# GAS-LIQUID FLOW IN A RECTANGULAR PARTIALLY AERATED BUBBLE COLUMN: COMBINED EFFECT OF ASPECT RATIO AND SUPERFICIAL GAS VELOCITY

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## INTRODUCTION

Bubble columns are multiphase equipments used to bring into contact gas and liquid phases. Gas, that constitutes the dispersed phase, is distributed at the bottom of the column and rises as bubbles through the liquid that constitutes the continuous phase. They are frequently used in the industry although the partial knowledge of the fluid dynamics of the gas-liquid flow have hindered a complete control over their design and scale-up.

The calculation of the optimum conditions for mass and heat transfer in bubble columns is intimately related to precise identification of the existing flow regimes. Depending on the particular values of the superficial gas velocity ($U_G$), the properties of the phases, the gas distributor design and the column dimensions two different flow regimes can be observed [1-6]: the dispersed bubble and coalesced bubble flow regimes. The coalesced bubble flow regime can be subdivided into the vortical and turbulent flow regimes.

In this study, a partially aerated plate is used and the combined effect of $U_G$ and the liquid height/width of the column ratio (aspect ratio (H/W)) on the resulting flow regimes is studied. The use of partially aerated plates can generate bubble plumes [4, 5, 7-11] that show an oscillatory movement and create ascending and descending liquid circulation structures. The resulting unsteady flow patterns differ considerably from the time-averaged flow regimes [4, 12]. In this work, the quantitative analysis of the flow regimes is based on the measurements of wall pressure fluctuations while qualitative description of the type of flow is obtained by image analysis. The analysis of existing time-averaged flow patterns for given experimental conditions is based on the representation of the global gas hold-up ($\varepsilon_G$) versus $U_G$ [13] while the study of non-stationary structures is based on the spectral analysis, a method that provides information of the oscillation frequency of the bubble plume [7] as well as of the different physical phenomena taking place in the bubble column [2, 7, 14-17] through the resulting spectra and the mean and characteristic frequencies.

## EXPERIMENTAL

A transparent rectangular bubble column 0.2 m wide and 0.04 m deep, made of Plexiglas® constitutes the central point of the experimental set-up. Water at room temperature and atmospheric pressure constitutes the liquid phase in all the experiments. Air constitutes the gas phase for all runs as well. It is fed from the gas chamber through an aluminum sparger with 8 centered holes of 1mm of diameter and 6 mm pitch. This perforated plate results into symmetrical as well as partial aeration of the bubble column. The superficial velocity was varied from 2.4 $mm \cdot s^{-1}$ to 21.3 $mm \cdot s^{-1}$ by means of the appropriate combination of volumetric flow meters. The aspect ratio is varied from 1.25 to 2.25 in increments of 0.25 and the whole range of $U_G$ is studied for each value of the aspect ratio. The modification of the aspect ratio is based on the variation of the liquid height, being the column width kept as constant. Flow characterization is carried out by means of wall pressure fluctuations time series and high-speed video imaging. The high-speed digital video imaging system consisted on a high-speed digital camera (Redlake MotionScope PCI ® 1000 s) used to take images at 500 fps and a 500 W halogen lamp that provides the necessary light. The pressure time series are obtained by means of two piezo-resistive sensors (Keller PR35X, 0-200 mbar and 0-500 mbar with a resolution of 0.002% of the full scale) flushed mounted on the sidewall of the column. The pressures taps used in this work are place at 3.8 cm, 21.3 cm, 26.3 cm, 31.3 cm, 36.3 cm and 41.3 cm above the sparger. The pressure signals were directly stored in a PC. All calculations related to the wall pressure fluctuations were performed using custom-made routines in Matlab®.

## RESULTS

The variation of the aspect ratio and $U_G$ leads to very different pictures of the flow inside bubble columns. When the aspect ratio is set to 1.25, no oscillating bubble plume is observed and the flow presents a pseudo steady state behavior. For small superficial gas velocities ($U_G \leq 9$ $mms^{-1}$), a single circulation cell having the width of the column is observed (single cell bubbly flow (SCBF)). As $U_G$ is increased, two symmetrical vortices develop. A basically symmetrical flow pattern is observed with the liquid phase moving up following the column's centerline and moving down along the sidewalls (double cell turbulent flow (DCTF)). As the aspect ratio is increased to 1.50, an oscillatory bubble plume is observed at low values of $U_G$ ($U_G \leq 8$ $mms^{-1}$). The resulting unsteady flow consists on two vortices moving periodically with very small amplitude and high period (vortical flow (VF)). As the superficial gas velocity is increased, the flow becomes steady and the flow regime characterized by the two symmetrical circulation cells is recovered. Similar results were obtained for aspect ratios of 1.75 and 2.00 but the transition from the unsteady flow pattern to the steady state regime takes place at increasing values of the superficial gas velocity ($U_G \approx 10.0$ $mms^{-1}$). Finally, with an aspect ratio of 2.25 the flow is unsteady for all values of $U_G$ studied in this work and three transient circulation cells can be clearly recognized. The bubble plume moves alternately from right to left with decreasing period and increasing amplitude as $U_G$ increases.

The study of the evolution of the global gas hold-up ($\varepsilon_G$) with $U_G$ and the spectral analysis confirmed these observations. Three regimes (SCBF, transition and DCTF) are detected for aspect ratios equal to 1.25 and 1.50. The absence of highly unsteady bubble plumes for all values of $U_G$ at the aspect ratios of 1.25 and 1.50 confirms the pseudo steady state nature of the different flow regimes. This is clearly identified by analyzing the evolution of the mean frequency with $U_G$. On the contrary, the unsteady nature of the flow patterns for higher aspect ratios are confirmed by the existence of the low frequency band. The plume oscillation period establishes the values of $U_G$ that provide non-stationary structures. At (H/W)=1.75 and 2.00, bubble plumes occur at velocities up to 10 $mm \cdot s^{-1}$ and a transition to the DCFR is observed.

As the aspect ratio is increased, both the plume oscillation frequency and the generated power increase. When (H/W)= 2.25, the flow is unsteady for all values of $U_G$, resulting in turbulent flow. It is interesting to point out that even though the flow is coalesced bubble flow for aspect ratios of 2.25, the spectral analysis provides the information needed to determine the existence of two types of flow: the transition vortical flow (TVF) and the beginning of the fully developed vortical flow (FDVF). Both regimes are characterized by the unsteadiness and the heterogeneity of the flow, as the visual observations and the analysis of the evolution of $\varepsilon_G$ with $U_G$ revealed. However, they have particular characteristics. These types of flow result from the evolution of the bubble size distribution, the aeration of the bubble column and the plume oscillation period [18].

## CONCLUSIONS

Low aspect ratios and high values of $U_G$ favor the pseudo steady state flow patterns while the unsteady flow structures prevail as $U_G$ decreases and the aspect ratio increases. In this way, at low values of $U_G$, there is a transition from the pseudo steady state flow regime consisting on a single circulation cell that takes place with aspect ratios of 1.25 to the unsteady flow structures generated by the oscillation of the bubble plume at higher aspect ratios. As $U_G$ increases, the symmetrical two vortices turbulent flow that takes place when the aspect ratio is 1.25 evolves to the non-stationary vortical flow pattern as the aspect ratio is increased to higher values. The velocity of transition increases as the aspect ratio is increased from 1.25 to 2.00. For aspect ratios equal to 2.25 no transition is observed and the unsteady flow pattern prevails for all values of $U_G$.

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