube diameter, inclination and surface wettability during two - phase flow in pipes [1-4]. The behavior of a single gas bubble released in a column of liquid contained in a vertical tube depends on the size of the bubble and diameter of tube [5]. A single gas bubble moving under the influence of gravitational, inertial, viscous and interfacial forces, relative to another fluid contained in a vertical cylindrical tube. Two-phase flows through millimeter channels may exhibit different behaviors due to the surface tension becomes significant in small-size channels [5-9]. Wall effect is important for millimeter channel. As the diameter of the circular tubes became small, the upward motion of the gas bubble is slowed down, and ceases completely when the tube size was sufficiently reduced (diameter less than 5 millimeter for air-water) [9]. Fluid-surface interaction can become dominated in small - channel. Gas-liquid flow in small channel is importance in a wide range of technical applications process [9-12]. Examples include heat transfer system, steam generation, numerous chemical industrial processes such as continuous loop reactors, bubble column reactors and monolithic reactors for fine chemical industries. In nuclear power plants and boilers, gas or vapor phase contained in a working two - phase flow plays an important role in determining the overall heat transfer efficiency of the system [12-15]. For example, boiling heat transfer and frictional pressure loss in a system depend on the behavior and volume of the gas phase. The two-phase flow behavior is very complicated even in an adiabatic two-phase flow system [14-18]. This complexity is due to the complicated interfacial forces between the two phases exerted by surface tension and fluctuations of pressure and velocity. In this paper experimental observation of air-water down, up and horizontal flow in different pipe diameters are presented [12]. Experiments have been performed over a wide range of superficial velocity of both the phases to investigate the hydrodynamics of air-water flow through small diameter pipes. The present industrial trend has also triggered the demand for a comprehensive understanding of the hydrodynamics of two-phase flow through such small diameter pipes in order to advance their design and process control [15].

Experimental Setup and Procedure for Air Water Two Phase Flow

Extensive experiments have been performed to investigate of air water two phase flow in different pipe diameters.

Experimental Setup

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 and the corresponding photograph of a part of the setup is shown in Figure 2. The setup comprises of fluid handling devices (pump, flow meters, storage tanks), test section (TS) and T - junction. Distilled deionised 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.

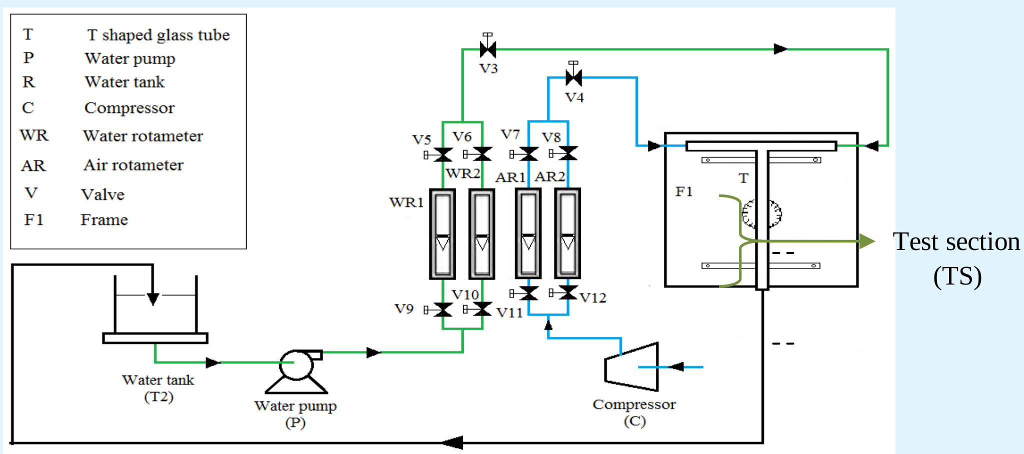

Figure 1: Schematic diagram of experimental setup.

