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Experimental and Numerical Analysis of a Gas-Liquid Flow Operating in the Heterogeneous Regime

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Experimental and CFD studies in a laboratory scale cylindrical bubble column under different operational conditions were performed. Axial liquid velocities were measured with the non-intrusive PIV technique. The effects of breakup and coalescence were applied with population balance method. For the interfacial forces, only drag was considering by the Zhang and Vanderheyden model. The effects of turbulence in the continuous phase were applied for the continuous phase with the k-ε model. It was found that the approach used in this work provided physically consistent results, showing good agreement between the experimental and numerical data obtained for a heterogeneous flow regime.

1. Introduction

Bubble columns, as one of the most efficient multiphase reactors, are used in many important industrial fields (Wu et al., 2009) due to their simple operation, high mass and heat transfer rates and no moving parts. Despite the simplicity in mechanical design, fundamental properties of the two-phase fluid dynamics associated with the operation of a bubble column are still not fully understood because of the complex nature of multiphase flow (Dionísio et al., 2007).

Gas-liquid fluidization systems operate by injection of the gas phase in the bottom of a column filled with liquid. This operation depends on several factors such as fluid physical properties, column dimension and inlet gas velocity. There are basically two kinds of flow regime: the homogeneous and the heterogeneous. The homogeneous is characterized by low superficial gas velocity, and the bubbles are nearly uniform in size and shape, where bubble breakup and coalescence phenomena are considered to be insignificant. Nevertheless, at the heterogeneous superficial gas velocity is high, as well as the turbulence, inducing bubble breakup and coalescence.

Despite of the advances on measurements techniques, reliable experimental data of bubble columns operating in the heterogeneous regime are still rare, which makes more

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difficult to provide a mathematical model capable of representing the hydrodynamics of a gas-liquid system at high gas flow rates.

One of the main problems in the CFD simulation of gas-liquid systems are the simplifications of the bubbles dynamic behavior. In practically all the industrial process, bubbles are at high velocities and the column operates in the heterogeneous regime. So for the correctly application of the CFD technique, aiming industrial process, it is necessary to consider the breakup and coalescence phenomena.

Thus, more and more attention has been focused on coupling the PBM (population balance model) and the Computational fluid dynamics (CFD) framework to improve the accuracy of estimation of the interfacial area in multiphase flow systems (Jia et al., 2007). The PBM concept was implemented as the so-called multiple-size-group model (MUSIG) in the commercial CFD package ANSYS CFX 12. In the MUSIG, bubble size results directly from the population balance equation and bubble-bubble interactions are controlled by bubble coalescence and breakup laws (Buwa and Ranade, 2002).

In the present work, the hydrodynamics of a laboratory scale bubble column operating in the heterogeneous regime was analyzed. The axial liquid velocity was measured with the non-intrusive PIV (Particle Image Velocimetry) technique and the results were compared with CFD simulations considering different bubbles sizes by the implementation of population balance model.

2. Experimental

The laboratory bubble column has 14.5cm of inner diameter and 1m of height, the gas phase gets into the column through a gas distributor with 37 holes with 1mm of diameter each. The gas-liquid system is composed by compressed air and tap water with modified carboxi-acrylate as tracers. The column was fitted up with water to a height of 70cm from the gas distributor, and then measurements were taken with the PIV system at a height of 52cm from the gas distributor. The operational conditions were shown at Table 1, where the Δt is the different between the first and the second photo.

Table 1: Operational Conditions

Flow rate (L/min)	Δt (μs)	Laser power
30	1000	41%
50	900	61%
70	800	68%

3. Modeling and Simulation

The equations used to describe bubbly flows were the mass and momentum conservation for both phases, and they follow the Navier-Stokes equations. The interactions between the phases were modeled using the Eulerian-Eulerian approach.

In this study only the drag force was applied, since lift and turbulent dispersion forces can be neglected (Santos et al., 2007; Wu et al., 2009). The Zhang and Vaderheyden drag coefficient was used and it is expressed as:

$$C_D = 0.44 + \frac{24}{Re_b} + \frac{6}{1+\sqrt{Re_b}} \quad (1)$$

where,

$$Re_b = \frac{d_b U_s \rho}{\mu} \quad (2)$$

where, d_b is the bubble diameter, U_s is the slip velocity.

The turbulence was considering by the k-ε model for the liquid phase and bubble induced turbulence by Sato and Sekoguchi model. The parameters values of $C_\mu = 0.09$, $C_{\varepsilon 1} = 1.44$, $C_{\varepsilon 2} = 1.92$, $\sigma_k = 1$, $\sigma_\varepsilon = 1.3$ and $C_{\mu b} = 0.06$.

The MUSIG model was used for modeling bubble size distribution; in this model all size groups have the same bubble velocity. Breakup and coalescence were considered with Luo and Svendsen, and Prince and Blanch models respectively.

