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A CFD comparison of interfacial phase change models for boil-off, self-pressurisation and thermal stratification in liquid hydrogen storage tanks

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Adoption of liquid hydrogen (LH_2) as a clean, high-energy-density fuel across heavy-duty road vehicles, marine propulsion, and aerospace applications will form a critical component in the decarbonisation of the transport sector. Its ability to deliver zero-carbon energy with rapid refuelling and long-range capability makes LH_2 a cornerstone of future sustainable mobility. However, the cryogenic nature of LH_2 introduces significant engineering challenges, particularly in its storage and handling. Self-pressurisation and boil-off losses due to ambient heat ingress can compromise safety, efficiency, and operational reliability, making accurate predictive modelling of these phenomena essential for system design and optimisation.

This study presents a comparative assessment of three widely used interfacial phase change models: the Schrage, the Modified Energy Jump (MeJ), and the Lee model. A parametric study was conducted across three coefficients for each model, with validation against five benchmark experiments from NASA's K-Site and MHTB cryogenic tank datasets. These cases focused on planar interface problems under normal gravity with thermally induced phase change. Simulations were performed using STAR-CCM+, evaluating each model's ability to predict tank pressure evolution, temperature distribution, and boil-off behaviour.

The Schrage model emerged as the most robust and accurate, demonstrating minimal sensitivity to coefficient variation and achieving a maximum mean absolute percentage error (MAPE) of 3.0% in pressurisation predictions. The MeJ model showed comparable performance when its heat transfer coefficient was carefully tuned, underscoring its empirical dependence. In contrast, the Lee model exhibited numerical instability and significant deviation in pressure predictions, with errors reaching up to 11% MAPE.

Further results of the flow field and boiloff flux distribution highlight the discrete difference between the near-wall liquid-vapour interface, showing significantly higher boiloff mass flux at the wall, while near-uniform boiloff mass flux is present away from the wall, often showing values signifying condensation. The high-fidelity results highlight a clear need for the near-wall boiloff mass flux to be considered in reduced-order models.

This work delivers practical guidance for CFD practitioners and LH_2 system designers, enabling more reliable and physically consistent modelling of LH_2 storage tanks. The findings support the deployment of hydrogen technologies in industrial applications, contributing to the broader decarbonisation of transport and energy systems.

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