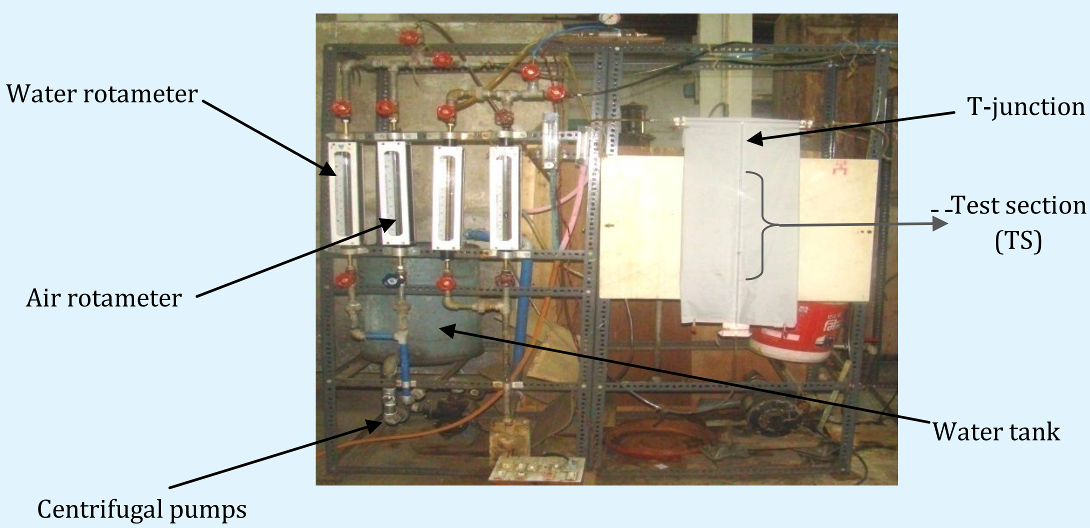

Figure 2: Photographical view of experimental setup.

T - Junction

An enlarge diagram of the entry zone is shown in Figure 3. In two phase flow setup a glass tube with a T shaped entry section is pivoted to a wooden frame. The test section are made of borosilicate glass comprising of equal diameter arms (D_1 = D_2 = D_3). Air and water are introduced at the two branches. From the T - junction, the two fluids enter the test section. After the test section they are introduced in a separator. Water is recycled back to the main tank and air is escapes to the atmosphere.

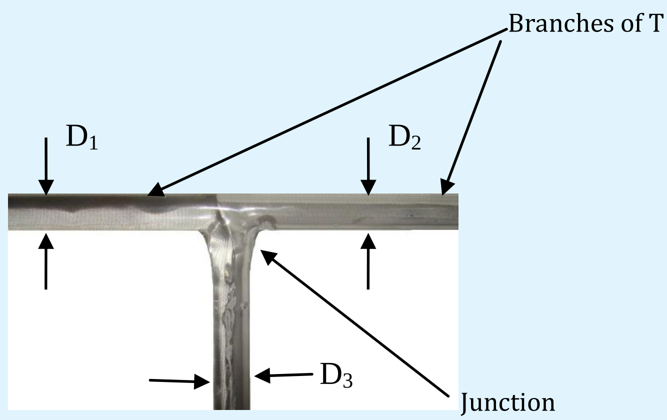

Figure 3: Photographical view of T-junction.

Flow Rate Measuring Devices

A pair of calibrated rotameters WR1 and WR2 of different ranges are connected in parallel to measure the flow rate of water. Similarly air flow rate is measured by rotameters AR1 and AR2. The rotameter for water range from 0 to 2 LPM with a list and for air range from 0 to 2 LPM. The rotametrs with two different ranges has been installed in pipes to enable flow rate over a wider range. The rotameter have been calibrated by the standard method of noting the volume of the liquids collected over a measured interval of time [5,8].

Fluid Circulation System

Water is stored in tank of capacity 0.2 m^3 and circulated from tank to the test section by centrifugal pump (P in Figure 1) of 1.5 hp each. Air is circulated by a reciprocating compressor. The simultaneous adjustment of the bypass valves control the flow of the respective phases (Table 1).

Equipment	Specifications			
Centrifugal pumps	Head= 30 m of water, capacity=0 - 120 lpm			
Compressor	Capacity =0-160 lpm, test pressure = 19.8 kgf/cm2			
Rotameters		**Range**	**Least count**	**Accuracy**
	Water	0 - 10 lpm	0.1 lpm	± 1%
		10 - 100 lpm	1 lpm	± 2%
	Air	0 - 100 lpm	2 lpm	± 2%
		0 - 1.5lpm	0.05 lpm	± 2%

Table 1: Specifications of the equipment used.

Experimental Technique

Before initiation of the experiments rotameters are calibrated for both water and air. Then water is introduced in the T-junction by operating the valves (V5, V6, V9, and V10). The flow of water is initiated before the entry of air, so that the pipe wall is wetted by water. After adjusting the water flow rate, air at the required flow rate is introduced in the T-junction by operating the valves (V7, V8, V11, and V12). mixing is occur at junction and two phase mixture flows through the test section In order to estimate the flow patterns or flow regimes during the simultaneous flow of the two fluids, experiment have been carried out for different combination of two fluids. Air velocity is increased at a constant water velocity. The flow patterns for different combinations of air and water superficial velocities are observed visually and photographed by a high speed digital camera (SONY DSC-F717).

