

Heat transfer study on cryogen evaporation in stationary and moving tank

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The cryogen evaporation rate is of prime concern in various industrial as well as research settings. Even with high insulation of cryogenic tanks, heat in-leak from ambient is unavoidable. The thermal characterisation of cryogenic fluids is quite important during their storage due to external heat inleaks. Due to their low viscosity, cryogenics are prone to large liquid motions (sloshing) during their transportation. This phenomenon causes a higher rate of internal heat generation due to viscous dissipation. In addition to this, the thermal stratification in the cryogenic storage container is disturbed. These have an impact on the pressure and temperature of the tank, depending on the intensity of sloshing. In the case of an isobaric tank (open vent), loss of boil-off gases happens, while for a close vent condition, self-pressurization of the tank takes place. The availability of experimental data with regards to, both isobaric and non-isobaric evaporation of cryogenic liquids, is very limited. Due to this, validation of various thermodynamic and CFD models is still a challenging task.

In the present work, as a first step, a transient two-phase thermodynamic model, for a stationary liquid nitrogen cylindrical tank, is developed for two cases, first to understand the boil-off rate (isobaric condition /vent open) and second to measure transient pressure evolution (closed condition /vent close) due to external heat in-leak. Experiments are performed for the validation of the model with a 25-liter cryogenic tank of cylindrical geometry, considering liquid nitrogen as the working fluid. Experiments are carried out in both stationary and moving (slosh) conditions of the cryogenic tanks. Sloshing exhibits a higher boil-off rate than a stationary tank as demonstrated by experimental results due to interface fluctuations and forced convection.

Due to the insulation of cryogenic vessels, the boiling mechanism is governed by interfacial surface evaporation. In isobaric conditions, keeping constant ullage pressure, thermal stratification in both liquid and vapour phases is studied for the stationary condition of the cryogenic tank. To understand the temperature stratification, thermocouples are placed vertically along the axis of the tank at different heights. The liquid phase is thermally homogeneous during isobaric evaporation, except for the boundary layer caused by natural convection. Temperature stratification in the vapour domain tends to exhibit a pseudo-steady state except in the zone near to the interface.

When the vent is closed, self-pressurization leads to an increase in ullage pressure inside the tank due to the continuous evaporation process. A theoretical equilibrium model is developed in the present work so as to generate an expression for the rise in pressure and drop in liquid level based on time. It integrates the Clausius-Clapeyron equation to relate the saturation temperature with the saturation pressure. Experiments are performed to measure the pressure evolution inside a 110-liter cryogenic tank in stationary conditions. The effect of transient pressure build-up on interface temperature and liquid thermal stratification is discussed in this paper.

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