Details about the equations and the models used to predict the gas-liquid flow can be found in Silva et al.(2010).

3.1 Mesh and computational code

The unstructured mesh used is composed of 100,000 control volumes (Figure 1 (a)), the gas distributor details are shown in Figure 1 (b). Adaptation of the mathematical model for generation of the numerical model was achieved with the use of the ANSYS CFX 12.0 commercial simulator, which is based on the finite volume method, incorporating the highest upwind interpolation scheme.

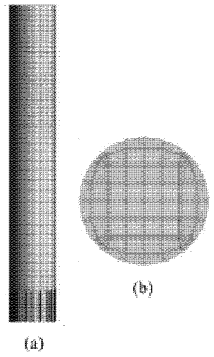

Figure 1: Numerical mesh - (a) column and (b) gas distributor

3.2 Simulation

Air was considered as a polydispersed phase with three different diameters (1, 3 and 5mm) and water as a continuous one. At the entrance all the velocities and concentrations were specified, bubble group of 3mm was specified as a volume fraction of 1. The superficial gas velocity was specified at the inlet and the gas-phase pressure was defined at the exit, assuming atmospheric pressure. At the wall non-slip conditions were adopted for both phases. The time step varies from 10^{-4} to 10^{-2} depending on the residual target. The real-time simulation was approximately 100s for both cases. Time averaged profiles axial liquid velocities were obtained by averaging over time and angular direction.

4. Results and Discussion

In this study all the superficial gas velocities evaluated are in the transition or heterogeneous regime, thus to obtain the velocity field with the PIV technique the plane of measure was divided in two in order to improve the laser passing, because in this type of regime, there are too many bubbles inside the column, which difficult the data acquisition.

The comparison between the experimental and simulated data for the axial liquid velocity is shown in Figure 2 for the three different flow rates.

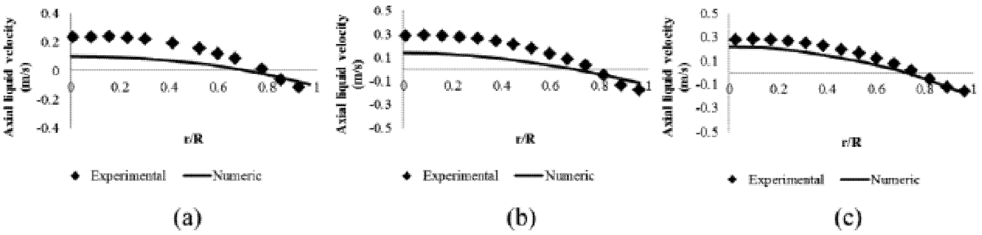

Figure 2: Axial liquid velocity profiles – (a) 30L/min (b) 50L/min (c) 70L/min

It can be observed in Figure 2 that for all the different gas flow rates, the simulated results represent well the experimental data. In all cases, the model was capable of capturing the flow reversion approximately in r/R = 0.7. The numeric data underestimate the experimental at the centre of the column for the lowest flows rates. Nevertheless, for all flow rates evaluated, the model has good agreement with the experimental data near the wall.

The flow patter was also achieved by the proposed model, where the flow rises in the centre of the column, while at the walls it is downward. Figure 3 shows the velocity vectors near the gas distributor, the sparger region (Figure 3 (a)), and at the fully developed region.

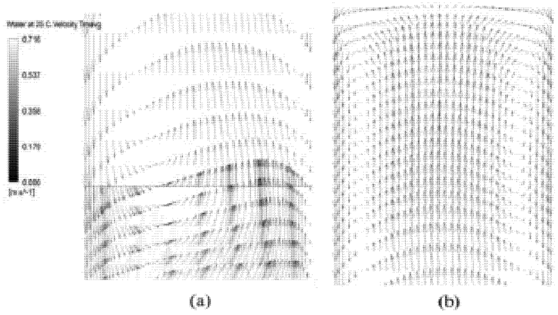

Figure 3: Velocity vectors - (a) sparger region (b) fully developed region

It can be seen in Figure 3 that at the sparger region the flow is not symmetric, since this region exists oscillations and instabilities due to the intermittent gas flow at the entrance. However at the fully developed, it can be noted a radial symmetry, this was also reported by Silva et al. (2010).

5. Conclusions

Experimental and numerical simulations were performed to obtain a better understanding of the complex behavior in a cylindrical bubble column operating in the heterogeneous regime. A population balance model was applied to take account the breakup and coalescence phenomena in different flow rates.

The predicted axial liquid velocity profiles show good agreement with the experimental data obtained with the PIV technique for all the flow rates evaluated. The model was capable of capturing the flow reversion, which occurs in r/R=0.7.

A radial symmetry was obtained at the fully developed region, while near the gas distributor the flow is not uniform.

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