



The hydrodynamic analysis of the two-phase flow in the bubble column

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ABSTRACT

Bubble columns are widely used as gas/liquid contactor. Their Applications affect the chemical, petrochemical and organic industry. They provide several advantages during operation and maintenance such as high heat and mass transfer rates, compactness and low operating and maintenance costs. In this work, an experimental study was carried out in a bubble column with an internal diameter of 144mm for an air-water two-phase combination. In order to study the two-phase pressure drop in the bubble column three absolute pressure transducers were used for different gas superficial velocities. Tests were run with the gas superficial velocities ranged from 0.022 to 3.5 m/s. The pressure drop analysis was conducted. It showed that for the two-phase flow the pressure drop depends on the flow configuration. The two-phase pressure drop measurement technique was used to calculate the void fraction. Examination of the pressure signal time series as well as the visual analysis made it possible to identify the different flow configurations obtained. Spectral Power Density (PSD) has been applied to pressure signal time series to quantify the frequency of two-phase structure. The latter showed persistence of frequency for most of the conditions except that at low gas superficial velocities were a higher frequency are observed.

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Introduction

Bubble columns are widely used as multiphase contactors for performing a wide variety of gas/liquid or gas/liquid/solid reactions, such as oxidation, hydrogenation, chlorination, aerobic fermentation, wastewater treatment, and liquefaction of carbon. Knowledge of bubble properties, including bubble velocity, pressure drop, bubble size, void fraction, and specific interface area, is very important for the design and proper functioning of the columns Bubbles, and plays a key role in determining the rate of heat and mass transfer. Several intrusive and non-intrusive techniques have been used to characterize the hydrodynamics of two-phase flows. However, these techniques are always combined with some difficulty due to the complexity and nature of the two-phase flows. One of the widely used measurement techniques is the two-phase pressure drop measurement technique, because of its advantages: high speed, low cost of construction, high safety.

The majority of published work has been directed to the pressure drop as well as the pressure drop prediction models. Biesheuvel and Gorisson (1990) used a one-dimensional conser-

vation equation to describe the evolution of the void fraction. Their process has a similar characteristic to those developed by Batchelor (1988) for fluidized beds. Letzel et al. (1997) carried out experiments to measure the time series fluctuations in pressure as a function of the gas superficial velocity. The operating pressure was between 0.1 and 1.3 MPa for air-water mixture in a 0.15 m column diameter. Lin et al. (1999) carried out experiments on fluctuations in pressure drop in a column diameter of 0.0508 m with a nitrogen paratherm system at different temperatures (298-350 K) and operating pressures (0,1 to 15 MPa). The transition rates were determined on the basis of the standard deviation of the pressure drop fluctuations. The aim of the study was to investigate the flow in the column bubble, to understand the phenomena that occur inside it.

Experimental

A schematic diagram of the experimental apparatus employed for these two-phase flow measurements in the bubble column is shown in figure 1. The vertical column bubble was made of transparent acrylic resin (PMMA), which permits visual observation of the flow pattern, is about 2.5 m long with an inner diameter of 144mm and a wall thickness of 4mm. The bubble column is completely loaded with water. Air is supplied from a compressor (1) with an accumulator of 500 liters, compressed to 12 bars. This air is provided to the operating pressure by a pressure regulator (2) connected

