International Journal of Hydrogen Energy

Date: 12 October 2026

Show more

Research article Get rights and content ↗

Comparison of simulation models for the self-pressurization time profile forecast of liquid hydrogen storage tanks for maritime sector

Michela Zanelli [a], Diego Micheli [b], Stefano Malabotti [a], Michele Capobianco [a], Rodolfo Taccani [b] Show more

Cite Add to Mendeley Share | 10.1016/j.ijhydene.2026.157634 ↗

Access through your organi... Purchase PDF

Highlights

The submitted paper presents the following key results.

- A systematic comparison of four zero-dimensional liquid hydrogen tank boil-off models is provided.
- A validation of the numerical models with experimental data available in literature is given.
- The paper allows to point out the best model in terms of accuracy and computational effort.
- By clarifying model strengths and limitations, this study supports safer LH_2 tank design and operation in shipping.

Abstract

A relevant technical challenge in LH_2 storage and transport to deal with is managing Boil-Off Gas (BOG). In closed systems, BOG is accumulated and this leads to pressure increase, requiring 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.

This paper presents the implementation and validation of four numerical simulation models. The models were implemented in MATLAB and validated against experimental data for both LN_2 and LH_2. A comparative analysis was conducted to evaluate the influence of heat transfer coefficients at the liquid-vapor interface on pressure trend over time. The results demonstrate that the last model provides the highest accuracy in predicting pressure trends, offering a robust balance between computational efficiency and physical reliability.

Keywords

Cryogenic fluid storage; Liquid hydrogen; Numerical modelling; Self-pressurization

Introduction

Cryogenic gases, such as hydrogen and natural gas, are attracting increasing interest as energy carriers. Although the liquefaction process is still expensive in both economic and energy terms, cryogenic gases in their liquid phase are able to achieve satisfactory energy densities, compared to other low-carbon energy carriers. This aspect makes them suitable for the transport sector, specifically for heavy duty vehicles and maritime applications. One of the earliest and niche applications of cryogenic fuels is in aerospace sector as propellant for spacecrafts: the Atlas-Centaur was the first rocket to use liquid hydrogen as a fuel (its Centaur upper stage, burning liquid hydrogen and liquid oxygen, performed the first successful in-flight burn of such an engine in 1963 [1]). Nowadays their application is spreading throughout the transport sector mainly with the aim of decarbonization.

Considering the maritime transport sector, the International Maritime Organization (IMO) has set targets of reduction of Green House Gases (GHG) emissions: by 2030 reduction in carbon intensity of international shipping by at least 40%, and net-zero GHG emissions by or around 2050, with indicative checkpoints to reduce total annual GHG emissions by at least 20% (striving for 30%) by 2030 and by at least 70% (striving for 80%) by 2040, all relative to 2008 emissions [2]. For the achievement of the medium-term goal, the application of Liquified Natural Gas (LNG) can be a valuable solution. Technologies related to LNG are mature and it is already used as fuel. For the achievement of the long-term goal, Liquified Hydrogen (LH_2) is preferred since it allows zero-emissions, if it is produced through renewable energy sources. However, technologies and infrastructures related to LH_2 are still under development and hydrogen applications are not yet directly addressed in IMO regulations [3]. Most relevant rules for hydrogen applications are IGF Code (International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels), the reference standard for the ships using low-flashpoint fuels, and IGC Code (International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk), the reference standard for the cargo carriage of liquified gases. For now, IGF Code considers only LNG as fuel, but it can be used as reference for the objectives and functional requirements to be pursued. In the absence of specific rules for LH_2, the “alternative design approach” shall be applied, which requires extensive analysis in order to reach an equivalent level of safety of the existing technologies. It promotes innovation but requires detailed analysis to demonstrate safety and feasibility of the proposed solution [4,5].

The present paper takes into account as case study a LH_2 storage system which is foreseen to supply a zero-emission fuel cell based energy system for a medium-size cruise ship. This energy system shall power the entire ship only for a limited time period, when the ship enters a zero-emission area. Since rules regarding bunkering of hydrogen are not yet existing and the bunkering is considered a hazardous operation, the alternative solution of portable cryogenic tanks has been explored within the sHYpS project [6]. The cryogenic storage system is designed to store the exact amount of fuel needed to power the ship for an entire cruise profile in zero-emission mode, because the available space onboard for the new energy system is limited, and due to safety reasons, it is challenging to bring onboard a large amount of LH_2.

A relevant technical challenge in LH_2 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.

Article preview

Abstract

Introduction

Section snippets

References (37)

The aim of this work is to provide a tool able to help in managing LH_2 tanks for the maritime transport sector, dealing with a generic navigation profile: self-pressurization phase at full tank, 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 LH_2 tanks, by simulating internal conditions and pressure trends by means numerical models. Four numerical models have been selected from the literature due to the assumptions on which they are based, that allow them to be easily developed and implemented in a more extensive simulation model. These models are compared to literature experimental data, focusing mainly at the two conditions where the tank is likely to be in self-pressurization phase, i.e. at almost full tank and at almost empty tank.

The novelty of this work does not lie in the individual models, which are largely drawn from the open literature, but in their systematic comparison within a single consistent framework, validated against both LN_2 and LH_2 experimental data and oriented to the long, non-stationary operating profiles typical of maritime missions. The study quantifies the trade-off between physical fidelity and computational cost.

