Dynamics of bubble pinch-off in a stagnant water pool

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We present an experimental and numerical study of the detachment of a gas bubble growing quasi-statically at a constant flow rate from a vertical nozzle placed at the bottom of a quiescent water pool. In particular we focus on the dynamics of the necking process and its dependence on the Bond number, defined as $\mathrm{Bo} = \rho g a^2/\sigma$, where a is the inner radius of the nozzle. The time evolution of the neck radius during the collapse process has been obtained by means of a high-speed digital video camera, using a microscopic lens which provides with spatial and temporal resolutions of $5\,\mu$m/px and $10\,\mu$s respectively, in the range of Bond numbers $0.012 \leq \mathrm{Bo} \leq 1.23$. Our experimental data indicates that the asymptotic law recently obtained for the inviscid pinch-off of a bubble, $\tau \propto r_0^2 \exp\left(-\log\left(r_0^2\right)\right)^{1/2}$, where τ is the time to pinch-off, is never achieved down to about $20\,\mu$m, suggesting an extremely slow approach to the asymptotic regime. However, we provide with a simple model based on the cylindrical Rayleigh-Plesset equation which closely reproduces the time evolution of both the minimum radius, r_0, and the associated local axial curvature, r_1 (see Fig. 1(a)). The model, derived assuming slenderness of the local shape near the minimum radius, consists of a couple of ODEs for r_0 and r_1 which, in the limit of large Reynolds numbers and negligible gas effects, take the form $-\log(r_0 r_1)\,\mathrm{d}\log(r_0\dot{r}_0)/\mathrm{d}s + 1 - 2(1-2r_1 r_0)r_0/(r_0\dot{r}_0)^2 = 0$, $-\log(r_0 r_1)\,\mathrm{d}\log(r_0 r_1)/\mathrm{d}s - 1 + (1-2r_1 r_0)r_0/(r_0\dot{r}_0)^2 = 0$, with $s = -\log(r_0)$, $\dot{r}_0 = dr_0/dt$. We propose a simple scaling law for the collapse time based on the good agreement among the experiments, the results obtained with a boundary integral numerical code and the model for the entire range of Bond numbers. Finally, we will present some preliminary data concerning the axial velocity of the Worthington jet entering the bubble after pinch-off (see Fig. 1(b)).

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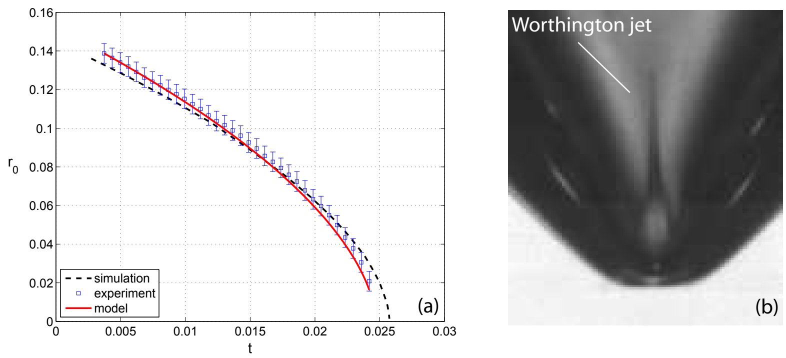

Figure 1: (a) Bubble collapse for Bo= 0.9. (b) Worthington jet.