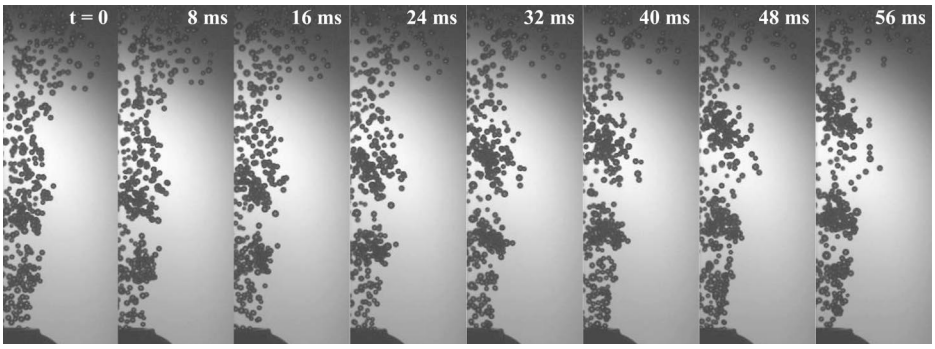

FIG. 1. Bubble clustering associated with the shear layer large-scale vortices.

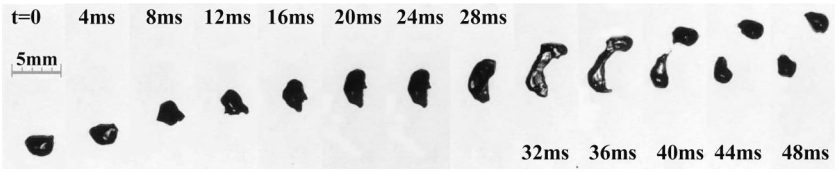

FIG. 2. Turbulence induced bubble breakup within the jet shear layer.

Bubble Behavior in the Shear Layer of a Bubbly Jet

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Three phenomena of bubble interaction with the developing shear layer in the near-field of a vertically upwards water–air bubbly jet are portrayed in this contribution. The first phenomenon is that of bubble clustering and is illustrated in Fig. 1. The near field of the bubbly jet ($\mathrm{Re}_j = 6000$, volumetric flow ratio $\beta = 3\%$, bubble diameter of 1275 and 223 μm standard deviation) displays spatially and temporally periodic bubble clusters developing in the shear layer. The bubble clusters are associated with the rollup of the shear layer instability vortices. They are formed under the action of the centripetal force, which leads the lighter than the carrier liquid bubbles towards the center of the vortices, while depleting the braid region. The initiation of clustering appears at a level where the shear layer thickness is at least three times the bubble size and Sene's [J. Fluid Mech. **259**, 219 (1994)] inertial and ''trapping'' parameters are approximately 0.3 and 3, respectively. The second phenomenon is that of bubble break-up and is illustrated in Fig. 2. A large bubble (approximately 3 mm) is caught in the turbulent shear layer of the jet ($\mathrm{Re}_j = 18\,000$) at a location where its thickness is of the order of the bubble itself. The bubble is torn into two pieces in a process that bears the signs of turbulence-induced breakup. Indeed the bubble surface displays bulges and cell-like surface structures as it breaks up, while the ''break-up'' parameter associated with the local velocity gradient is strongly subcritical (of the order of 10^{-2}). The third phenomenon is that of bubble ejection and is illustrated in Fig. 3. A bubble of approximately 750 μm is ejected violently outside the shear layer of the jet as it emerges from the nozzle. The acceleration of the bubble during this phase is estimated to be approximately $75g$ laterally and $24g$ upwards. The bubble then experiences equally drastic deceleration, of order $80g$ laterally and $12g$ upwards, and slowly resumes upward motion. The shear layer thickness at the exit is approximately one-half the bubble size. A bubble-size-to-shear-layer-thickness ratio of more than one appears to be prerequisite for the ejection phenomenon. The bubble is initially deformed as it approaches the shear layer ($t = 4$ ms). The ejection process is very rapid and the deformation of the bubble appears to be playing a significant role. This has been verified by observing bubbles of similar size in the same jet shear layer but with higher surface tension. Under that condition there was no significant deformation and no ejection was observed. A plausible explanation of the phenomenon may be that the energy stored in the shear-induced deformation of the bubble is released when the bubble escapes the vice grip of the shear layer, providing a substantial propulsion force.

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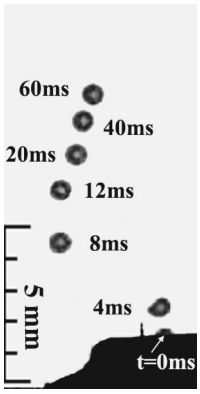

FIG. 3. Bubble ejection from jet shear layer.