Results and Discussion

Identification of Flow Pattern from Visual and Photography

The Flow pattern as observed from visual and photographic recording has been discussed for different orientation of tubes and for different tubes diameter in this section. A digital still camera is used with proper light arrangement for photography. The specification of camera is mention in chapter 3. The ranges of existence of the different patterns have also been depicted in the form of flow pattern maps. The superficial velocities of both the phases have been selected as the co-ordinate axes.

Air-Water Two Phase Upward Flow in Vertical Pipes

A number of different flow patterns are observed during upward flow of air and water in 5.5 mm tube diameter. A schematic of flow pattern and their range of existence are given in the flow pattern map of Figure 4 and Figure 7 respectively. The map shows that at lower to moderate phase superficial velocity (Usa = 0.025 - 0.2 m/s and Usw = 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 (Usw > 0.1 m/s) velocity and low air flow rate (Usa < 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. As the air velocity is increased (> 6.32 m/s) at low to moderate water velocity (0.06m/s < Usw < 0.18m/s) the pattern exhibits annular flow.

Air Water Two Phase Downward Flow in Vertical Pipes

A schematic of flow pattern and their range of existence are given in the flow pattern map of Figure 7 and a few photographs of the various flow patterns are presented in Figure 5. The Table shows that such a lower phase flow rate smooth stratified flow has been observed in 5.5 mm diameter pipe. This pattern extends for the range of 0.06 m/s to 2 m/s of air velocity and 0.06 m/s to 0.25 m/s of water velocity with further increase in water velocity, the pattern exhibits annular flow. At very high water velocity (> .7m/s) slug flow regime has been observed. A survey of the past literature shows that annular flow is the natural flow pattern for gas-liquid down flow [18-22].

Air Water Two Phase Flow in Horizontal Pipes

The map (Figure 5(b)) shows the pattern at low water velocity and low to moderate air flow rates is stratified. Bubbly flow as shown in Figure 5b is characterised by spherical or non-spherical bubbles which may be of a size equivalent or less than that of the channel diameter. At high liquid and moderate gas velocities, spherical bubbles were observed as shown in Figure 4a and with further increase in gas velocity, the size of the bubble reduces, and the frequency with which the bubbles appear increases. A smooth interface has been observed in the range of flow velocities used in the present study. As the water velocity is increased further, bullet shaped Taylor bubbles is form this flow pattern is termed as the “slug flow pattern”. At very high water velocity and low to moderate air velocity the air bubbles are cap shape or oblate spheroridal it is therefore name as bubbly flow pattern (Figure 6) (Figure 6).

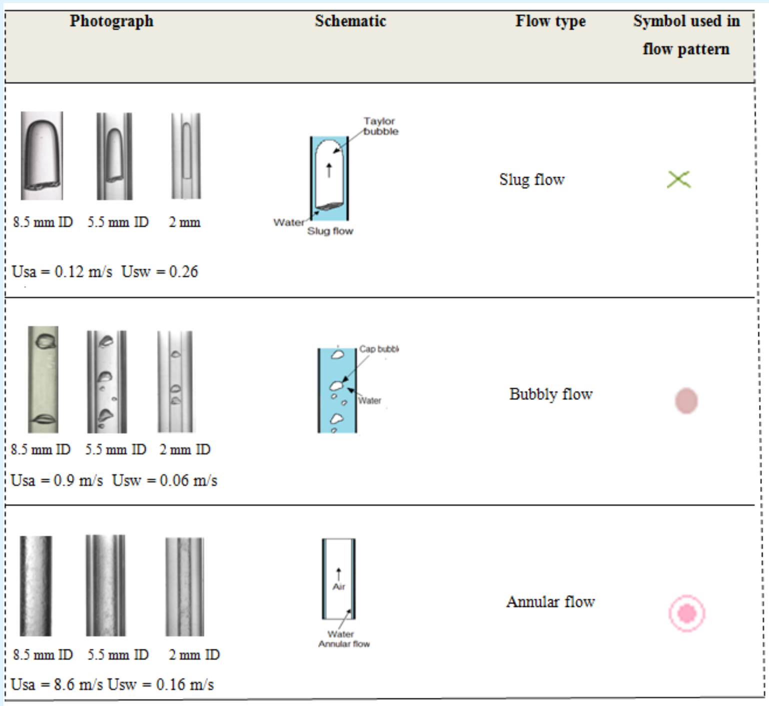

Figure 5: Photograph and schematic representation of air water two phase up flow in vertical tubes.

