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Interrogating the effect of an orifice on the upward two-phase gas–liquid flow behavior

Ammar Zeghloul [a], Abdelwahid Azzi [a,*], Faiza Saidj [a], Barry J. Azzopardi [b], Buddhika Hewakandamby [b]

[a] University of Sciences and Technology Houari Boumedien (USTHB), FGMGP/LTPMP, Bab Ezzouar 16111, Algiers, Algeria
[b] Faculty of Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom

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ABSTRACT

Experiments are reported on an air–water mixture flowing through an orifice in a vertical pipe. Time series of cross-sectionally averaged void fractions have been measured at nine axial positions by using a conductance probe technique. A series of six orifices with different thicknesses and apertures were employed. The Probability Density Function, the Power Spectral Density of the time series of cross sectionally averaged void fractions and the cross-correlation of time series from adjacent probes have been obtained to determine the effect of the orifice on the flow characteristics. The diameter area ratio and the thickness of the orifice have a higher influence on bubbly than on slug and churn flows. The recovery length is about 20, 10 and 7 pipe diameter downstream the orifice for these three flow patterns respectively. Homogenization effect needs a minimum liquid superficial velocity. Its position occurs depends on the value of this velocity and on the orifice fractional open area.

Just downstream the orifice, the structure velocity increases for the bubbly and slug flows and decreases for churn flow. For bubble and slug flows, there is persistency of the frequency when passing through the orifice from the upstream to the downstream pipe.

Introduction

Gas–liquid two-phase flows through orifices are encountered in a variety of industrial plants. Some examples are: flow characteristics of rupture discs in engineering relief system of chemical reactors; leaks from ruptured vessels and pipes in power generation units; control of two phase flow using choke valves on oil production platforms; desalination process by multistage flash (MSF) and the metering of two-phase flows.

The evaluation of the pressure drop caused by the orifice and the knowledge of its upstream and downstream influences is necessary for safe and adequate design of the equipment where orifices might occur. There has been significant effort in modeling single-phase flow through orifices and the corresponding pressure drops. Details of flow behavior and models of pressure drops can be found in fluid mechanics textbooks such as Idel'chik et al. (1994).

In two-phase flow the flow mechanics are more complex due to the nature of the flow. These can exhibit a wide range of phase configurations as a consequence of the deformable interface. The majority of published work has been directed to the pressure drop as well as the pressure drop prediction models (Simpson et al., 1983; Chisholm, 1983; Morris, 1985; Fitzsimmons, 1964; Saadawi et al., 1999; Roul and Dash, 2012 and to a lesser extent to the flow behavior through orifices.

Fossa et al. (2006) investigated the pressure profiles for slug flow through sharp edge orifices in horizontal pipes. Time series of cross-sectionally averaged void fraction were been measured using conductance probe technique upstream and downstream of the orifice which had dimensionless plate thickness of 0.023–0.59 and area ratio of 0.54 and 0.73. They found that the void fraction usually reaches a maximum at a distance of about one diameter downstream of the throat. This maximum can be up to twice the value recorded in the fully developed flow regime far from the orifice. The flow in the developing region and the developing length (downstream of the contraction) is also dependent on the upstream flow patterns and area ratio. Fossa and Guglielmini (2002) noticed that this behavior was observed irrespective of the orifice thickness for high liquid flow rate and even more evident when the area ratio is low.

Recently Roul and Dash (2012) investigated numerically the behavior of two-phase air–water flow through orifices placed in horizontal pipes. For their study, they used the same experimental conditions (flow conditions, orifice geometries) as those employed by of Fossa and Guglielmini (2002). They report findings similar to those of Fossa and Guglielmini.

* Corresponding author. Tel.: +213 (0) 771 45 89 26.
E-mail address: azzi_abdelwahid@scientist.com (A. Azzi).

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Salcudean et al. (1983) analyzed the effect of the flow obstructions on flow patterns and void fraction in horizontal tubes. They found that a central obstruction and an orifice plate influence on the flow pattern. The central obstruction was found to have the strongest effect on the transition between stratified smooth and stratified wavy and between stratified wavy and intermittent flows while the orifice plate has a stronger effect on the transition from intermittent to annular flow.

Shannak et al. (1999) provided the measurements of contraction coefficient, which is the narrowest flow cross-section downstream the orifice divided by cross section of the pipe. They worked with single phase and air–water two phase flows in a horizontal pipe using a photographic technique. The results demonstrate that the contraction in the two-phase flow is limited to very narrow ranges of mass flow qualities of less than 1.2% and greater than 99% where the flow regimes are bubbly and spray flow respectively.

Annular flow in vertical tube was studied by Azzopardi (1984) who examined the effect of thick orifices on the drop/film split. He used eight orifices with different angles of convergence/divergence, orifice diameter and thickness; he found that the film flow rates decreased after the contraction, subsequently returning back to the upstream value. He observed that the measured minimum film flow rate decreased with an increase in the angle and decrease in throat diameter. This work was extended by McQuillan and Whalley (1984) who presented similar results to those of Azzopardi (1984) from their study of effect of thin orifices on the film/drop split in annular flow. They noticed that the orifice plate caused extra atomisation of the film and the liquid returns to the film downstream of the orifice plate.

