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C3Po1D-05: Fundamental insights into liquid hydrogen flow boiling: bubble dynamics and flow characteristic parameters

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Hydrogen, as a promising alternative energy carrier, has garnered significant attention. Liquid hydrogen (LH_2) exhibits a high density of 70.9 kg/m^3, approximately 1.8 times that of hydrogen compressed at 70 MPa. Its high energy density, efficient transport characteristics, and ability to be stored and transported at low pressures make LH_2 an attractive solution for large-scale commercial hydrogen storage and distribution. However, due to its extremely low boiling point and latent heat of vaporization, LH_2 is prone to rapid phase transition within storage and transport systems, leading to two-phase gas-liquid flow. The development of high-efficiency, high-precision cryogenic fluid management technologies is therefore crucial for enhancing the performance and reliability of LH_2 systems. From both economic and environmental perspectives, minimizing LH_2 losses during pipeline precooling remains a critical challenge.

In this study, a three-dimensional numerical model for LH_2 flow boiling in cryogenic pipelines was developed based on the Euler–Euler two-fluid model. The simulation results exhibited strong agreement with experimental data and predictions from empirical heat transfer correlations. The study systematically investigates the governing mechanisms of bubble dynamics during LH_2 boiling, including bubble departure diameter, detachment frequency, and nucleation site density. Notably, significant discrepancies were observed among different theoretical models used to predict LH_2 boiling heat transfer performance. The findings reveal that bubbly flow, characterized by small bubbles, is a dominant feature in LH_2 boiling. This behavior can be attributed to the low saturation vapor pressure of LH_2, which results in minimal pressure differentials between the liquid and vapor phases, thereby suppressing bubble growth. Additionally, the extremely low surface tension of LH_2 prevents bubble coalescence, further inhibiting the reduction of surface energy. Furthermore, the influence of LH_2 thermophysical properties on pipeline cooling efficiency was examined, considering key parameters such as inlet mass flow rate, operating pressure, and degree of subcooling. The effects of gravity orientation and microgravity conditions were also explored as critical factors. This study provides valuable insights into the fundamental two-phase flow and heat and mass transfer mechanisms of LH_2 boiling, offering theoretical guidance for the development of high-efficiency pipeline cooling strategies.

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