Hydrogen Dispersion and Safety Assessment of Vent Mast Releases on LH_2 carrier in LH_2CRAFT Project

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Abstract. The high flammability and explosion risk of hydrogen pose significant safety challenges in handling and storing liquefied hydrogen (LH_2) as an alternative marine fuel. This study examines hydrogen dispersion from a vessel's vent mast to enhance safety in future LH_2 carriers. Using Computational Fluid Dynamics (CFD), various hydrogen release scenarios were modeled on an LH_2 carrier framework, considering regulatory requirements, wind conditions, and atmospheric dispersion. Due to hydrogen's low ignition energy and broad flammability range, even small leaks can escalate into severe incidents. Results showed that direct release through the vent mast could allow hydrogen to disperse toward the accommodation area, posing serious risks. These findings emphasize the need for strengthened safety protocols. As the maritime industry pursues decarbonization, addressing hydrogen safety is crucial for regulatory compliance and operational viability. Future ship designs must integrate advanced risk assessments and venting systems to ensure the safe use of hydrogen fuel in maritime operations.

Keywords: Liquid Hydrogen (LH_2), Hydrogen Safety, Vent Mast, Gas Dispersion, Risk Assessment

1 Introduction

The increasing focus on hydrogen (H_2) as a marine fuel in the shipping industry is largely driven by global greenhouse gas (GHG) reduction targets [1]. However, compared to conventional fossil fuels, hydrogen presents distinct environmental and safety challenges. Its wide flammability range (4–75% in air), extremely low minimum ignition energy (0.017 mJ), and high diffusion rate significantly elevate the risk of unintentional ignition and explosion, particularly in confined or semi-confined spaces [2].

Liquefied hydrogen (LH_2) offers a higher energy density but necessitates cryogenic storage at -253°C, introducing risks associated with rapid phase changes and material embrittlement [3]. Another critical concern is the potential for hydrogen to undergo a deflagration-to-detonation transition (DDT) in enclosed environments, posing a severe

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safety hazard [4]. Computational fluid dynamics (CFD) simulations indicate that while hydrogen disperses quickly upon release, under specific conditions, flammable clouds may persist. Consequently, strict design standards for fuel containment, leak detection, and ventilation are essential to mitigate potential hazards [5].

One of the key safety mechanisms in hydrogen-carrying vessels is the vent mast system, designed to release excess or leaked hydrogen in a controlled manner. By safely dispersing hydrogen away from critical areas where accumulation could lead to ignition, vent masts play a crucial role in risk mitigation. Therefore, their design must account for hydrogen buoyancy, wind interactions, and exhaust velocity, particularly in emergency scenarios such as overpressure events or fuel purging. The integration of CFD-validated vent mast configurations and compliance with classification society regulations, such as those established by the International Maritime Organization (IMO), are crucial for ensuring the operational safety of LH_2 carriers.

2 Case study

2.1 Vessel Specifications

For this research, a full-scale Liquefied Hydrogen (LH_2) carrier was carefully selected as the reference vessel, as depicted clearly in Fig. 1. This vessel represents a significant advancement in maritime technology, specifically designed to meet the stringent requirements necessary for safely transporting hydrogen in its liquid state. The reference vessel boasts an impressive length overall (LOA) of 299.06 meters and a substantial length between perpendiculars (LBP) measuring 291.00 meters, thereby providing ample space to accommodate large-scale hydrogen cargo volumes. Furthermore, the breadth of the vessel is established at 46.40 meters, which ensures adequate stability and sufficient internal volume to host advanced storage systems. The molded depth of the ship stands at 26.50 meters, combined with a trunk depth of 35.50 meters, dimensions specifically optimized for the efficient and secure transport of LH_2.

The vessel under investigation is classified as Ship Type 2G, a specialized categorization explicitly indicating its suitability and enhanced safety features tailored for the carriage of liquefied gases. Specifically engineered to store and transport LH_2, this vessel utilizes advanced membrane-type containment tanks, renowned for their superior insulation capabilities and structural integrity under extreme cryogenic conditions. The design specification mandates that these tanks maintain the LH_2 cargo at an exceptionally low temperature of approximately -253°C, reflecting hydrogen's boiling point under atmospheric pressure conditions.

Fig. 1. Illustration of the envisaged LH_2 carrier modeled by KSOE.

3 Numerical modelling

The dispersion model of hydrogen released from the vent mast was conducted using the FLACS (FLame ACceleration Simulator). FLACS is a CFD software extensively developed and widely utilized, particularly for gas dispersion simulations [6]. Due to hydrogen's high diffusivity and significant fire and explosion hazards, FLACS is highly suitable for capturing both the temporal and spatial variations of hydrogen dispersion under various release conditions, including vent mast emissions [7]. The governing equations used in FLACS simulations are based on the Reynolds-Averaged Navier-Stokes (RANS) equations. To model the turbulent transport of hydrogen gas, the standard k-ε turbulence model is employed. For numerical discretization, the Finite Volume Method (FVM) is utilized.

