Institute of
Plant and Process Technology

Thermodynamic Modeling of Mobile Cryogenic Tanks with a Liquid–Cooled Thermal Shield

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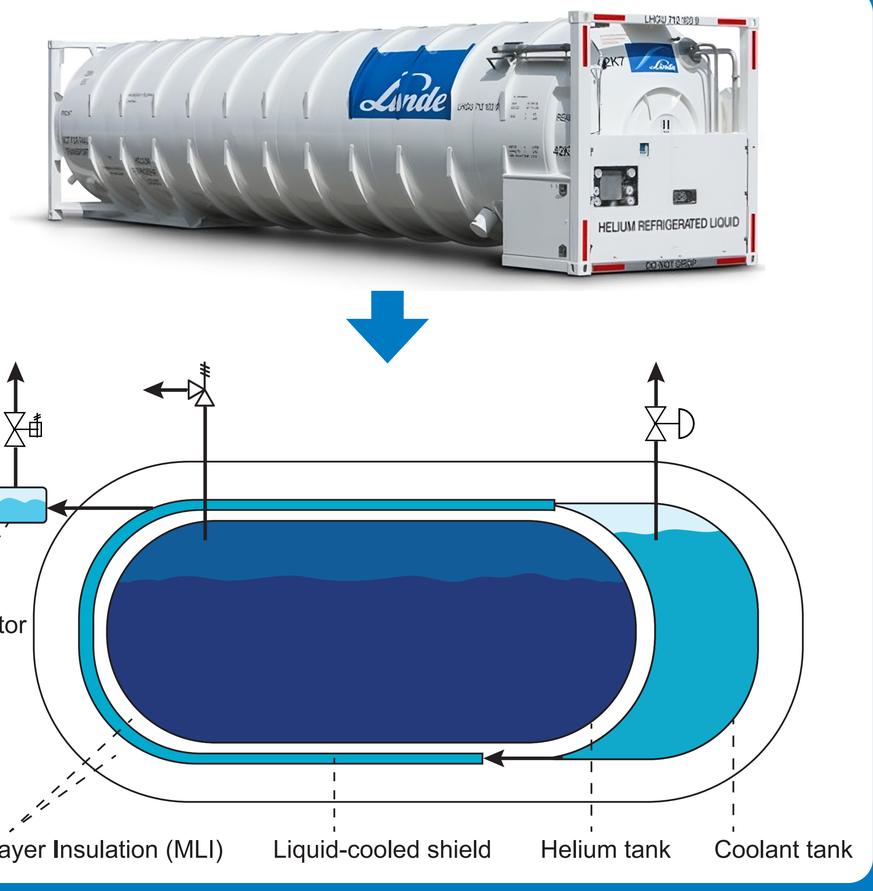
Motivation

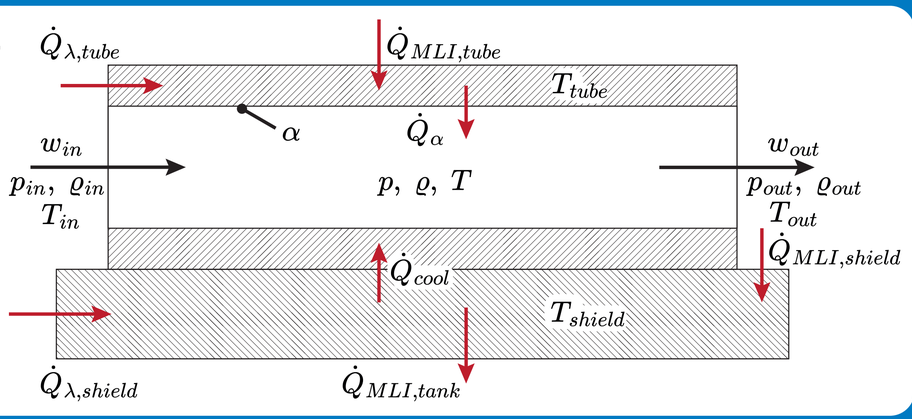
- Helium is in high demand for medicine, research, electronics, aerospace, and other industries
- Minimizing helium losses during transport is essential due to its high cost and limited availability
- Extended holding times are necessary for efficient long-distance transportation
- Analyzing heat leakage into the helium tank provides valuable performance analysis and manufacturing feedback