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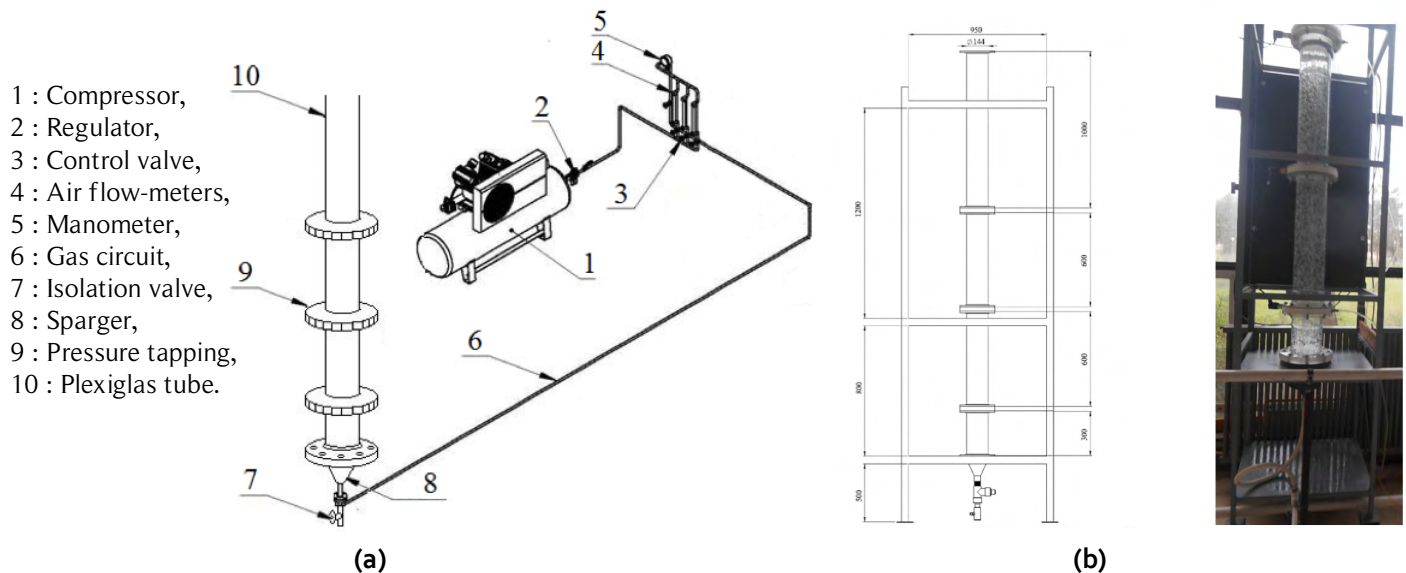


Fig. 1. Schematic diagram of the experimental facility, (a) Test facility, (b) the column bubble.

in series. The air will then pass through a calibrated rotameters mounted in parallel where the flow is controlled. Then it will be injected in to the sparger (8) which made of Polyvinyl chloride (PVC) with 128 holes with 0.5mm diameter spaced equally. Air from the sparger generates the gas bubbles, in other words the two-phase bubbly flow regime. Downstream of the mixer, the pressure drop in the column bubble is measured by using three absolute pressure transmitters mounted in parallel. These IMP transmitters have ranges of (0-150 kPa), with an accuracy of 2% of the full scale.

Results and discussion

Temporal evolution of the absolute pressure

The Fig. 2 represent the fluctuation of the pressure signal obtained by the second absolute pressure transducer as a function of time.

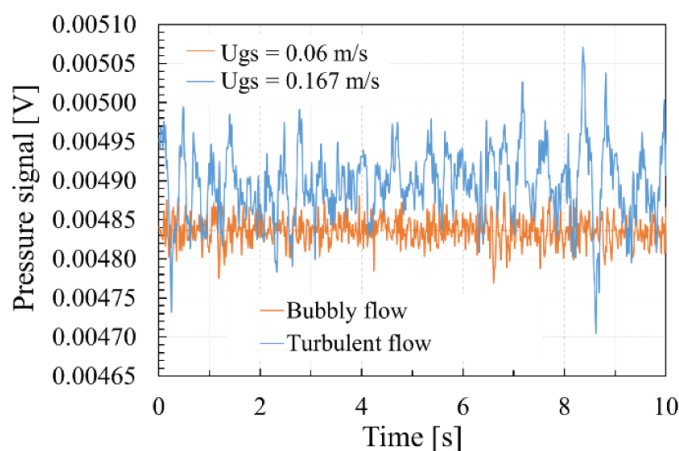


Fig. 2. Fluctuation of the pressure signal obtained by the second absolute pressure transducer for $U_{gs} = 0.06$ m/s, $U_{gs} = 0.167$ m/s.