In addition, the minimum required discharge flow rate of hydrogen gas from a membrane tank is determined according to the International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code). The release rate Q is calculated using the equation:

$$Q = FGA^{0.82} \tag{1}$$

where F represents the fire exposure factor, G is the gas factor, and A is the external surface area of the tank. For membrane tanks, the fire exposure factor is 0.1.
The gas factor G is defined as:

$$G = \frac{12.4}{LD}\sqrt{\frac{ZT}{M}} \tag{2}$$

where T is the absolute temperature at relieving conditions, representing the thermodynamic state of hydrogen during the release. It is specified as 53.15 K., L is the latent

heat of vaporization at relieving conditions, representing the amount of energy required to convert a unit mass of hydrogen from liquid to vapor without a temperature change. In this context, it is specified as 445.65 kJ/kg., and M **is th**e molecular mass of hydrogen, which affects its velocity and energy characteristics during vaporization. The value used is 2.016 kg/kmol., Z is the compressibility factor, which corrects for deviations from ideal gas behavior. The value used is 1

The term D is a coefficient related to the ratio of specific heats, given by:

$$D = \sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \tag{3}$$

where k is the ratio of specific heats at relieving conditions, with a value of 1.383. Finally, the mass flow rate of hydrogen gas from the membrane tank is determined as:

$$\dot{m} = \rho Q \tag{4}$$

where ρ represents the density of hydrogen gas at relieving conditions. This equation ensures that the pressure relief system is appropriately sized to handle emergency venting scenarios, maintaining the safety of the liquefied hydrogen containment system, resulting in a calculated mass flow rate of 2.72 kg/s.

3.1 Computational domain and boundary conditions

FLACS-CFD simulation primarily utilizes a three-dimensional Cartesian grid composed of cubic or rectangular cells Fig. 2 and Table 1 illustrate the computational domain, which is defined with dimensions of 400 m × 120 m × 100 m along the X, Y, and Z axes, respectively, consisting of a total of 3,530,592 grid cells. In particular, to effectively capture localized dispersion effects from the ejection point within the vent mast to the vicinity of the vent mast outlet, the minimum grid size was set to 0.12 m, enabling a more detailed calculation of dispersion phenomena.

Outside the vent mast, an elongated grid was applied to balance precision and computational cost. To prevent abrupt transitions between the fine grid and the core grid region, the grid spacing was gradually increased. The maximum stretching factor was set to 1.2, and the largest grid cell size in the stretched region was limited to 2.2 m, optimizing computational efficiency while maintaining accuracy.

Boundary conditions were selected for hydrogen dispersion modeling, with the inlet boundary conditions configured based on hydrogen flow rate, temperature, and pressure parameters at the vent mast release point. Considering a scenario where the wind blows from the bow to the stern, the XLO boundary (the lower boundary in the X-direction) was modeled as a nozzle and assigned a pressure outlet condition to facilitate smooth fluid discharge. The XHI boundary (the upper boundary in the X-direction) simulated incoming airflow with wind speeds of 1 m/s or 6 m/s. The YHI and YLO boundaries (the upper and lower boundaries in the Y-direction, respectively), as well as the ZHI boundary (the upper boundary in the Z-direction), were set to neutral wind conditions with a velocity of 0 m/s, thereby preventing any additional inflow or outflow

of air. The ZLO boundary (the lower boundary in the Z-direction) was configured as a combination of nozzle and solid wall conditions, acting as a smooth wall surface to ensure accurate modeling of boundary-layer interactions.

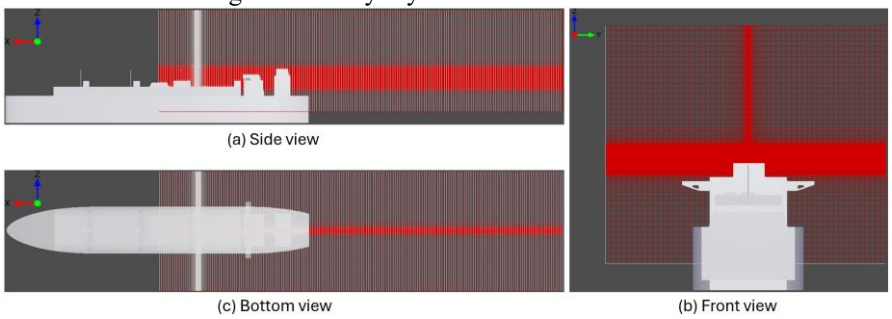

Fig. 2. Computational domain for vent mast simulation.

Table 1. Computational domain for core and stretched grid regions.

	Grid Coordinates	Minimum [m]	Maximum [m]
Core grid region	X	109.34	109.92
	Y	-0.3	0.3
	Z	24.5	42
Stretched grid region	X	-250	150
	Y	-60	60
	Z	0	100

3.2 Case description

Table 2 presents the input parameters used in the vent mast simulation, specifically focusing on the LH_2 storage tank, environmental conditions, and release properties. The simulation considers a hydrogen storage tank with a volume of 43,485.67 m^3, operating at a pressure of 0.7 barg and a temperature of -253°C.

