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Vapor bubble growth in liquid nitrogen pool at normal gravity

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Cryogenic propellants are increasingly considered the best candidates to fuel future space propulsion systems, as they offer the best performances. However, their effective exploitation requires reliable in-space long-term storage and the capability of performing safe and efficient fluid transfer to allow in-orbit tank refilling. Both aspects remain a formidable challenge due to the susceptibility of cryogenic liquids to phase change under even small thermal disturbances. The mitigation of undesired vapor generation is critical, since uncontrolled boiling not only leads to propellant losses but also introduces bubbles that can compromise the performance of liquid acquisition devices and disrupt propellant transfer operations in microgravity.

In current storage concepts, multilayer insulation (MLI) is applied extensively to minimize heat leaks, but structural penetrations such as tank struts remain unavoidable thermal bridges. These localized conduction paths can generate hot spots at the liquid–wall interface, initiating nucleate boiling. Bubble nucleation at such sites is a critical phenomenon: the resulting vapor bubbles grow, detach, and coalesce, influencing both local and global thermodynamic stability. Understanding the dynamics of bubble nucleation and growth under cryogenic conditions is therefore essential to anticipate and mitigate the risks of phase change during long-term storage in space.

The present work addresses this issue by investigating nucleate boiling in a controlled cryogenic environment. Experiments are conducted in a liquid nitrogen pool, chosen as a representative cryogenic fluid, where nucleation is triggered on a well-defined artificial cavity. Localized heating is provided by a Joule heater embedded at the nucleation site. The experimental setup enables direct visualization of bubble dynamics under steady thermophysical conditions. Images are acquired to capture the growth, shape evolution, and detachment of individual vapor bubbles generated at the cavity.

The analysis focuses on the equivalent bubble diameter as a function of time during the growth phase preceding detachment. By quantifying this parameter, insights are gained into the kinetics of vapor generation. The experimental results provide valuable benchmarks for validating theoretical models of nucleate boiling in cryogenic fluids, which remain scarce compared to the extensive body of knowledge available at ambient conditions.

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