From this graph it can be seen that the pressure signal for the gas superficial velocity, $U_{gs} = 0.167$ m/s is higher than the pressure signal for $U_{gs} = 0.06$ m/s. This is due to a large amplitude (voltage) in the churn flow regime and to a low

amplitude (voltage) in the bubble flow regime. A second point that can be raised is the most perpetual fluctuations that characterize the churn flow.

Two-phase pressure drop in the bubble column

The Fig.3 shows the absolute two-phase pressure drop distribution as a function of the injected air-flow rate for the 3 pressure transducers

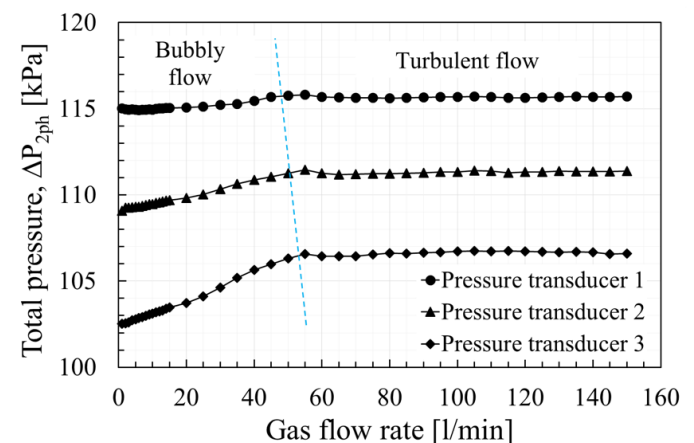


Fig. 3. Two-phase flow pressure drop as a function of the injected air-flow rate.

We noticed that the three transducers have the same curves. For each curve, there are two zones. In Zone 1, we notice that the absolute pressure increases progressively and this is due to domination of the liquid phase in the bubble flow regime (the density of the mixture approaches the density of the water). In zone 2, the absolute pressure remains practically stable and this is due to the dominance of the gas phase in the turbulent churn flow regime (the density of the mixture approaches the density of the gas).

In zone 1 and for the third pressure transducer, there is a greater slope with respect to the second and the first one, which means that for the homogeneous flow, the differential pressure between tapings 1 and 2 as well as 2 and 3 is not the

same, in other way to say that the flow need some distance to be completely developed, contrary to the turbulent flow or the pressure are stable as function of the injected air flow rate.

Evolution of the void fraction in the bubble column

Figure 4 shows the variation of the void fraction obtained from the measurement of the pressure drop as function of the superficial gas velocity. For this geometry, total and fractional pressure drop are given as following equation from the hydrodynamic balance:

$$\Delta P_{\text{pipe}} + F_{m,\text{pipe}} = gh_p \cos \theta (\rho_l - \rho_m) \quad (1)$$

With: ρ_l and ρ_m are the density of the liquid and mixture phase, $F_{m,\text{pipe}}$ represents the frictional pressure drop, ΔP_{pipe} the measured pressure drop and h_p is the distance between the two pressure taps. The mixture density is given by:

$$\rho_m = \alpha \rho_{\text{air}} + (1 - \alpha) \rho_{\text{eau}} \approx \rho_{\text{eau}} (1 - \alpha) \quad (2)$$

From the equation, (1) and (2) we can find the void fraction α :

$$\alpha = \frac{(\Delta P_{\text{pipe}} + F_{m,\text{pipe}})}{(\rho_{\text{eau}} - \rho_{\text{air}}) gh_p} \quad (3)$$

