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Development of a numerical model for liquid hydrogen storage tanks for maritime sector

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Abstract

Introduction. A relevant technical challenge in liquid hydrogen (LH2) storage and transport to deal with is managing boil-off gas (BOG), which is formed by unavoidable heat leakage into cryogenic tanks. In closed systems, BOG is accumulated and this leads to pressure and temperature increase, requiring effective strategies to extend the holding time and ensure operational safety. For this reason, it is important to be able to accurately predict tank internal conditions so that operations can be carried out safely and the BOG can be properly managed.

Objectives. The aim of the work is to provide a tool able to help in managing LH2 tanks for the maritime transport sector, dealing with a generic navigation profile: self-pressurization phase at full tank, possible pressure setting through an evaporator, fuel withdrawal, BOG management, and self-pressurization phase at empty tank. The main objective of this paper is to investigate the self-pressurization phase of LH2 tanks, by simulating internal conditions and pressure trends thanks to the development of four numerical models. These models are compared to experimental data at two conditions where the tank is likely to be in self-pressurization phase: one at full tank (83% volume) and one at empty tank (29% volume).

Material and methods. The numerical models are developed in MatLab and are zero-dimensional (with 1, 2 or 3 zones, see Fig.1) in which no thermal gradient in single-phase volumes is considered. These models have been developed starting by the open scientific literature and they will be here referred to as: Homogeneous Model (HM) [1], Superheated Vapor and liquid in thermal equilibrium Model (SVM) [2], subcooled liquid and vapor in thermal equilibrium, or Surface Evaporation Model (SEM) [3], Subcooled Liquid and Superheated Vapor and interface in thermal equilibrium Model (SLSVM) [4].

Results. In general, results of the numerical models are in good agreement with those reported in the papers taken as reference, when reasonable values of the calibration parameters are applied.

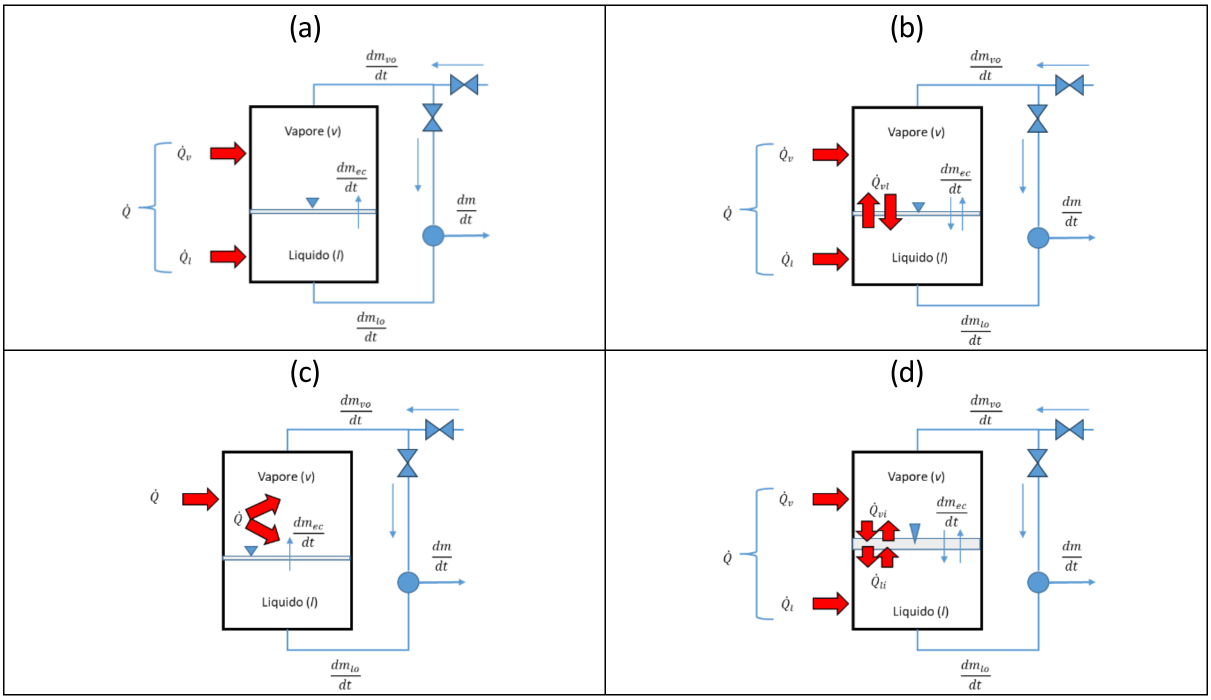

Figure 1 – Schematic of the tank models: (a) HM, (b) SVM, (c) SEM, (d) SLSVM.