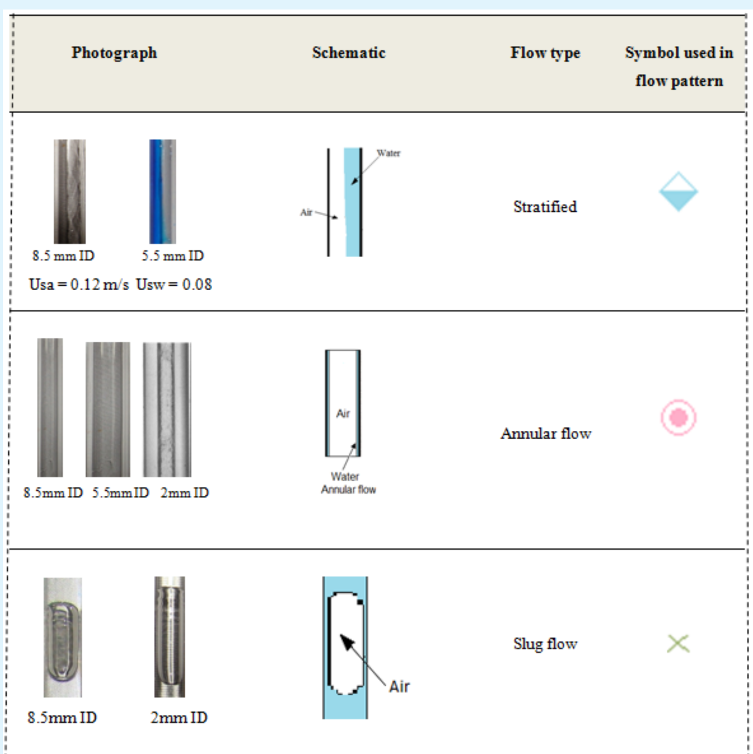

Figure 6: Photograph and schematic representation of air water two phase down flow.

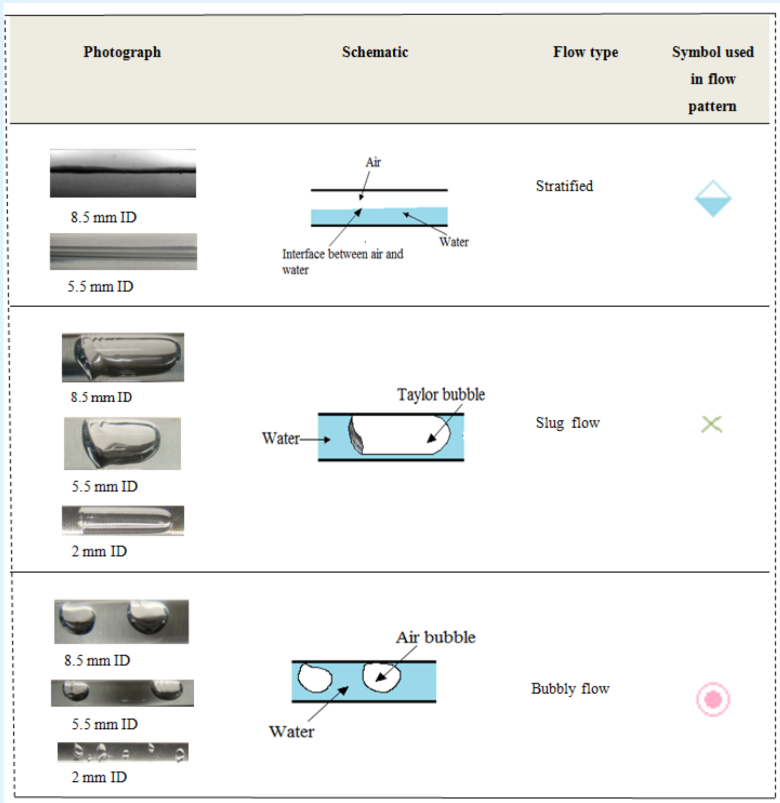

Figure 7: Photograph and schematic representation of air water two phas flow in horizonta tubes.