For liquid–liquid mixture flow Chakrabarti et al. (2009) used the optical probe technique to analyze the influence of the orifice on the phase distribution during stratified water–kerosene flow. They concluded that this obstruction can be recommended as homogeniser/emulsifier for liquid–liquid systems. On the other hand from their study of pressure drop generated by this fitting they encouraged the use of the orifice as flow-metering device for liquid–liquid stratified flow.

In studies of sudden contractions, Azzopardi et al. (2014) examined the variation of the frequency of Taylor bubbles in slug flow between the upstream and downstream pipes. They found that though the lengths of the Taylor bubbles and liquid slugs increase from upstream to downstream, the frequency essentially remains at the same value. They termed this persistence of frequency. They also found a similar behavior between the pipe upstream and the throat of a Venturi and in pipeline-bend-riser arrangements in the work of, e.g., Saidj et al. (2014).

This paper is an attempt for understanding the fundamentals of the effect of the orifice on the two-phase flow behavior through this fitting. It will be shown how the orifice geometry mainly affects bubbly, slug and churn flow patterns. The extent that this effect can persist downstream of the obstruction before the flow finally resumes the form that it has far upstream the orifice.

Experimental setup and the methodology

A schematic diagram of the experimental apparatus employed for these two-phase flow measurements is shown in Fig. 1.

The vertical test section was made of transparent acrylic resin (PMMA), which permits visual observation of the flow pattern, is about 6 m long with an inner diameter, D_t, of 34 mm and a wall thickness of 4 mm. Tap 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.

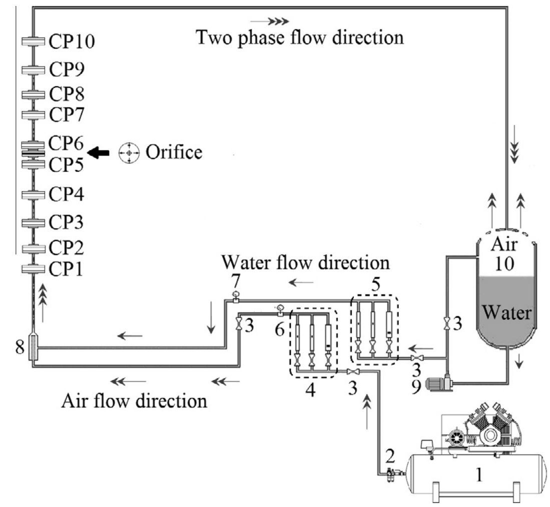

Fig. 1. Schematic diagram of the experimental facility. 1: Compressor, 2: Pressure regulator, 3: Valve, 4: Air flowmeters, 5: Water flowmeters, 6: Manometer, 7: Thermometer, 8: Mixer, 9: Pump, 10: Tank/Separator, CP1–CP9: Conductance probes.

The mixer made of Polyvinyl chloride (PVC) has a short concentric pipe, with 64 holes with 1 mm diameter spaced equally in 8 columns over a length of 80 mm on the cylindrical surface and with the top blanked off as the gas injector. The liquid is introduced into the annular chamber surrounding this gas injector, creating thus, a more even circumferential mixing effect.

Downstream the mixer, the air–water mixture flows through the vertical pipe, a bend, a horizontal 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. Inflow of air and water are controlled by valve and metered using banks of calibrated rotameters mounted in parallel before the mixing unit. The maximum uncertainties in the liquid and gas flow rate measurements are 2%. The static pressure of the air flow is measured prior entering the mixing section. A thermometer with a precision of 0.1 °C is used for temperature measurement. The temperature during the experiments was around 25 °C. Tap water, which was used in the experiments, was found to have conductivity around 600 μS/cm (measured with LUTRON YK-43C electrical conductivity meter). The electrical conductivity showed an increasing with temperature. To avoid larges variations of conductivity with the same experimental run, which could influence on the measurement of the electrical resistivity of the medium, fresh water was fed continuously to the storage tank and discharged to the drain.

A series of six orifices have been used in the present study. Table 1 summarizes the dimensions of these orifices. According to the criterion set by Chisholm (1983), orifices having $t/D_t < 0.5$ can be classified as thin whilst those $t/D_t > 0.5$ as thick. Thus, orifices 1, 2, 4 and 5 are thin whilst 3, 6 are thick ones.

Table 1
Dimensions of the orifices.

Orifice	Diameter, d (mm)	Thickness, t (mm)	Diameter ratio $\sigma = d/D$	Thickness ratio t/d
1	25	2.5	0.73	0.1
2	25	5	0.73	0.2
3	25	14.7	0.73	0.59
4	18.5	1.9	0.54	0.1
5	18.5	3.7	0.54	0.2
6	18.5	10.8	0.54	0.59