In particular, in SLSVM the values of the heat exchange coefficients at the interface on both the vapor and liquid sides must be accurately chosen. Nonetheless, the developed models present some limitations. For instance, the SEM assumes that all the incoming heat is used to evaporate the fluid while the vapor phase is maintained at saturation condition. This condition limits the application of the model to pressure values below that at which, as the enthalpy increases due to the heat transmitted from the walls, the vapor shall be superheated; from the h-s diagram of para-hydrogen, this pressure limit is 3.38 bar.
Another example of limitation regards the SLSVM, which gives results highly sensitive to the initial tank temperature: going from an initial condition of phases equilibrium to one of vapor superheating of 1K and liquid subcooling of 1K, pressurization time results are quite different.
For the comparison among the models, the experimental data reported in [1] has been considered. The pressure trends are reported in Figure 2 for four cases: fill level of 29% and 83% with heat input of 2 W/m^2 and 3.5 W/m^2. From the summarized outcomes of the models' comparison, it results that the HM highly underestimates the pressure increase; the SVM also underestimates the pressure increase but its trend is slightly faster than the HM; the SEM, instead, overestimates the pressure increase; finally, the SLSVM can provide the closest trend to the experimental data.

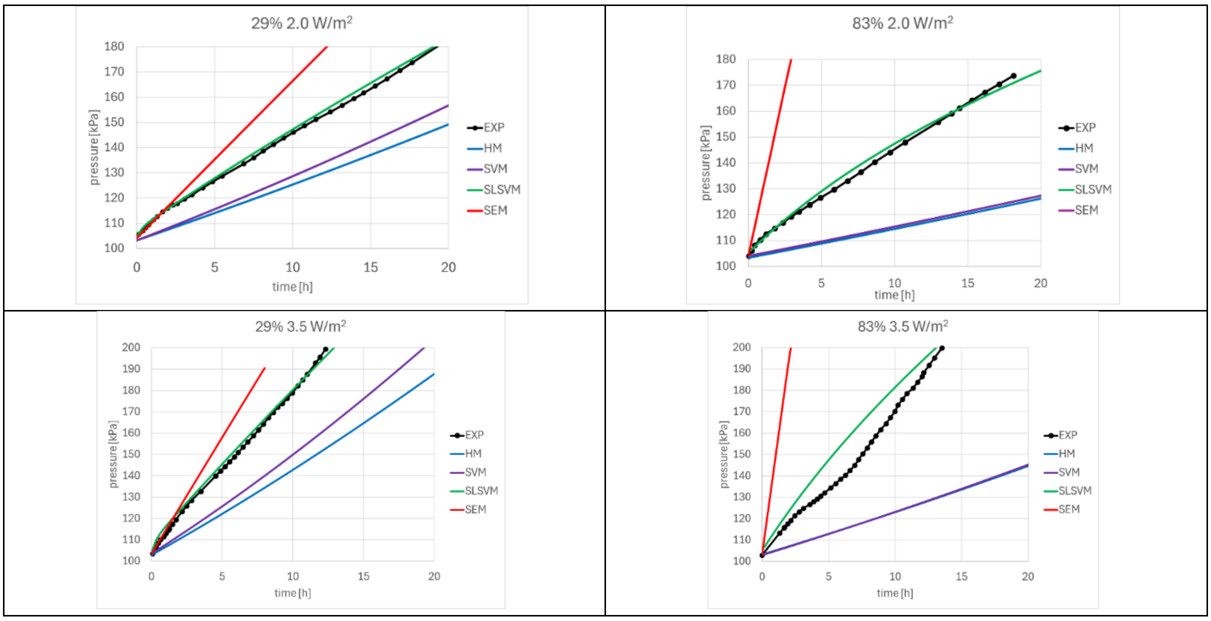

Figure 2 – Numerical vs. experimental results from [1].

Conclusions. The main focus of the paper stands in the comparison of different simulation approaches regarding the self-pressurization phase of LH2 storage tanks, as part of a more complex numerical model capable of simulating an entire navigation profile for tanks of different sizes and shapes.

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References

[1] *Van Dresar, N.T., Lin, C.S., Hasan, M.M., 1992. Self-Pressurization of a Flightweight Liquid Hydrogen Storage Tank: Effects of Fill Level at Low Wall Heat Flux. NASA Technical Memorandum 105411.*

[2] *Perez, F., Al Ghafri, S.Z.S., Gallagher, L., Siahvashi, A., Ryu, Y., Kim, S., Kim, S.G., Johns, M.L., May, E.F., 2021. Measurements of boil-off gas and stratification in cryogenic liquid nitrogen with implications for the storage and transport of liquefied natural gas, Energy 222 119853.*

[3] *Gursu, S., Sherif, S.A., Veziroglu, T.N., Sheffield, J.W.,1993. Analysis and Optimization of Thermal Stratification Effects in Liquid Hydrogen Storage Systems – Part 1: Model Development. Journal of Energy Resources Technology, Vol. 115, 221-227.*

[4] *Wang, H,R., Wang, B., Pan, Q.W., Wu, Y.Z., Jiang, L., Wang, Z.H., Gan, Z.H., 2022. Modeling and thermodynamic analysis of thermal performance in self-pressurized liquid hydrogen tanks. International Journal of Hydrogen Energy, 47, 30530-30545.*