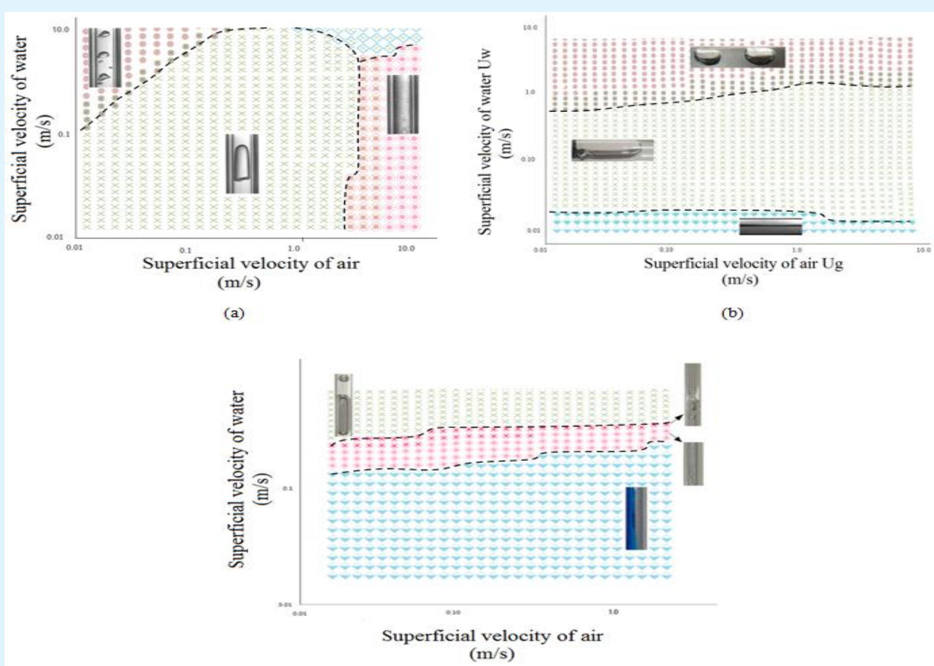

Figure 8: Flow pattern map for 5.5 mm diameter pipe (a) Up flow (b) Horizontal flow (c) Down flow.

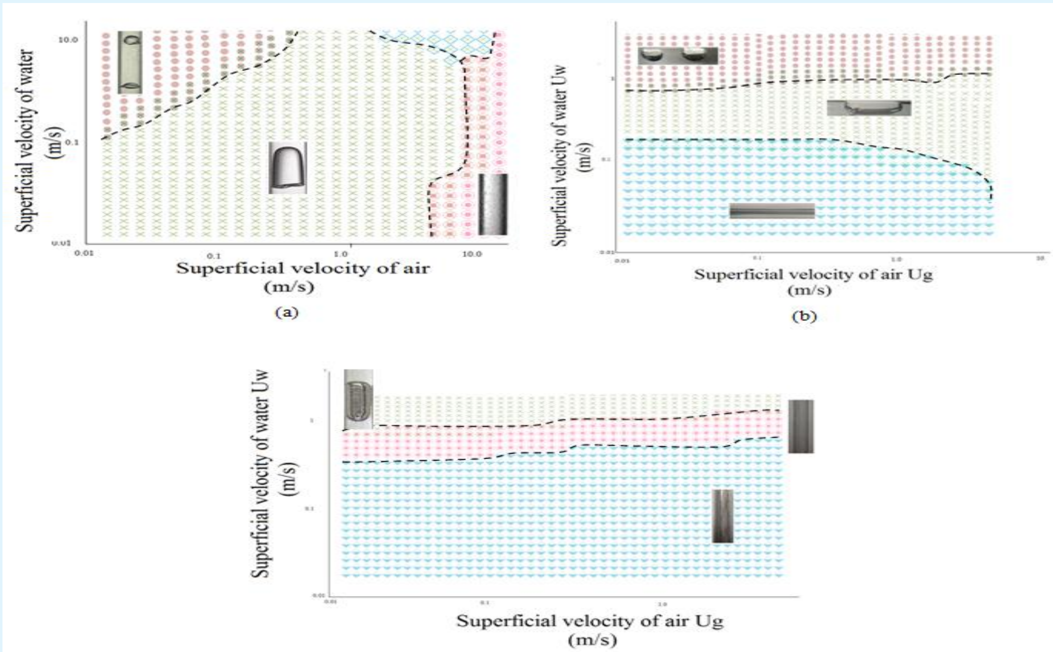

Figure 9: Flow pattern map for 8.5 mm diameter pipe (a) Up flow (b) Horizontal flow (c) Down flow.

