LOCAL MEASUREMENTS OF INTERFACIAL AREA AND VOID FRACTION FOR UPWARD BUBBLY FLOW IN A LARGE DIAMETER PIPE

I. Gerges*, M. Shoukri* and I. Hassan**

*Faculty of Engineering, McMaster University, Hamilton, Ontario, Canada.
**Faculty of Engineering and computer science, Concordia University, Montreal, Quebec, Canada.

In this paper, the two-phase flow structure of an air-water, bubbly, upward flow in a 200 mm diameter pipe is presented with a particular emphasis on the local interfacial area concentration. The radial distribution of void fraction, bubble velocity, bubble size, bubble frequency and interfacial area concentration were measured using a local dual-optical probe. The experimental results showed that the saddle-type distribution of void fraction and interfacial area concentration, which are common in bubbly flow in small diameter pipes, only appeared in the present experiments under conditions of very low area-averaged void fraction ($\langle\varepsilon\rangle < 0.04$). The interfacial area concentration in large diameter pipes showed higher values as compared with data obtained under the same flow conditions in small pipes.

INTRODUCTION

The present work was driven by the need to obtain data on flow regimes and interfacial area parameters in large-diameter vertical pipes in support of a proposed design of a new passive cooling system in CANDU reactors. The proposed passive moderator cooling system uses flashing-driven natural circulation to carry the heat from the calandria to an external heat sink via a separator, condenser and subcooler. The cooled and condensed heavy water returns to the bottom of the calandria. Flashing takes place in one, or more, large-diameter vertical pipes connecting the calandria to the separator. Thermal-Hydraulic codes used for the design and analysis of such systems are typically based on the two-fluid model formulation for which knowledge of the interfacial area concentration in terms of other flow parameters is required. Available correlations for the interfacial area concentration are based on data obtained in small diameter pipes and hence the need for data in large diameter vertical pipes ($D \geq 200$ mm).

EXPERIMENTAL FACILITY

The Two-Phase Flow Loop

A schematic of the test facility is shown in Figure 1. This facility can be operated either in a natural circulation mode, as an air lift pump, or in a forced circulation mode using a centrifugal pump. The main components of the facility are the riser, which includes the test section, downcomer, separator, a stand-by pump, air injection line and connecting piping and valves. Both the riser and the downcomer were connected at the top by the air separator. The separator was made as a 2.25 m long, 0.93 m wide and 0.79 m high rectangular stainless-steel tank. Air separation from the incoming two-phase flow mixture was ensured by having long separation path and large separation interface area. The riser pipe was extended into the tank by about 40 cm to discharge the two-phase mixture at a level higher than the water level in the tank. The separated air was vented out through openings near the top of the tank. The riser and the downcomer were connected at the bottom by a PVC pipe with a gate valve (V1 in Figure 1) for controlling the flow rate. A centrifugal stainless-steel pump with a rating of 450 US gallons/min at 10 m head was used in the forced circulation tests.

The air was supplied to the test facility by a 50.8 mm stainless-steel inlet pipe. The air was filtered and its pressure regulated prior to its injection into the test loop. The air was injected