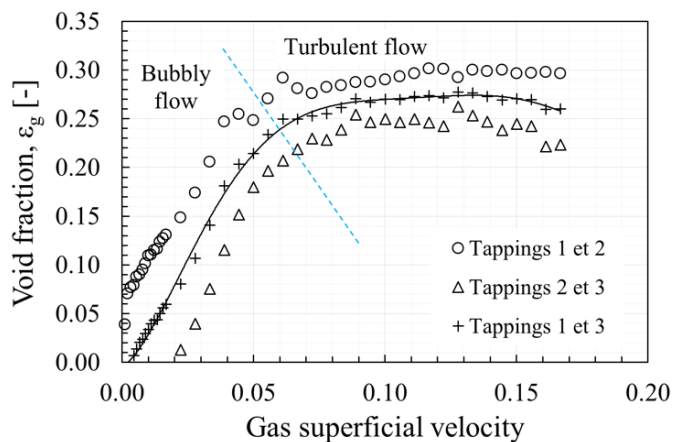


Fig. 4. Evolution of void fraction as a function of gas superficial velocity.

According to this graph, it should be noted that the 3 curves have the same shape, the symbol in a circle represents the void fraction that marks between the pressure transducer 1 and 2; The triangular symbol represents the void fraction which lines up between the pressure transducer 2 and 3; The cross symbol represents the void fraction that blinks throughout the bubble column. There are two zones. In zone 1 where the flow is bubbly, it can be seen that the void fraction increases with the gas superficial velocity until reach a constant value where the flow is turbulent (churn), this is due to the dominance of the gaseous phase in the turbulent churn flow regime.

Dominant frequency in the bubble column

The dominant frequency was determined using the power spectral density (PSD) technique applied to the time series of the pressure transducer. The PSD corresponds to the Fourier transform of the autocorrelation sequence of the pressure time series. Figure. 5 shows the evolution of the do-

minant frequency in the bubble column as a function of the gas surface velocity. Two different results are represented; the first one is obtained from the PSD technique using a Matlab program. The second result is that obtained with a Visual Basic program developed by Kaji (2009) in the form of macros. Since both results are based on the PSD technique.

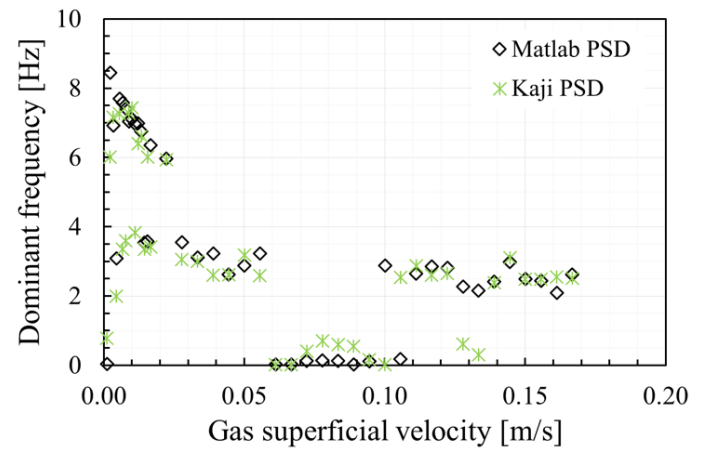


Fig. 5. The dominant frequency as a function of the gas superficial velocity.

From this graph, we can see that the two results are very similar, which gives reliability to our program. It is also noted that the frequency of the two-phase flow structure is stable at most conditions of the gas superficial velocity except at low values, where higher frequency is observed. We can conclude that there is a persistence of frequency for most conditions, which means that in the bubble columns the frequency is constant and does not depend on the flow regimes. It is noted that the same result was obtained by Safa Sharaf (2011).

Visual analysis of the flow through the test section

The simplest approach to studying the behaviour of the two-phase flow in a bubble column is the visualization with the human eye through a transparent pipe. This technique becomes unreliable at high superficial gas speeds where the flow is often very chaotic and difficult to describe and interpret. For this, photographic methods tend to be more appropriate as mentioned by Hewitt and Roberts (1969).

