Cavitation bubble-particle interactions induced by shock waves

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The strong mechanical effects characteristic to cavitation can be harnessed for applications in medical technologies, environmental engineering as well as pharmaceutical processes, among others. Processing applications involving cavitating particle suspensions, either through acoustic or hydrodynamic cavitation, exhibit effects such as cavitation-induced particle fragmentation, separation, and cleaning.[1] Since many of these processes comprise heterogeneous cavitation nucleation on the suspended particles, gaining a deep understanding on the cavitation mechanisms at play at a single particle level is crucial for effective control. It has been shown that micro-particles can host stable nanometric gas pockets that serve as cavitation nuclei.[2] Exposure to negative pressure can trigger an explosive growth of these gas cavities, which then strongly interact with the hosting particle. This involves the strong acceleration of the particle [3], its ejection into the medium, as well as the bubble collapse including the potential formation of an intense jet.

The goal of this work is to experimentally identify micro-scale phenomena responsible for cavitation in processing applications and their dependence on external factors such as the excitation pressure and the properties of the host medium or the particle. The experiments are conducted using high-speed imaging of particle-water suspensions in small, submerged containers, ensuring minimal particle movement. A shock wave generator was used to expose the suspensions to shock waves showing a rarefaction part of a few MPa. Combining classical shadowgraphy with side illumination, which offers particularly sharp details of the process, the visualisations reveal the bubble morphology and allow for a detailed analysis of its influence on the growth and collapse dynamics. An example is shown in Figure 1. A single particle can host multiple nuclei, resulting in two bubbles merging during the expansion phase. Furthermore, as the particle accelerates to ∼24 m/s, it entrains the bubble's interface, forming a neck. After the detachment of the particle, this deformation represents a surface singularity, causing a jet directed to the distal side of the bubble. Furthermore, a small separated vapour cavity is entrained with the particle, collapsing shortly after it detaches from the neck of the initial bubble. This process resembles air cavities formed when a solid object impacts a water surface.[4] Expecting similar dynamics, this likely produces a second jet with similar strength directly impacting the particle, which could potentially serve as an important mechanism for particle damage or the separation. A wide parameter space is explored to gain deeper insight into the process.

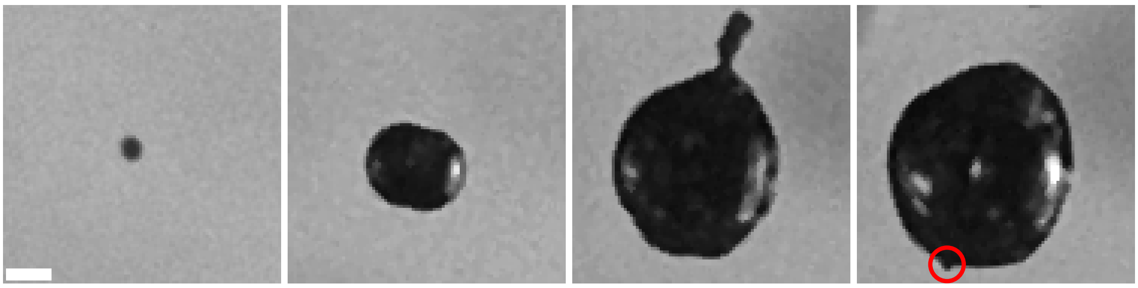

Figure 1: High-speed visualisation of shock wave induced vapour bubble growth from a 50 μm large polyamide particle for time instants $t = \{0, 3, 19, 34\}\ \mu$s. Observable phenomena: growth of two bubbles, formation of a necking region, ejection of the particle entraining a vapour cavity and jet impact on the distal side of the bubble (red circle) (scale bar $\widehat{=}$ 100 μm)

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[1]Tiwari et al., *Crystal Growth & Design* **23 (12)**, 8620-8636 (2023)
[2]Atchley and Prosperetti, *The Journal of the Acoustical Society of America* **86**, 1065-1084 (1989)
[3]Borkent et al., *Journal of Fluid Mechanics* **610**, 157–182 (2008)
[4]Gekle et al., *Phys. Rev. Lett.* **102**, 034502 (2009)