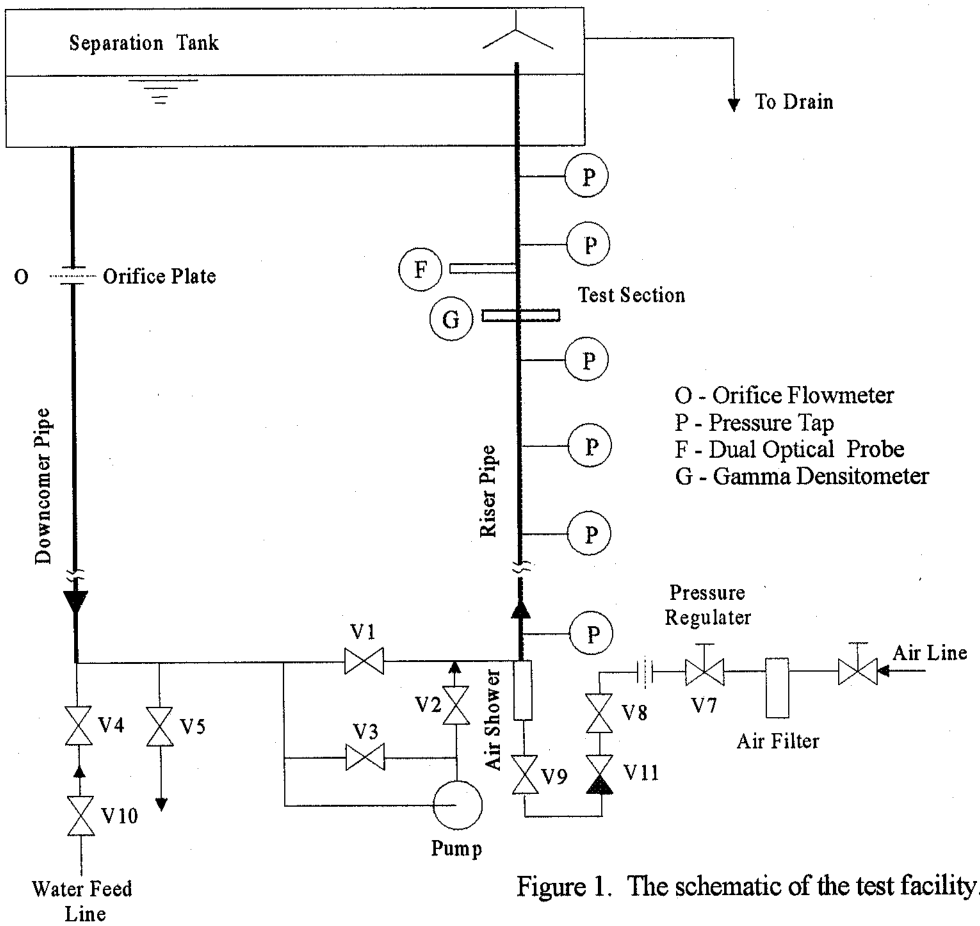

Figure 1. The schematic of the test facility.

upwardly from a circular disc, made as a showerhead-like geometry, which covered almost the entire pipe cross-section through a large number of 1 mm holes. A honey comb flow straightener and a coarse grid mesh were installed downstream, at the inlet of the transparent riser, to reduce swirling and to improve radial bubble distribution.

A transparent acrylic test section, with a diameter of 200 mm and 10 m height, was used in the present work. The measurements were taken at L/D ratio of 43 to ensure "fully developed" void fraction distribution and flow regime.

Measurements and Instrumentation

The measurements performed during the tests included: the air and water flow rates, radial distribution of void fraction, radial distribution of bubble velocity, bubble size, bubble frequency and interfacial area concentration, the pressure drop along the test section, and air and water temperatures. Both air and water flow rates were measured by orifice meters. Several orifice plates with various orifice sizes were used to cover the entire range of test conditions. The pressure drops across the orifice plates were measured by pressure differential cells. Pressure measurements were also carried out, at one-meter intervals, along the test section using multi-tube mercury or water manometers. Details of the measurement techniques used in the present work were given in [1]. However, a brief description of the dual-sensor optical probe used in the present work is given in the full paper.

Test Conditions

Conditions tested were in the following ranges at nearly atmospheric pressure:

Local superficial liquid velocity, J_L	0 – 0.4 m/s
Local superficial gas velocity, J_G	0.02 – 0.1 m/s

ANALYSIS OF EXPERIMENTAL DATA

The full text of this paper will include the complete analysis along with comparisons with results in small diameter pipes. Following is a sample of the experimental results:

Figure 2 shows a typical local distribution of void fraction, bubble velocity, bubble frequency and bubble size at a local superficial gas velocity of 0.04 m/s and different values for superficial liquid velocity. The local void fraction profiles were integrated to yield the area-averaged void fraction, and the results were validated by comparing them with the average void fraction calculated from the pressure drop measurements. Stankovic [4] has shown that the average void fractions obtained by the two methods were in good agreement, within ±10%. The bubble size is the average chordal bubble length in the flow direction obtained from knowledge of the bubble velocity and the time of contact between the front probe and the bubbble. Under the present test conditions, the bubbles observed were essentially spherical. According, the measured bubble size is equivalent to the mean bubble diameter. The bubble size measurements (at very low void fraction) were validated against high video images. As shown in the figure, the local void fraction, bubble velocity and bubble frequency profiles are generally parabolic in nature. The bubble frequency increased with decreasing liquid velocity at constant gas velocity, i.e. with increasing the void fraction. The measured bubble diameters were in the range of 2.5 – 4 mm. The bubble size tended to increase only slightly with increasing the void fraction (i.e. decreasing the liquid velocity at constant gas velocity). The bubble size also tended to increase closer to the pipe wall. The present observations, on bubble diameter, are in good agreement with those of others, e.g. [5] while [3] showed a decrease in bubble size near the pipe wall. Revankar and Ishii [3] also measured higher bubble diameters than those measured in the present work. It is important to note, however, that the work of Revankar and Ishii was carried out in a small