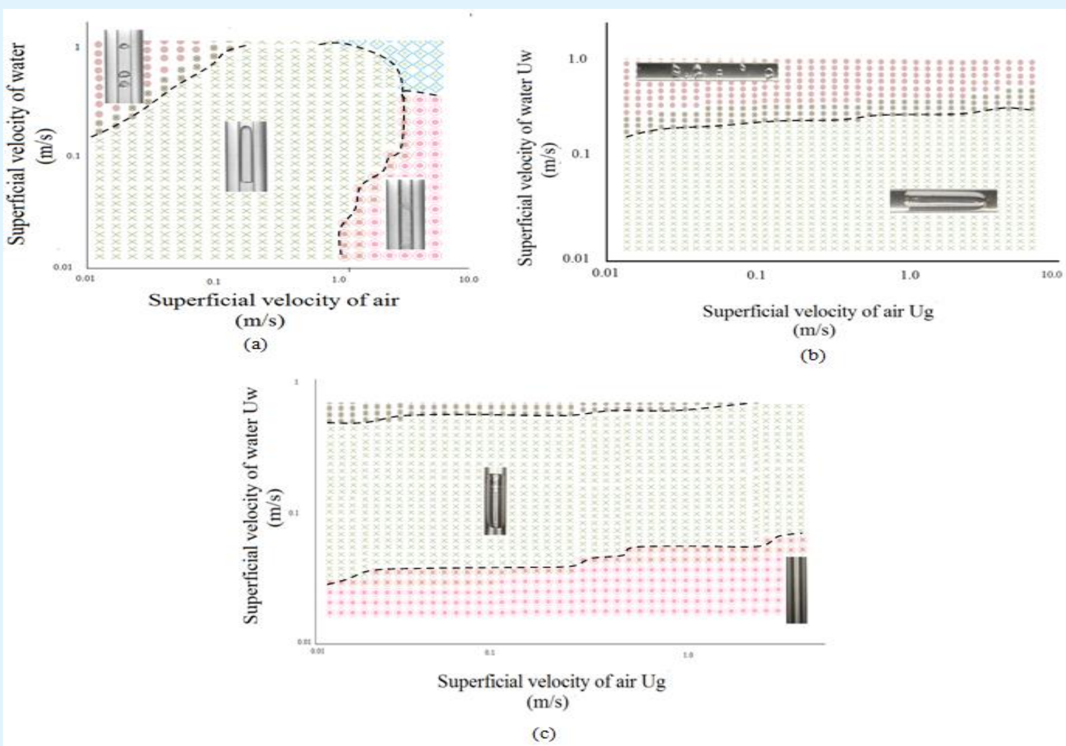

Figure 10: Flow pattern map for 2 mm diameter pipe (a) Up flow (b) Horizontal flow (c) Down flow.

Effect of Pipe Diameter

Observed flow patterns were bubbly, slug, annular, stratified and annular flow are shown in Figure 4 to Figure 6. The flow pattern map has been compared for different tube diameter (2 mm, 5.5 mm and 8 mm) to understand the influence of pipe diameter on the hydrodynamics of air - water flow. Flow map similar for 5.5 mm and 8 mm pipe but drastic differences in flow distribution of 2 mm pipe. In case of horizontal flow at lower phase flow rate smooth stratified flow has been observed in 8.5 mm and 5.5 mm pipes. There is no existence of stratified flow in 2 mm horizontal pipe probably due to pronounced wall effect in this case. At moderate water superficial velocity and low to moderate air flow rate the patterns become slug flow for all cases. This flow pattern appears water velocities greater than 0.3 m/s for 8.5 mm, 0.035 m/s for 5.5 mm, 0.015 m/s for 2 mm tube diameter. At higher water velocities bubbly flow appears in pipes. Another interesting point is that bubbly flow stars at higher phase flow rates in small diameter tube as compared to large one. This is probably because the effect of interfacial tension is higher in 2 mm diameter pipe compared to that in 8.5 mm pipe.

In case of down flow in vertical tubes smooth stratified flow has been observed in 8.5 mm and 5.5 mm diameter pipe at lower phase velocity. With increase in water velocity annular flow has been observed in 8.5 mm and 5.5 mm tubes. There is no existence of stratified flow in 2 mm diameter. At lower phase flow rate the pattern exhibits annular flow for 2 mm pipe diameter and with increase in water velocity slug flow has been observed in 2 mm diameter tube.

In case of flow up in vertical tube, slug flow has been observed for all cases at low to moderate phase velocity. The pattern exhibits annular flow characteristics with increase in air velocity at low to moderate water flow rates in all pipe diameters. This flow pattern appears air velocities greater than 9 m/s in 8 mm, 6.32 m/s in 5.5 mm and 1.25 m/s in 2 mm, tube diameter (Figures 11-13).

