Proceedings of the ASME 2010 3rd Joint US-European Fluids Engineering Summer Meeting and
8th International Conference on Nanochannels, Microchannels, and Minichannels
FEDSM-ICNMM2010
August 1-5, 2010, Montreal, Canada

FEDSM-ICNMM2010-30493

EXPERIMENTAL ANALYSIS OF A TWO PHASE AIR-WATER FLOW IN A TUBE OF SMALL SIZE DIAMETER UNDER VARIOUS INLET CONDITIONS

S. Zeguai
Institut des Sciences et de Technologie, LMP2M,
Université de Médéa, Algeria

S. Chikh
Faculté de Génie Mécanique & Génie des Procédés, USTHB, Bab Ezzouar, Alger 16111, Algeria

O. Rahli
Aix-Marseille Université (U1, U2),
Polytech'Marseille, Laboratoire IUSTI,
CNRS UMR 6595,
Technopôle de Château Gombert, 5 rue Enrico Fermi, 13453 Marseille, France

L. Tadrist
Aix-Marseille Université (U1, U2),
Polytech'Marseille, Laboratoire IUSTI,
CNRS UMR 6595,
Technopôle de Château Gombert, 5 rue Enrico Fermi, 13453 Marseille, France

ABSTRACT

An experimental apparatus is setup to analyze a two phase air-water upward flow in a vertical tube with an inner diameter of 3 mm. Air is axially injected through a microduct of 260 μm inner diameter. Various inlet conditions for air pressure and water flow rate are tested covering a wide range of superficial velocities J_L = 0.221 to 0.312 m/s and J_G = 0.061 to 0.083 m/s for a given position of air injection (x= 8cm). A fast camera with 250 fps is used to visualize different flow regimes. Experiments showed that the flow type is very sensitive to inlet conditions and several flow regimes were observed namely: the bubbly flow, the slug flow and the annular flow.

INTRODUCTION

Two phase flow patterns in small scale tubes have been investigated by many researchers. But, discrepancy in the proposed results remains up to now. The limits of flow characteristics in microchannels and in normal size tubes are not clearly set yet. Triplett et al. (1) conducted experiments using air-water flow in minichannels with a cross section of circular shape and triangular shape with rounded corners. The range of hydraulic diameters investigated goes from 1.09 to 1.49 mm. Five flow regimes were identified namely bubbly flow, slug flow, churn flow, slug/annular flow and annular flow. All observed configurations are morphologically the same as the ones in conventional channels. Chen et al. (2) used R134a as a working fluid to study boiling in tubes of inner diameter of 1.10, 2.01, 2.88 and 4.26 mm. Dispersed bubbly flow, bubbly flow, confined bubble flow, slug flow, churn flow, annular flow and mist flow were observed. They concluded that the flow characteristics in tubes of 2.88 and 4.26 mm are identical to those in normal size tubes and flow characteristics in the tubes with diameters of 1.10 and 2.10 mm are those of minichannels. Chinnov and Kabov (3) analyzed two phase flow regimes in capillary channels of diameter ranging from 20 to 255μm. The capillary effect was examined and compared to other effects. A channel classification was then established based on the importance of the capillary effect. Non circular channels were also considered and results showed that thermo-capillary effect may be significant in nonisothermal microchannels under small gravity conditions. Mosyak et al. (4) carried out experiments to analyze two phase air–water and water–vapor flow in parallel microchannels of triangular cross section. Infrared radiometry was used to visualize the flow. They showed that, simultaneously, different flow regimes were observed in different microchannels under the same flow rate conditions. They also concluded about the anomaly between air–water flow and water–vapor flow. Serizawa et al. (5) studied two phase air–water flow in microtubes of inner diameter of 20, 25 and 100µm and a water-vapor flow in a microtube of inner diameter of 50µm. They visualized the dispersed bubbly flow, the gas slug flow, the liquid ring flow, the liquid lump flow, the annular flow, the frothy or wispy annular flow, the rivulet flow, the liquid droplets flow and other particular flow regimes. They used imagery to compute the void fraction and to show in the case of a slug flow that a good agreement exists between their results and the correlation of Armand for large size tubes.

