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Motion of a single bubble rising in a countercurrent flow in a Hele-Shaw cell

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We investigate experimentally the motion of isolated bubbles rising in a vertical Hele-Shaw cell in the presence of a downward flow. The bubbles are strongly flattened in the plane of the cell, their equivalent diameter d being large compared to the gap of the cell e. Furthermore, their dynamics is strongly influenced by the confinement which imposes thin liquid films between the bubble and the walls and strongly attenuates the flow perturbation in the liquid due to wall friction. The control parameters of the problem are: the confinement ratio e/d, the Archimedes number $Ar = \sqrt{gd}.d/\nu$, the Bond number $Bo = \rho g d^2/\sigma$ and the channel Reynolds number based on the average velocity of the counterflow $\mathrm{Re}_c = U_Q e/\nu$. The Archimedes numbers considered are larger than 100, so that inertia plays an major role in this configuration. The Bond numbers vary between 0.01 and 100 corresponding to regimes with or without deformation of the bubble. The countercurrent flow remains laminar ($70 < \mathrm{Re}_c < 125$).

The bubble dynamics is controlled by the coupling between the wake (possibly unsteady) and the degrees of freedom of the bubble motion in translation, rotation and deformation. The aim of this study is to determine the effect of the counterflow on the motion and shape of inertial bubbles as compared to their behavior in liquid at rest ([1]). The motion and deformation of the bubbles have been characterized by a shadowgraph method. The flow perturbation induced in the liquid by the bubble motion will be measured by high-frequency PIV.

We observe that the bubble dynamics changes remarkably in the presence of a counterflow. Notably, the mean relative rise velocity of the bubble ($\overline{U} - \overline{U_Q}$) is higher in a counterflow than in a quiescent liquid. The bubble's velocity follows the relation: $\overline{U} = 0.5\overline{U_Q} + \overline{U_\infty}$, where $U_\infty = 0.64\sqrt{gd}$ (for $500 < Ar < 4000$) is the velocity of the bubble in liquid at rest (Figure 1). The explanation of this behavior might be found in the change in mean aspect ratio of the bubble, which is less stretched in the horizontal direction in the presence of a counterflow. The onset of an oscillatory path of the bubble is also modified, the corresponding Archimedes number being lower in the countercurrent flow configuration (Figure 2). The frequency ω and the horizontal and vertical velocities amplitudes $\widetilde{V_x}$ and $\widetilde{V_z}$ are modified by the flow in the cell, but the Strouhal number $St = \omega d/\sqrt{gd}$ and the velocities amplitudes normalized by the velocity scale $\sqrt{gd}$ are shown to be independent of Re_c (Figure 2).

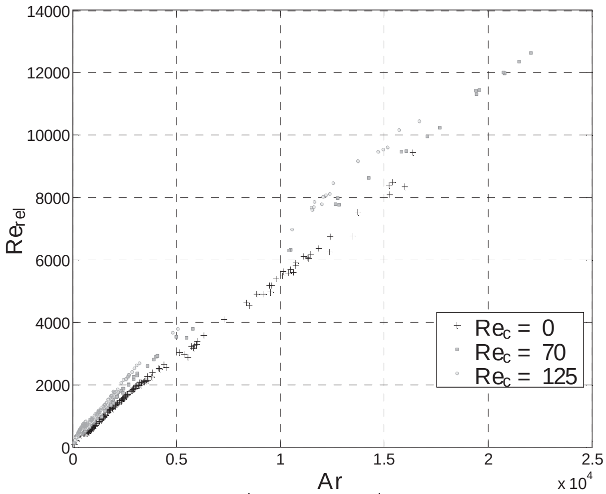

Figure 1 : $\mathrm{Re}_{rel} = (U + 0.5U_Q)d/\nu$ as a function of Ar.

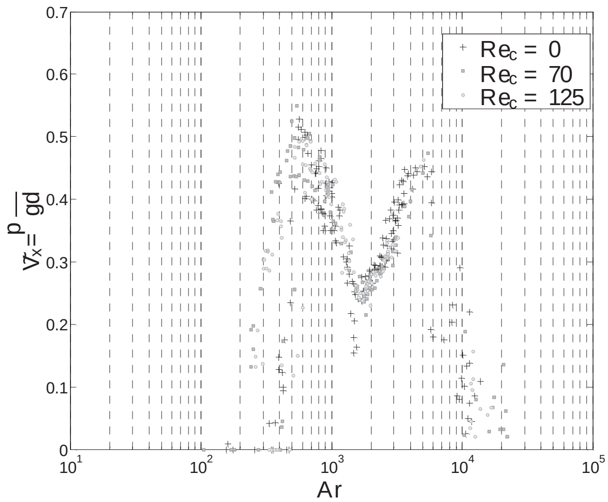

Figure 2 : Normalized amplitude of the horizontal velocity as a function of Ar.