FLOW PATTERNS OF A VERTICALLY DOWNWARD TWO PHASE FLOW

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INTRODUCTION

Two-phase gas-liquid flow is frequently encountered in several industrial applications. These flows can have several orientations. Vertical upward, horizontal, inclined as well as downward vertical flows. The latter is the less investigated one despite its importance and numerous applications in industrial domains. For instance in petroleum industry, multiphase flow reactors such as Packed bubble column and Trickle bed reactors, and in different chemical reaction processes for instance, hydrogenation, hydrodesulfurization, biological treatment of waste water, electrochemical treatment and chemical industry.

Most of the studies concentrated on the elaborating of flow pattern maps for the downward flow, however none of them succeeded in including all the fundamental parameters characterizing the flow. Barnea et al. [1] developed two flow pattern maps for vertical downward flow in tubes of 25 and 51mm diameters based on theoretical considerations. They set transition boundaries between flow regimes. This study reported three flow regimes: annular, slug and dispersed bubble flow. They included the churn flow in the slug flow region. Similarly Usui [2] carried out a same study and added the falling film flow regime. It can be concluded from the literature that the map of Usui [2] is the most coherent one and in well agreement with several experimental data which has been confirmed by Julia et al. [3] and Lee et al. [4]. Other researches also propose flow pattern maps as Kendoush and Alkhatab [5], Crawford et al. [6], Yamagushi and Yamazaki [7] and Sekogushi et al. [8]. In most of these studies the major flow regimes are the bubbly, slug, annular and falling film flow. The majority of them didn't report the presence of the churn flow or in other cases couldn't establish a transition boundery between this flow and slug or annular flows.

EXPERIMENTAL FACILITY

A schematic diagram of the experimental apparatus employed for these two-phase flow measurements is shown in Figure 1. The vertical test section was made of transparent acrylic resin (PMMA), which permits visual observation of the flow pattern, is about 6m long with an inner diameter of 34 mm and a wall thickness of 4 mm. The water is drawn by pump from a storage tank, which also acts as a phase separator, and injected in to the

mixer where it is combined with the air supplied from the compressor. Downstream of the mixer, the air-water mixture flows downwardly through the vertical pipe and finally to the storage tank, where the air and the water are separated. The water is recirculated and the air is released to the atmosphere. Inflows of air and water are controlled using banks of calibrated rotameters mounted in parallel before the mixing unit. Same mixing unit of Zeghloul et al. [9] has been used.

The thermometer used has a 0.1°C precision and showed a temperature of about 25°C during the experiment. The void fraction measurement were performed using the conductance probe method. The probes were constructed by mounting two stainless steel plates separated by a spacer between a pair of thick acrylic blocks and machining a hole through them so that they were flush with pipe inner wall. The configuration is characterised by the thickness of electrodes, s, and the distance between them. The dimensions De/D and s/D were 0.264 and 0.058 respectively where De is the distancebetweenelectrodes (mm). The eight ring shaped plate conductance probes were placed at 5D, 36D, 51D, 66D, 82D, 97D, 128D, 167D, where D is the tube diameter.

