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C3Po1B-01: Visualization of film condensation onset and microscale cryogenic condensate film

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In-space cryogenic resource utilization (ISRU) is a critical technology for long-duration space exploration missions. The condensation of cryogen is a fundamental heat and mass transfer process of ISRU operations such as the liquefaction of gases at the colder wall temperatures, and the condensation-induced pressure collapse in a cryogenic tank during the fill. Due to their low surface tension, cryogens primarily condense by forming a thin condensate film on cold walls. Using Nusselt's theory for saturated vapor, this condensate film is estimated to be tens of microns thick, reflecting the microscale nature of the phenomena. For superheated vapor with non-negligible vapor velocity, condensate thickness is expected to be smaller than saturated vapor. Yet, detailed visualization of the onset of condensation and measurement of film thickness at superheated conditions has not been reported in the literature. In this research, measurements of condensate film thickness and the transient onset of condensation are investigated for the superheated vapor of cryogens. Experiments were conducted with the three ISRU-relevant pure gases namely methane, oxygen, and nitrogen. An experimental setup was developed to induce condensation of the superheated gas on a cold vertical wall, while a visualization setup captured the phenomena of downflow film condensation. The micro-scale thickness of the cryogenic condensate film was measured using a high-resolution shadowgraph. The transient phenomena of the condensation onset was captured using a high-speed visualization. The onset of condensation occurred at the localized cold spot near the trailing edge of the cold wall. Later, the condensation front exhibited growth from the cold spot towards the leading edge against the direction of gravity. The measured steady-state condensate film thickness was compared with Nusselt's theory and existing correlations. These insights into timescale and length scales of condensation will support the development of accurate sub-grid models for ISRU operations.

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