Vessel Structure



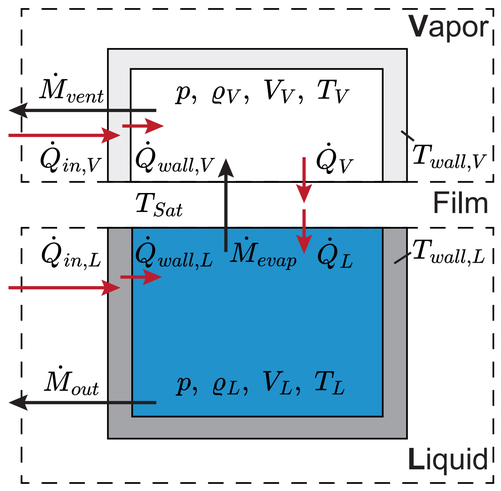
Shield Model

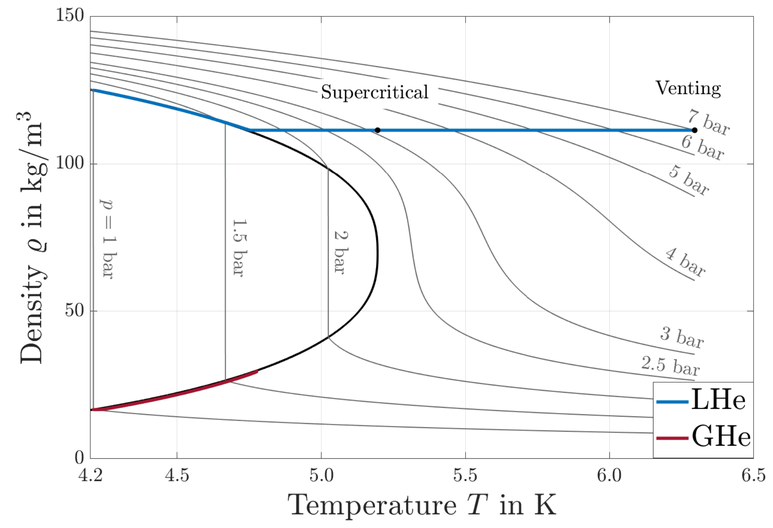
- Evaporation-driven two-phase flow when liquid coolant is available
- Convective gas flow when liquid coolant is consumed
- Plug flow model
- Single control volume



0–D non–equilibrium (NEQ) Tank Model

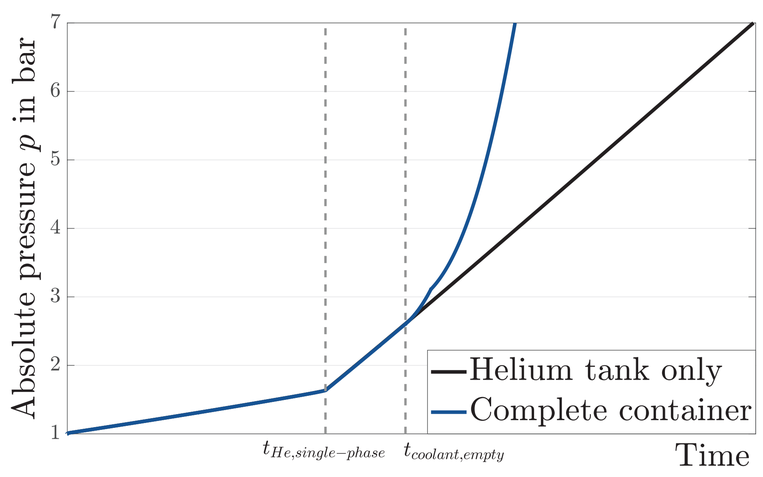
- The tank is modeled with three control volumes (CVs), assuming the saturated film layer is negligibly thin:
$$\frac{dU_F}{dt} = 0$$
- The wall of the *coolant tank* is assumed to maintain a uniform temperature: $T_{wall,V} = T_{wall,L} = T_{wall}$
- In the *He tank*, the wall is part of both the vapor and liquid CVs. Given the low heat capacities of stainless steel at the observed temperatures for liquid helium (LHe), the wall temperature changes significantly, creating a notable gradient between the two CVs. Additionally, at these temperatures, heat conduction between the two wall segments can be neglected
- Each control volume contains only a single designated phase at any given time





Results

- Comparison of pressure build-up between the cryogenic container model and a standalone tank NEQ model, assuming a constant heat flux into the helium tank to represent an indefinite supply of liquid coolant
- Significant divergence occurs after the liquid coolant is fully consumed, as supported by recorded field data
- The maximum holding time is overestimated by more than 50% when the tank is modeled using a constant heat flux value



Summary and Outlook

Summary

- The pressure build-up in the main tank is significantly influenced by the availability of the coolant
- Depletion of coolant causes a significant reduction in the maximum holding time due to changes in heat flux
- Modeling the entire container enables more precise prediction of expected holding times and analysis of insulation performance, facilitating optimization of the manufacturing process

Outlook

- Continued refinement of the model, encompassing discretization, transferability, and additional validation

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