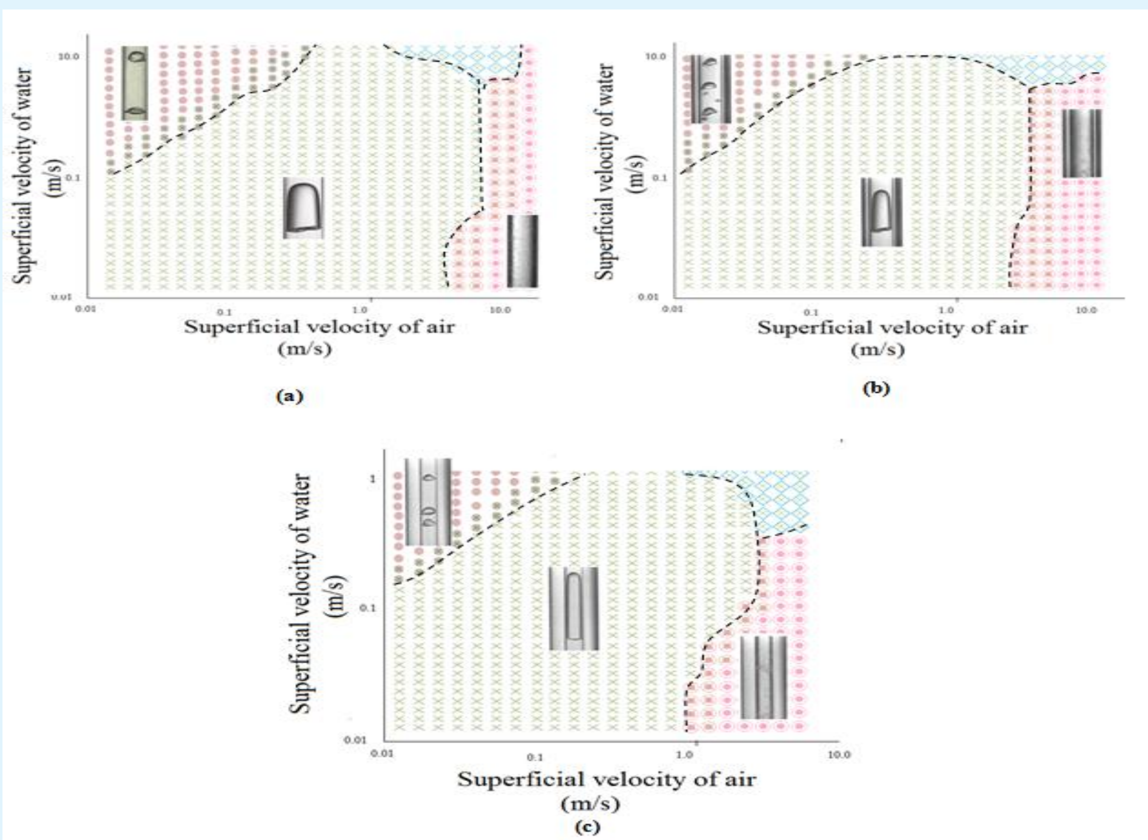

Figure 11: Flow pattern map for up flow (a) Pipe diameter is 8.5 mm (b) Pipe diameter is 5.5 mm (c) Pipe diameter is 2 mm.