In the following, sequences of the different flow configurations are shown. These sequences are obtained from videos taken using a mobile phone LG (G2) with a resolution of 12 Mega pixels. The qualitative description of the flow patterns observed through the bubble column is detailed below.

For $U_{gs} = 0.01$ m/s we notice a distribution of small gas bubbles dispersed in the liquid phase as we notice also that the distribution of bubbles is not really homogeneous. For $U_{gs} = 0.06$ m/s, a distribution of gas bubbles which are larger than the first picture ($U_{gs} = 0.01$ m/s) is observed. There is also a homogeneous distribution of the bubbles in the bubble column. We can say that the flow regime is homogeneous. For $U_{gs} = 0.014$ m/s there is a domination of the gas phase but here the disadvantage is that one cannot clearly see the size of the bubbles and their geometry. For this speed this kind of camera is unreliable. We can say that the flow regime is transitional. For $U_{gs} = 0.022$ m/s, it is impossible to see the size of the bubbles and their geometry. For these speeds, the technique of visual analysis does not become reliable where the flow becomes very chaotic and difficult to describe and interpret. However, it can be said that the flow regime is turbulent.

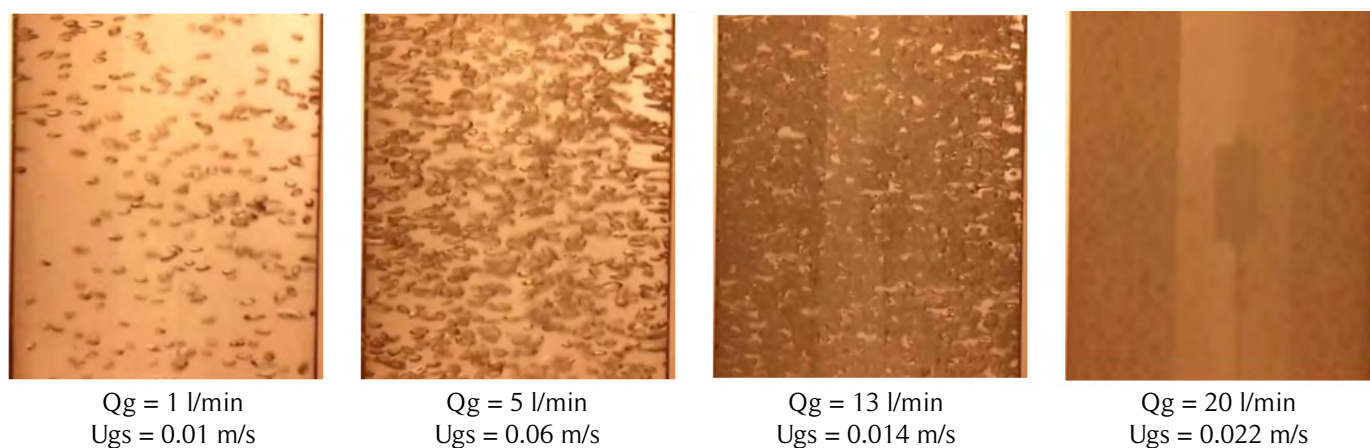


Fig. 6. Flow visualization through the bubble column.

Conclusion

In this paper, the hydrodynamic characteristics of two-phase (air–water) flow in the bubble column were experimentally investigated. Based on the results obtained from the experimental investigations. The analysis of the time series of the absolute pressure as well the visual analysis by the photographic technique made it possible to identify the different configurations of the flow regimes. The evolution of the void fraction along the bubble column has shown that the latter generally increase for a bubble flow and a stable for a turbulent flow. Analysis of the structure frequency by the application of the PSD technique showed that there is a persistency of frequency for most gas superficial velocity conditions, which means that in the bubble columns the frequency is constant and does not depend on the flow regimes.

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Conflicts of interest

Authors declare no conflict of interests.

Notes

The authors declare no competing financial interest.

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