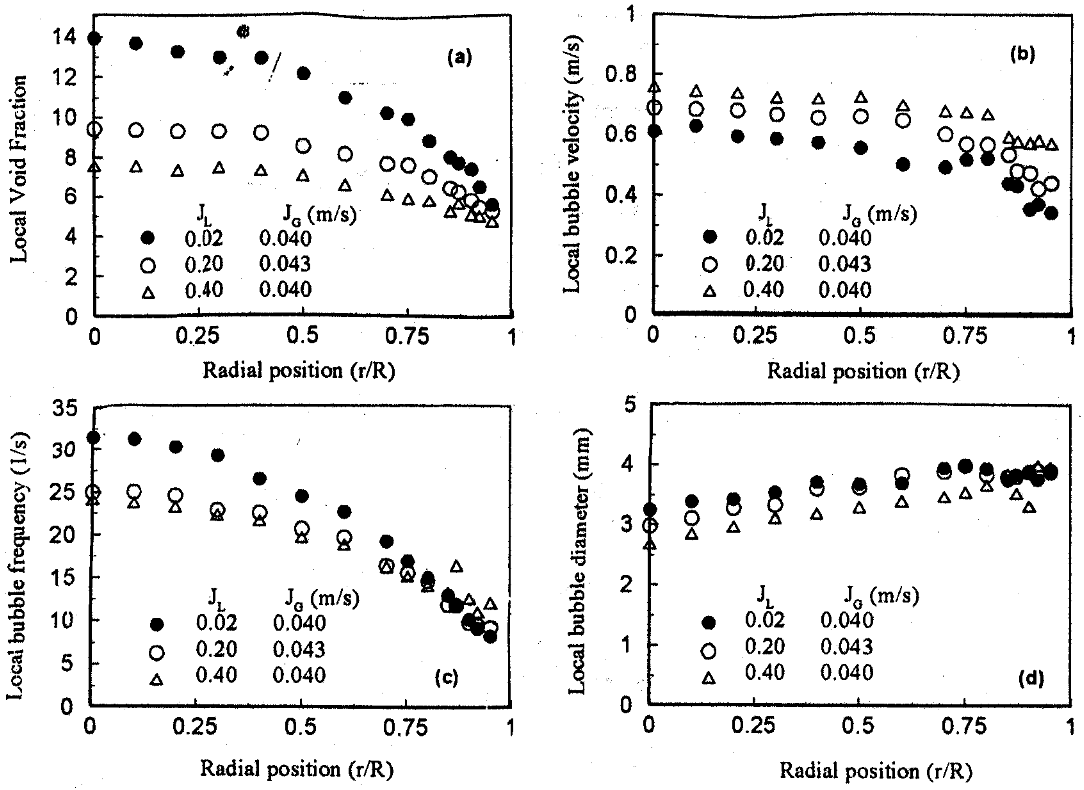

Figure 2. Variation of local parameters at $J_G = 0.04$ m/s.

diameter pipe (50 mm). More data on void fraction, bubble velocity, bubble size and bubble frequency profiles were reported by [1].

The void profiles obtained in the present work were compared with published data for small-diameter pipes at the same L/D and flow conditions. Figure 3 shows a comparison between the results of [5] and the present results. It can be seen that Liu et al. measured a saddle-type profile (sharp peak in void fraction near the wall, with low and near uniform void profile in the central region) in a 38 mm diameter pipe while a parabolic profile was obtained in the 200 mm diameter pipe in the present work under similar conditions. The saddle-type void fraction distribution was encountered in the 200 mm test section at low average void fraction ($< \varepsilon > < 0.04$). This profile was typically observed (not presented here) at high liquid velocity and low gas velocity.