In the present study, experiments are conducted in a 3 mm inner diameter tube to visualize the upward flow regime. Various inlet conditions characterized by inlet air pressure and the height of the water column are tested for a given position of air injection. Air is injected in a co-current manner through a tube of 0.26 mm inner diameter. The next section explains the experimental procedure. It is then followed by some visualizations obtained under various inlet air pressure and water column height corresponding to different values of water flow rate arriving to a stabilizing room through a 6 mm inner diameter tube. Finally a flow map is deduced with respect to the liquid and air superficial velocity.

EXPERIMENTAL PROCEDURE

Figure 1 shows a schematic of the test section. A 3 mm inner diameter glass tube is used in a vertical position. A mixing room whose dimensions are illustrated in Fig. 1 is used before the inlet of the test section. The total height from the bottom of the mixing room to the exit of the tube is 88 cm. Water flows from a reservoir kept at a constant height and with a constant level of water. It is injected into the mixing room through a tube of 6 mm inner diameter and with an angle of 30° as shown in Fig. 1. Air arrives by an injector of 0.26 mm of inner diameter. Its pressure is manually controlled at the inlet. The vertical position of air injection is varied and its effect is analyzed. At the exit of the tube, water is discharged in a reservoir and the flow rate is measured. Three parameters that are the water reservoir height (h), the inlet pressure of air (P_{air}) and air injector position (x_{BJ}) are considered. During each test, two parameters are kept constant and the third one varied. The flow is then visualized with a fast camera with 250 fps, a resolution of 512x256, a zoom of 150 times and an aperture of 1/10000 s.