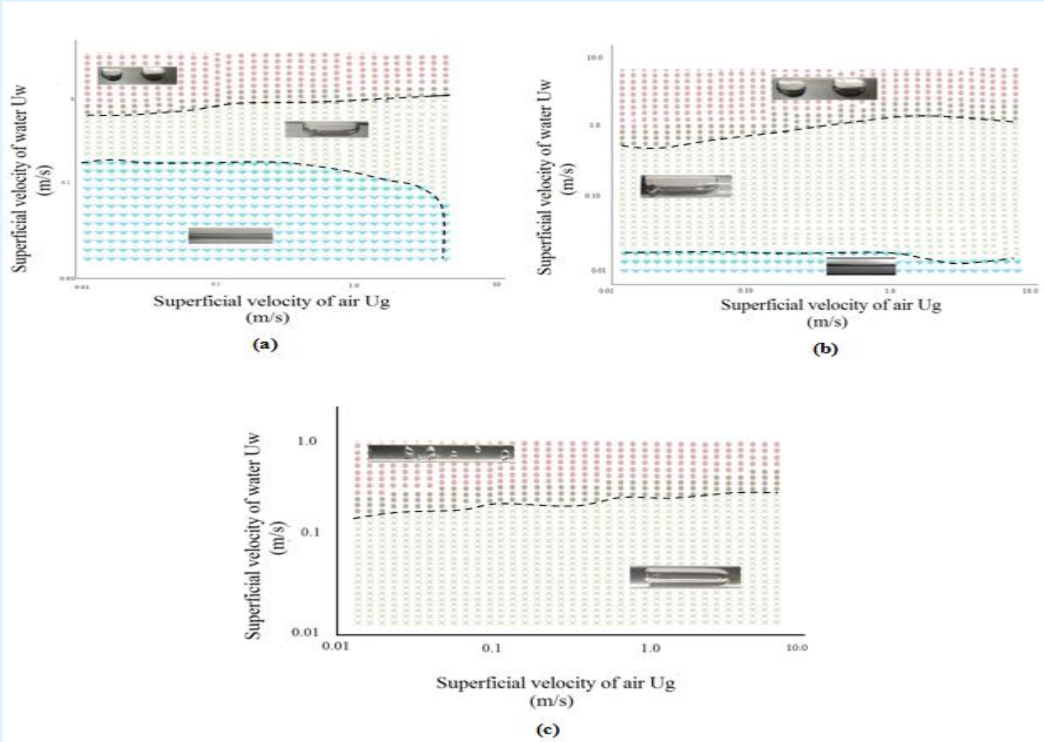

Figure 12: Flow pattern map for Horizontal flow (a) Pipe diameter is 8.5 mm (b) Pipe diameter is 5.5 mm (c) Pipe diameter is 2 mm.

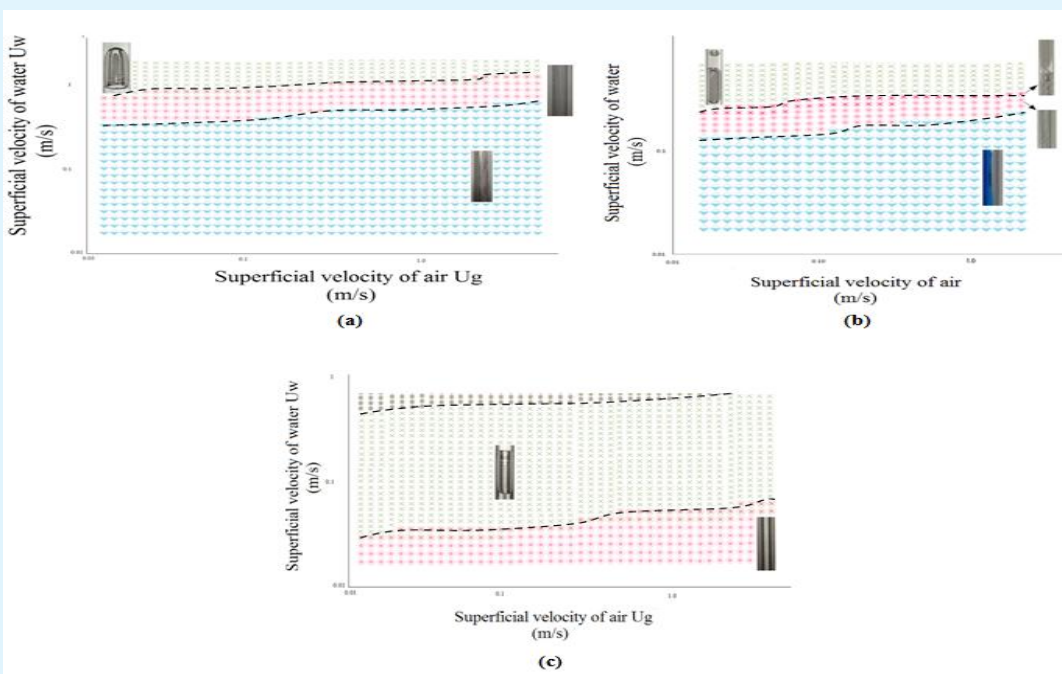

Figure 13: Flow pattern map for down flow (a) Pipe diameter is 8.5 mm (b) Pipe diameter is 5.5 mm (c) Pipe diameter is 2 mm.

Conclusion

In this paper, air - water, two - phase flow patterns were investigated experimentally for milli channels with diameters of 2 mm, 5.5 mm and 8.5 mm. An image processing technique was used for detection of flow patterns from pictures derived from films recorded with a high speed digital camera. The obtained flow patterns reveal that there is no noticeable difference between two - phase, upward flow patterns in this range of diameters. Similarly flow pattern was observed in 8.5 and 5.5 mm diameter tubes for down flow. Annular flow pattern was not observed in the horizontal tubes even at high-gas velocities. In the 2 mm diameter tube, slug flow is characterised by breaking of the longer slugs followed by shorter slugs. A new flow pattern map was achieved for vertical milli channels, due to a comparison of the flow patterns of these three diameters of pipe. In case of horizontal flow at lower phase flow rate smooth stratified flow has been observed in 8.5 mm and 5.5 mm pipes. There is no existence of stratified flow in 2 mm horizontal pipe probably due to pronounced wall effect in this case.

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