Figure 4 shows the local interfacial area concentration at nominal values of local superficial gas velocities of 0.041 and 0.093 m/s, and different values for superficial liquid velocities. The interfacial area concentration is defined here, as the ratio of the total surface area of all bubbles in a reference volume to the size of that volume, and was obtained by the method proposed by Kataoka et al. [2]. In general, increasing the gas flow rate or decreasing the liquid flow rate would increase the interfacial area concentration and tend to flatten the interfacial area concentration profile. small-diameter pipes. It is also evident that the area averaged interfacial area concentration in large-diameter pipes is higher than that in small pipes under the same flow conditions. This is a reflection of the smaller diameter bubbles observed in the present work as compared with those reported in small-diameter pipes under the same flow conditions.

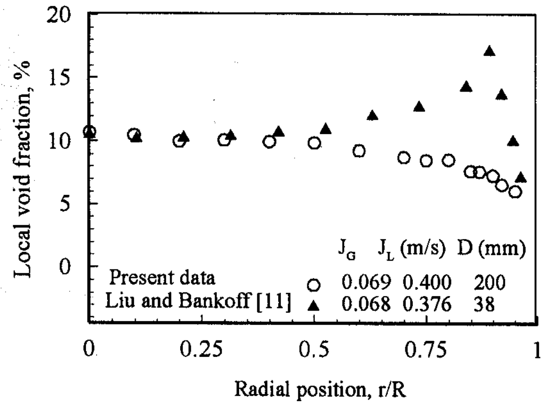

Figure 3. Comparison between void fraction from present work and [5].

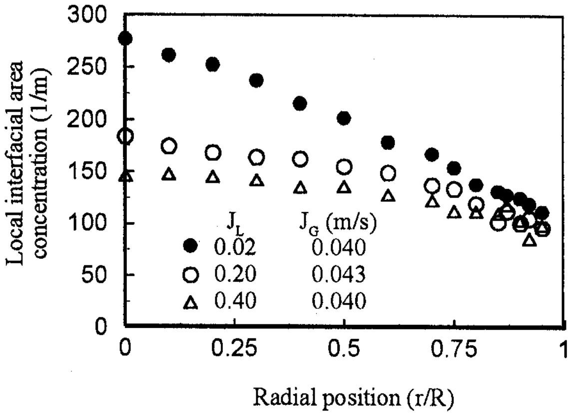

Figure 4a. Local interfacial area concentration using the method of Kataoka et al. [2].

CONCLUSIONS

The interfacial flow parameters of air-water bubbly flow in a 200 mm vertical pipe was experimentally investigated. The radial distribution of void fraction, bubble velocity, bubble size, bubble frequency and interfacial area concentration were measured using a local dual-optical probe. The saddle-type distribution of void fraction and interfacial area concentration which are common in bubbly flow in small-diameter pipes, only appeared in the present experiments under conditions of very low area-averaged void fraction ($<\varepsilon> < 0.04$). With increasing $<\varepsilon>$, the saddle-type distribution changed gradually to a parabolic profile. The detected local bubble sizes ranged from 2.5 - 4 mm in diameter, which is smaller than that reported for small-diameter pipes, and were fairly uniform over most of the pipe cross-section. As a result, the area-averaged void fraction in large-diameter pipes is higher than that in small-diameter pipes under the same flow conditions. The present data will be eventually used in developing reliable constitutive relations for the void fraction and interfacial area concentration in large diameter pipes.

REFERENCES

1. Gerges, I., Two-Phase Bubbly Flow Structure in Large-Diameter Pipes, *M.Eng. Thesis*, McMaster University, Hamitlon, Ontario, Canada, 1999.
2. Kataoka, I., Ishii, M. and Serizawa, A., Local Formulation and Measurements of Interfacial Area Concentration in Two-Phase, *Int. J. Multiphase Flow*, Vol.12, No.4, pp.505—529, 1986.
3. Revankar, S. T. and Ishii, M., Local Interfacial Area Measurement in Bubbly Flow, *Int. J. Heat and Mass Transfer*, Vol.35, No.4, pp. 913-925, 1992.
4. Stankovic, B., An Experimental Study on the Local Void Fraction Measurements in Large-Diameter Vertical Pipes using Optical Fiber Probes, *M.Eng. Thesis*, McMaster University, Hamilton, Ontario, Canada, 1997.
5. Liu, T.J., and Bankoff, S.G., Structure of Air-Water Bubbly Flow in a Vertical Pipe - II. Void Fraction, Bubbly Velocity and Bubble Size Distribution, *Int. J. Heat Mass Transfer*, Vol. 36, No. 4, pp. 1061-1072, 1993.