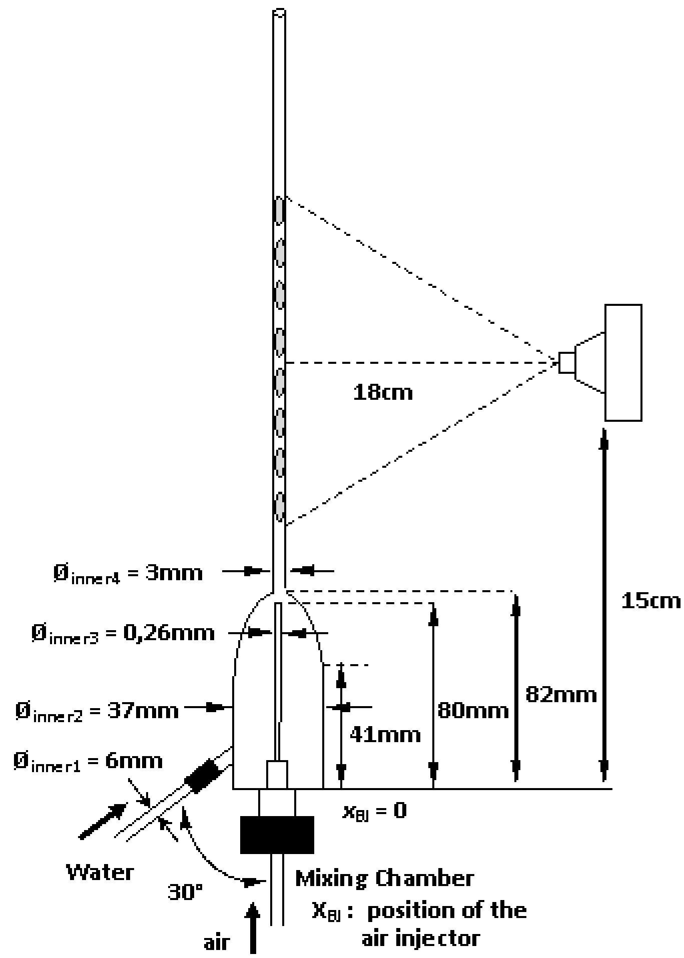


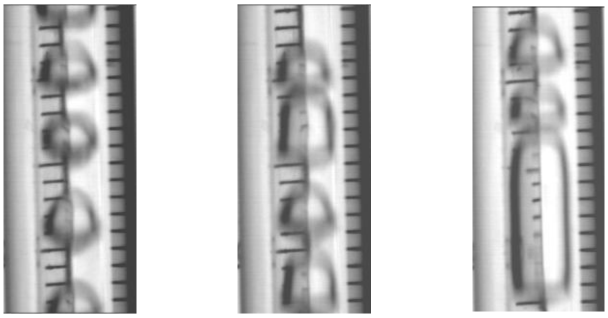
Fig.1: Schematic of the test section and the mixing room.

FLOW VISUALIZATIONS

Effect of P_{air}

The air injection is at a position x_{BJ} = 8 cm and the water reservoir at a height h = 105 cm. The air pressure is then varied by increment of 6 mm Hg which has a direct impact on superficial velocity of liquid and gas phases. Different flow regimes are obtained that are bubbly flow, bubbly/slug flow, slug flow and annular flow as displayed in Fig.2. From the recorded films, we can say that increasing the inlet air pressure yields longer slugs because of greater surface tension.

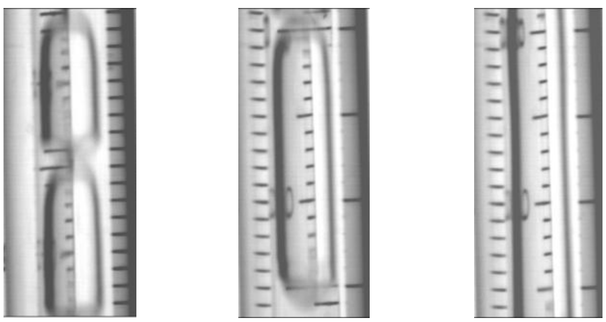
Table 1 shows the values of the superficial velocity of both liquid and gas phase and the obtained flow regimes. One may notice the effect of air inlet pressure on the water mass flow rate although the water column height is kept constant. h is defined as the height between the inlet to the mixing room and the position of the water free surface.



(a) P_{air} = 10640 Pa, $\dot{m}_w$ = 21.919.10^{-4} kg/s, J_L = 0.3102 m/s, J_G = 0.0685 m/s

(b) P_{air} = 11438 Pa, $\dot{m}_w$ = 21.982.10^{-4} kg/s, J_L = 0,3111 m/s, J_G = 0.0736 m/s

(c) P_{air} = 12103 Pa, $\dot{m}_w$ = 22.015.10^{-4} kg/s, J_L = 0.3116 m/s, J_G = 0.0777 m/s



(d) P_{air} = 12901 Pa, $\dot{m}_w$ = 21.891.10^{-4} kg/s, J_L = 0.3098 m/s, J_G = 0.08 m/s

(e) P_{air} = 13566 Pa, $\dot{m}_w$ = 21.814.10^{-4} kg/s, J_L = 0.3087 m/s, J_G =0.078 m/s

(f) P_{air} = 14364 Pa, $\dot{m}_w$ = 22.196.10^{-4} kg/s, J_L = 0.3141m/s, J_G = 0.0805m/s

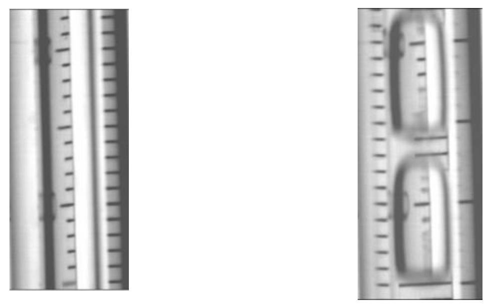
Fig. 2: Effect of P_{air} on flow regime
(h = 105 cm and x_{bj} = 8 cm)
(a) bubbly; (b), (c) bubbly/slug ; (d), (e) slug ; (f) annular