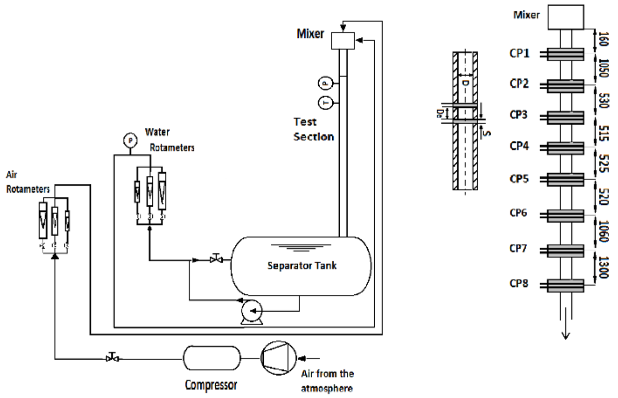

FIGURE 1. Schematic diagram of the experimental facility

RESULTS

Gas and liquid superficial velocities ranges are [0 – 3.25] m/s and [0.015 – 1.40] m/s respectively. In these ranges, the flow regimes observed are bubbly, cap bubble, slug, churn turbulent, annular and falling film flow. Bubbly flow can be descripted as for an upward flow as a continuous liquid phase interrupted by small dispersed bubbles. A noticeable difference in the downward configuration is the migration of the bubbles to the tube core. This phenomenon is called according to several studies as“The coring phenomenon”. It was reported by Julia et al. [3], Hibiki et al. [10], Bhagwat and Ghajar [11]. Coalescence between small dispersed bubbles due to increase in gas flow rate allows cap bubbles to form this flow regime was only reported by Julia et al. [3], Lee et al. [4]. The increase in the coalescence of the bubbles located in the centre of the tube permit to the so-called “Taylor bubbles” to form, followed by liquid slugs containing small dispersed bubbles so the slug flow can be formed. It is the shape of the Taylor bubbles that makes the differentiation between the upward and downward slug flow easy. The nose of the bullet shaped bubble is still in the upper edge but is less sharp and located near the tube wall, which is not the case for an upward orientation where the nose occupies the centre core. Churn turbulent flow was observed by most studies but due to the difficulty to distinguish it from the slug and annular flow it was included in the slug (or intermittent) regionUsui [2], Crawford et al. [6], Yamagushi and Yamazaki [7], Barnea et al. [1]. Falling film flow is characterised by a gas phase occupying the centre core of the tube, and a liquid phase flowing as a liquid film at the tube wall. This regime exists only in a downward configuration. The liquid film attached to the wall in the annular flow is more agitated and wavy, with increasing the gas flow rate small droplet of liquid begins forming from the waves of the falling film and interrupting the gas phase flowing in the centre of the pipe.

Figure 2. presents the time series developement of the eight conductance probes throught the test section for different flow condition and different flow regimes. Figure 2(a). Represent the time series of a coring bubbly flow. It can be seen that the average void fraction is of about 0.1 and its developpement is somewhat stable, no big fluctuations are noticed. This is confirmed by the probability density function (Figure 3(a).), the peaked shape of the PDF at low void fraction reported by Costigan and Whalley [12], is obvious.

Cap bubbly flow is represented by both Figures 2(b) and 3(b). The cap bubbles flowing through the pipe are seen as fluctuations in the time series and a small appearance in the PDF Figure at high values of void fraction. Slug flow is characterised by two peaks in the PDF representation and the appearance of long Taylor bubbles at high void fraction in the time series Figure 2(c) and 3(c). Churn turbulent flow is somehow a chaotic regime, it visually looks like an annular turbulent flow; it has a more disturbed time series and a specific shape of the PDF Figure 2(d) and 3(d) respectively. Falling film flow (Figure 2(e). and 3(e).) is presented by a practically not disturbed time series and a sharp peak PDF very high void fraction.

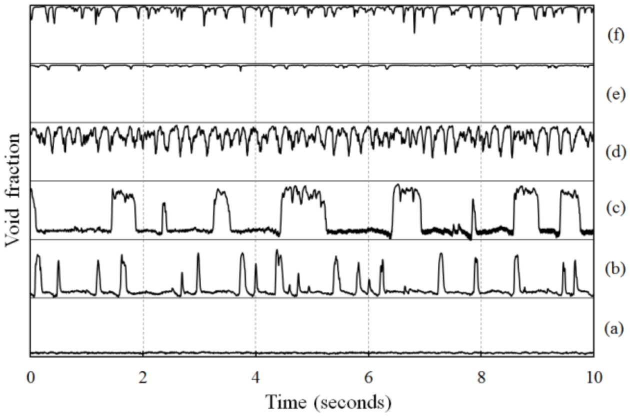

FIGURE 2. Void fraction time series: (a) Bubbly flow, (b) Cap bubbles flow, (c) Slug flow, (d) Churn turbulent flow, (e) Falling film flow, (f) Annular flow .

