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# Thermodynamic modeling of mobile cryogenic tanks with a liquid-cooled thermal shield

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Mobile cryogenic tanks are used to transport liquefied process gases in large quantities. To increase the possible distances and minimize the product loss due to evaporation, the tanks can be additionally equipped with a liquid-cooled thermal shield. The known vapor-cooled shields use the boil-off gas of the main product by feeding it through the pipe wound on the outside of the container to use its sensible heat before venting it into the environment [1,2]. In contrast, the liquid-cooled shield utilizes the vaporization of an initially liquid coolant to reduce heat leak from the environment into the main product tank. The lower the heat leak, the longer it takes for the main product to warm up and reach the maximum allowable pressure before some must be vented. The travel distance and time that the main product can be transported without loss are used to characterize the performance of mobile cryogenic tanks.

This contribution presents a dynamic simulation to describe the mobile cryogenic tank system that consists of an outer vessel, a multi-layer insulation, a coolant tank, a liquid-cooled shield, and an inner product tank. Both the main product and coolant may exist either in a single phase, or as a two-phase mixture of liquid and vapor. The model considers unsteady mass and heat transfer in both tanks and shield. All fluids are treated as real fluids.

A coupled differential-algebraic equation (DAE) system for the coolant tank, the liquid-cooled shield, the main product fluid tank, and the multi-layer insulation was implemented in MATLAB. The non-equilibrium system is described using implicit model formulation [3]. The equation system adapts dynamically depending on the fluid state and the operation mode. Required fluid properties were taken from the REFPROP reference database.

The presented model offers insights into the time-resolved behavior of a liquid-cooled cryogenic tank. The assumptions of unsteady flows and real fluids allow for a more precise representation of coupled thermodynamic processes in the system. The results allow for performance analysis and venting time prediction of mobile cryogenic tanks.

[1] W. Jiang., P. Sun, P. Li, Z. Zuo, Y. Huang, Y., Transient thermal behavior of multi-layer insulation coupled with vapor cooled shield used for liquid hydrogen storage tank, Energy 231 (2021) 120859. https://doi.org/10.1016/j.energy.2021.120859.
[2] D. Kang, S. Yun, B.-k. Kim, Review of the Liquid Hydrogen Storage Tank and Insulation System for the High-Power Locomotive, Energies 15 (2022) 4357. https://doi.org/10.3390/en15124357
[3] J. Hamacher, A. Stary, L. Stops, D. Siebe, M. Kapp, S. Rehfeldt, H. Klein, Modeling the thermodynamic behavior of cryo-compressed hydrogen tanks for trucks, Cryogenics 135 (2023) 103743. https://doi.org/10.1016/j.cryogenics.2023.103743

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