Table 1: Effect of air inlet pressure on the two phase flow regime, h =105 cm

Air inlet pressure [Pa]	Flow parameters	Two phase flow pattern
10640	$\dot{m}_w$= 21.919x10^{-4} kg/s J_L= 0.3102 m/s J_G= 0.0685 m/s	Bubbly flow
11438	$\dot{m}_w$= 21.982x10^{-4} kg/s J_L= 0.3111 m/s J_G= 0.0736 m/s	Bubbly/Slug flow
12103	$\dot{m}_w$= 22.015x10^{-4} kg/s J_L= 0.3116 m/s J_G= 0.0777 m/s	Bubbly/Slug flow
12901	$\dot{m}_w$= 21.891x10^{-4} kg/s J_L= 0.3098 m/s J_G= 0.0800 m/s	Slug flow
13566	$\dot{m}_w$= 21.814x10^{-4} kg/s J_L= 0.3087 m/s J_G= 0.0780 m/s	Slug flow
14364	$\dot{m}_w$= 22.196x10^{-4} kg/s J_L= 0.3141 m/s J_G= 0.0805 m/s	Annular flow

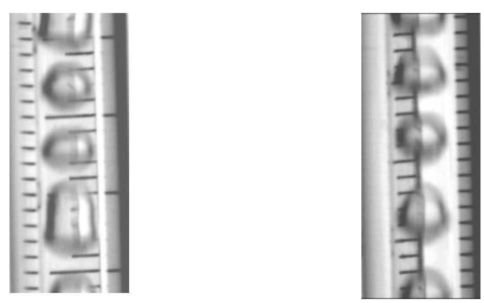
Effect of h

In order to analyze the effect of h, air injection is kept at x_{BJ} = 8 cm and air inlet pressure is at P_{air} = 10640 Pa. The height h is increased by 5 cm at once from 90 cm to 105 cm. This allows a higher water mass flow rate and thus a higher superficial velocity of the liquid phase. An annular flow, a slug flow, a bubbly/slug flow and a bubbly flow are visualized as presented in Fig.3.



(a) h = 90cm, $\dot{m}_w$ = 15.562.10^{-4} kg/s, J_L = 0.2202 m/s, J_G = 0.0682 m/s

(b) h = 95cm, $\dot{m}_w$ = 17.349.10^{-4} kg/s, J_L = 0.2455 m/s, J_G = 0.0634 m/s



(c) h = 100cm, $\dot{m}_w$ = 19.455.10^{-4} kg/s, J_L = 0.2753 m/s, J_G = 0.0615 m/s

(d) h = 105cm, $\dot{m}_w$ = 21.919.10^{-4} kg/s, J_L = 0.3102 m/s, J_G = 0.0685 m/s

Fig. 3: Effect of h on flow regime
(P_{air} = 10640 Pa and x_{BJ} = 8 cm)
(a) annular; (b) slug; (c) bubbly/slug; (d) bubbly

The results (Fig.3 and Table 2) seem to show that when the air inlet pressure is kept constant, the effect of increasing h i.e. increasing the water mass flow rate yields to a bubbly flow. It should be mentioned that although the air inlet pressure is unchanged, the superficial velocity of the gas phase does not remain constant when h is varied. When we increase the height of water reservoir, water superficial velocity increases as well as the difference ($J_L - J_G$). This yields a reduction of the surface tension and therefore a bubbly flow regime is observed.