Organizational access

Get full-text access by signing in with your organisation

Access through **your organization**

Other access options

Purchase PDF

Need help with access? ↗

Section snippets

Cryogenic storage tanks for liquid hydrogen

Despite its low density, hydrogen has a high gravimetric energy density (33.3 kWh/kg), that is 2.4 times that of natural gas (13.9 kWh/kg), among low-carbon energy fuels, six times that of methanol (5.6 kWh/kg) and 6.5 times that of ammonia (5.17 kWh/kg). Among main hydrogen storage methods, LH_2 gains high volumetric energy density (2363 kWh/m^3), three times that of Compressed Hydrogen (CH_2) at 350 bar (766 kWh/m^3) and 1.8 times that of CH_2 at 700 bar (1309 kWh/m^3) [4]. Furthermore, hydrogen …

Effect of main parameters on cryogenic tank management

In a no-venting cryogenic storage tank the thermal behaviour is complex to predict since many phenomena take place: the heat exchange at the tank wall is different for the liquid and the vapor phases, the heat flux entering the tank locally increases the fluid temperature and leads to convective currents, the fluid stratifies differently in liquid and vapor phases, fluid condensates and evaporates, the liquid-vapor mass transfer occurs and consequently the pressure increases or decreases.

Several recent studies have addressed the numerical modelling of LH2 self-pressurization, most of them adopting formulations of the subcooled-liquid/superheated-vapor type and validating them against the NASA Multipurpose Hydrogen Test Bed (MHTB) data. Matveev and Leachman [10] and Appel et al. [27] developed and progressively refined an SLSVM-type model, the latter also validated against IRAS (Integrated Refrigeration and Storage) and in-service data. Yu and Lim [19] proposed a closely related …

Results, validation and discussions

The models were first validated by comparison with numerical results from the papers taken as reference. In general, they resulted to be in good agreement, when reasonable values of any calibration parameters are applied, thus confirming their correct implementation.

Comparisons were then made with the relatively limited experimental results available in the scientific literature, to verify the applicability of the models to real-world operational cases. The main information of the tanks and …

Conclusions

In this paper the self-pressurization phase of cryogenic fluids in storage tanks has been investigated by implementing four zero-dimensional simulation models. Both numerical and experimental data from scientific literature with LH_2 and LN_2 have been used for validation of the models. The developed models are: Homogeneous Model (HM, with vapor and liquid phases in thermal equilibrium), Superheated Vapor Model (SVM, with superheated vapor and liquid in saturated condition), Surface Evaporation …

CRediT authorship contribution statement

Michela Zanelli: Writing – original draft. **Diego Micheli:** Software. **Stefano Malabotti:** Writing – original draft. **Michele Capobianco:** Writing – review & editing. **Rodolfo Taccani:** Supervision. …

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

Acknowledgment

This work has been partly funded by the Project sHYpS (sustainable HYdrogen powered Shipping) Horizon Europe call Horizon-CL5-2021-D5-01 – Grant Agreement ID 101056940. …

References (37)

Z. Wang *et al.*
Thermal performance of cylindrical and spherical liquid hydrogen tanks
Int J Hydrogen Energy (2024)

T. Yu *et al.*

J. Wang *et al.*
Thermodynamic modelling of pressurized storage and transportation of liquid hydrogen for maritime export
Int J Hydrogen Energy (2024)

Centaur: America's workhorse in space

Fourth IMO greenhouse gas study

Potential of hydrogen as fuel for shipping

J. Depken *et al.*
«Safety considerations of hydrogen application in shipping in comparison to LNG
Energies (2022)

International code of safety for ships using gases or other low-flashpoint fuels: IGF-code
(2015)

«sHYpS project(2025)

R. Barron *et al.*
Cryogenic heat transfer
(2016)

View more references

This article is part of a special issue entitled: EFCHC25 conference (Iulianelli) published in International Journal of Hydrogen Energy.

View full text

Recommended articles

Based on reading popularity

Research article Open access
Orchestrating acts of kindness: An exploratory framework for designing beneficial kindness interventions
Michelle K.P. Johnson, ..., Anna E. Pohlmeyer
Advanced Design Research • Volume 3, Issue 2 • 2025 • Pages 79-90

Research article Open access
Influence of post-processing on the adhesion of dual-species biofilm on polylactic acid obtained by additive manufacturing
Izabela Ferreira, ..., Andréa Cândido dos Reis
The Saudi Dental Journal • Volume 36, Issue 5 • 2024 • Pages 733-739

Research article
Human risk recognition and prediction in manned submersible diving tasks driven by deep learning models
Yidan Qiao, ..., Yao Wang
Advanced Engineering Informatics • Volume 62, Part D • 2024 • Article 102893

Software publication Open access
Gecko: A Python library for the generation and mutation of realistic personal identification data at scale

Comparison of simulation models for the self-pressurization time profile forecast of liquid hydrogen storage tanks for maritime sector

Article preview Recommended articles Metrics

Research article

Assessment of dynamic cognitive performance under different thermal conditions by multiple physiological signals

Yidan Qiao, ..., Dengkai Chen

Journal of Building Engineering • Volume 89 • 2024 • Article 109325

Software publication Open access

BWEFoam: An open-source Boussinesq types of equations solver based on OpenFOAM

Fangrui Liu, ..., Yaolin Shi

SoftwareX • Volume 27 • 2024 • Article 101808

Metrics

Captures

Mendeley Readers 1

PLUMX View details ↗

© 2026 Hydrogen Energy Publications LLC. Published by Elsevier Ltd. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

ELSEVIER

All content on this site: Copyright © 2026 Elsevier B.V., its licensors, and contributors. All rights are reserved, including those for text and data mining, AI training, and similar technologies. For all open access content, the relevant licensing terms apply.

RELX™