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NUCLEATE BOILING IN LONG-TERM CRYOGENIC PROPELLANT STORAGE IN MICROGRAVITY

Abstract

Efficient storage of cryogenic propellants in zero-gravity or rnicrogravity environments is one of the key requirements to enable new long-range space exploration missions currently envisioned by NASA. Recent advances in multi-layer insulation (MLI) allow to sharply reduce the heat leak into cryogenic propellant storage tanks through the tank surface and, as a consequence, significantly extend the storage duration. In this situation the MLI penetrations, such as support struts, feed lines, etc., become one of the most significant challenges of the tank's heat management. This problem is especially acute for liquid hydrogen (LH2) storage, since currently no efficient cryocoolers exist that operate at very low LH2 temperatures ("'20K). In the absence of active cooling the heat leaks through the MLI penetrations will inevitably cause the onset of localized boiling at the tank walls. Our estimates show that for realistic values of local heat inflow the rate by which vapor bubbles are generated near the penetrations will exceed by one or several orders of magnitude the rate of bubble collapse in the subcooled liquid. Therefore, with time vapor bubbles may accumulate within the liquid and drift towards the stagnation areas of the liquid flow in the presence of mixers. Thus, even small heat leaks under rnicrogravity conditions and over the period of many months may give rise to a complex slowly-developing, large-scale spatiotemporal physical phenomena in a multi-phase liquid-vapor mixture. These phenomena are not well-understood nor can be easily controlled. They can be of a potentially hazardous nature for long-term on-orbital cryogenic storage, propellant loading, tank chilldown, engine restart, and other in-space cryogenic fluid management operations. We have performed some basic physical estimates to evaluate the relative importance of different physical processes during long-term cryogenic storage. We concentrated on LH2, since it is the cryogen of primary importance to rocket propulsion and is also the most difficult in terms of cryogenic fluid management due to its low boiling point. Our main goal was to identify the processes and issues, such as safety hazards and design optimization parameters, which arise specifically during extended periods in zero- and microgravity. The next step in developing a better physical understanding of long-term cryogenic storage systems and finding new engineering design solutions is to obtain new fundamental data from on-orbit cryogenic storage experiments.