This study confirmed the statement of Zadrazil et al. [13], that the falling film can exist even at zero gas velocity but only for low liquid flow rates. To differentiate between the annular flow and the falling film flow could not be done only by looking to their PDF representation Figure 3(f) because a very slight difference can be seen, but from the time series representation, Figure 3(f), frequent fluctuation indicate the existence of small bubbles within the gas phase.

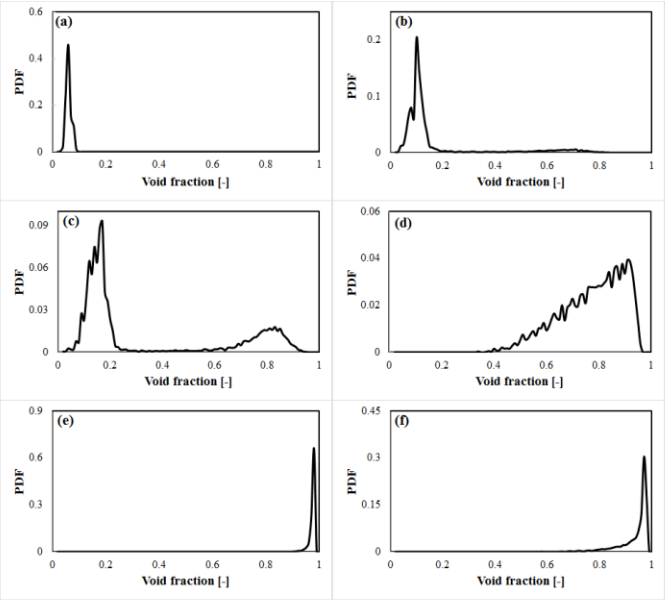

FIGURE 3. Probability Density Function: (a) Bubbly flow, (b) Cap bubbles flow, (c) Slug flow, (d) Churn turbulent flow, (e) Falling film flow, (f) Annular flow .

The boundaries between the flow regimes set by Usui [2], were gathered in a flow map and experimental data of the current study were inserted in it. Good agreement was found in the bubbly, slug and falling film regimes Figure 4.

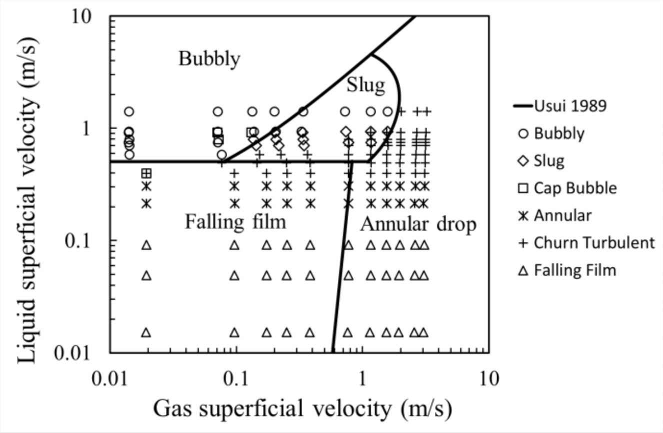

FIGURE 4. Flow pattern map with flow regime boundaries of Usui [2]

CONCLUSIONS

Investigation of downward two-phase flow pattern was presented in this paper. Six flow regimes were reported: bubbly, cap bubbles, slug, churn turbulent, annular and falling film flow, the latest was found to exist ever at zero gas flow rate. Time series and probability density function were presented and used to determine the nature of the flow regimes. Data points and flow regime boundaries set by Usui [2] were gathered in a map. Good agreement was noticed in the bubbly, slug and falling film flow. Further study must concentrate on the churn turbulent and annular areas, and also include an area for the cap bubble flow.

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