Table 2: Effect of h on the two phase flow regime, P_{air} = 10640 Pa

Water height h [cm]	Flow parameters	Two phase flow pattern
90	$\dot{m}_w = 15.562.10^{-4}$ kg/s $J_L = 0.2202$ m/s $J_G = 0.0682$ m/s	Annular flow
95	$\dot{m}_w = 17.349.10^{-4}$ kg/s $J_L = 0.2455$ m/s $J_G = 0.0634$ m/s	Slug flow
100	$\dot{m}_w = 19.455.10^{-4}$ kg/s $J_L = 0.2753$ m/s $J_G = 0.0615$ m/s	Bubbly/Slug flow
105	$\dot{m}_w = 21.919.10^{-4}$ kg/s $J_L = 0.3102$ m/s $J_G = 0.0685$ m/s	Bubbly flow

FLOW REGIME MAP

The usual method in the presentation of flow pattern data is to classify the flow pattern by visual observation and plot the data as a flow pattern map in terms of system parameters. Parameters used in the present study are the phase superficial velocities. The superficial velocities of air (J_G) and liquid (J_L) refer to the situation
where the designated phase flows alone in the channel. In the present study, both superficial velocities refer to average ambient conditions (1atm, 20°C). The present flow pattern transition map pertaining to two-phase air–water flow in a vertical circular minichannel with an inner diameter of 3mm is shown in Fig. 4. It should be noted that the flow patterns do not change suddenly, because of the uncertainty in the vicinity of the transitions between flow patterns. As a result, the transition boundary from one regime to another is rather a broad band rather than a single line.

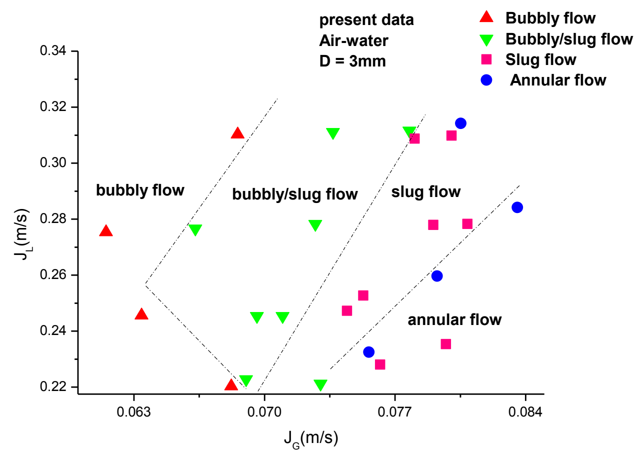


Fig. 4: Two phase flow pattern map for air/water through 3mm diameter channel

Comparisons of the present flow pattern data with selected existing transition boundaries are presented in this section. The dashed lines along with the flow pattern names indicated in Fig.4 refer to the transition boundaries proposed in the published literature for minichannels. The agreement with our results is fairly good.

CONCLUSION

An experimental study of two phase water – air upward flow is carried out in a 3 mm inner diameter vertical tube. Various inlet conditions are set. These are obtained by changing the air inlet pressure and water column height. According to inlet conditions, the superficial velocities of water and air have different values that allow visualizing with a fast camera, mainly three flow regimes: bubbly flow, slug flow and annular flow. Further investigations will be carried out for a better understanding of the flow regime map for various inlet conditions, tube diameter and tube tube inclination.

REFERENCES

1. Triplett. K.A, Ghiaasiaan. S.M, Abdel-Khalik. S.I, Sadowski. D.L, 1999, Gas-liquid two-phase flow in microchannels Part I: two-phase flow patterns. International Journal of Multiphase Flow 25, 377-394.
2. Chen. L, Tian. Y. S, Karayiannis. T.G, 2006, The effect of tube diameter on vertical two-phase flow regimes in small tubes, International Journal of Heat and Mass Transfer 49, 4220–4230.
3. Chinnov. E. A, Kabov. O. A, 2006, Two phase flows in pipes and Capillary Channels, High Temperature 44 N°5, 773-791.
4. Mosyak. A, Segal. Z, Pogrebnyak, E, Hetsroni. G, 2002, Two-phase flow patterns and heat transfer in parallel Microchannels, Journal of Thermal Sciences, Vol 11, N° 4.

5. Serizawa. A, Feng. Z, Kawara. Z, 2002, Two-phase flow in microchannels, Experimental Thermal and Fluid Science 26, 703-714