The environmental conditions include two different wind speeds: 1 m/s (Pasquill stability class F) and 6 m/s (Pasquill stability class D), with a wind direction of 180 degrees (from bow to stern). The ship is assumed to be stationary, with a speed of 0 m/s during the simulation.

Key release parameters include a hydrogen release rate of 2.72 kg/s, an upward-oriented vent with an exit diameter of 0.6 m, and a high release velocity of 285.59 m/s. The released gas is 100% hydrogen.

The surrounding atmospheric conditions are also defined, with a temperature of 20°C and an atmospheric pressure of 1.0 bara. These parameters help evaluate the dispersion characteristics of hydrogen gas under varying wind conditions and vent configurations. The results derived from these inputs contribute to assessing potential safety hazards and optimizing the vent mast design for effective gas dispersion.

Table 2. Input Parameters for Vent Mast Simulation: LH_2 Storage Tank, Environmental Conditions, and Release Properties

Parameter	Value
Hydrogen storage tank volume	43,485.67 m^3
Hydrogen storage tank temperature	-253 °C
Wind speed	1 m/s (Pasquill stability class F) 6 m/s (Pasquill stability class D)
Wind direction	180 degree (Bow to Stern)
Ship speed	0 m/s
Release rate	2.72 kg/s
Vent exit diameter	0.6 m
Vent orientation	Upward
Released gas	100% H2
Atmospheric temperature	20°C
Atmospheric pressure	1.0 bara

4 Results

The results from the CFD simulations provide a detailed analysis of hydrogen dispersion and velocity distributions resulting from vent mast releases on a LH_2 carrier. The simulations highlight the potential risks associated with hydrogen as a marine fuel, particularly under various environmental and operational conditions.

As illustrated in Fig. 3, the figure depicts hydrogen dispersion from the vent mast under wind speeds of 1 m/s and 6 m/s, respectively. In both cases, the hydrogen plume remains concentrated within a localized region, reaching up to 75 vol% near the leakage source. While the dispersion extends horizontally, the weak airflow confines the plume within a relatively small volume. In certain areas, the sustained high hydrogen concentration poses a potential explosion risk. Compared to the case with a wind speed of 6 m/s, an decrease to 1 m/s causes the hydrogen plume to spread farther, significantly increasing the dispersion distance. Enhanced mixing and dilution accelerate the reduction in hydrogen concentration. Although the formation of localized high-concentration hydrogen pockets becomes less likely, the overall affected area expands. At a higher wind speed of 1 m/s, hydrogen forms a high-concentration plume at the vent mast outlet, increasing the explosion risk., increasing the explosion hazard. Conversely, at a lower wind speed of 6 m/s, localized risks diminish, but the spread of flammable gases over a wider area increases exposure risks. Therefore, appropriate ventilation strategies and risk mitigation measures must be implemented for all scenarios, considering varying wind conditions. While low wind speeds lead to localized high concentrations, higher wind speeds promote broader dispersion while reducing peak concentrations.

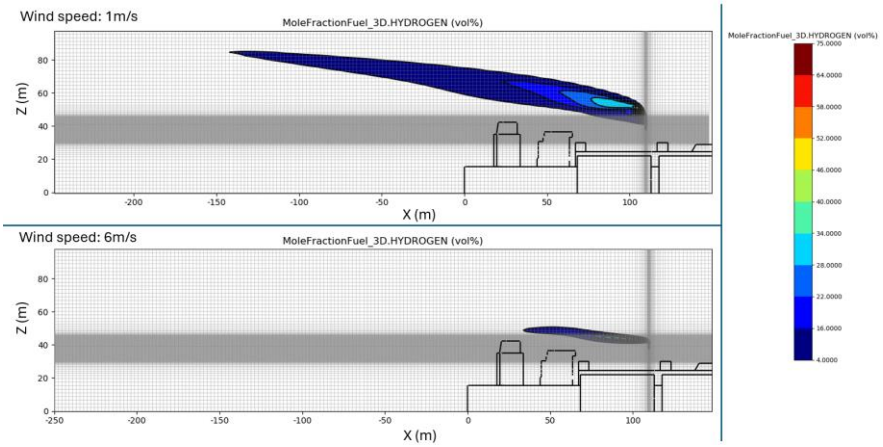

Fig. 3. CFD Simulation Results of Hydrogen Dispersion Under Different Wind Speeds (1 m/s and 6 m/s)

Fig. 4 presents the results of a three-dimensional computational fluid dynamics (CFD) simulation illustrating the dispersion characteristics of hydrogen released from a LH_2 carrier. The 3D visualization provides a clear representation of how hydrogen spreads throughout the surrounding environment.

According to the simulation results, hydrogen dispersion is primarily influenced by wind direction, interacting with the ship's structures as it spreads. Near the release point, the hydrogen concentration remains high but gradually decreases due to turbulent mixing with the ambient air.

These findings offer crucial insights into the potential formation of flammable hydrogen zones around the LH_2 carrier. The results can be utilized for optimizing vent placement, establishing emergency response procedures, and implementing safety measures to mitigate explosion risks.

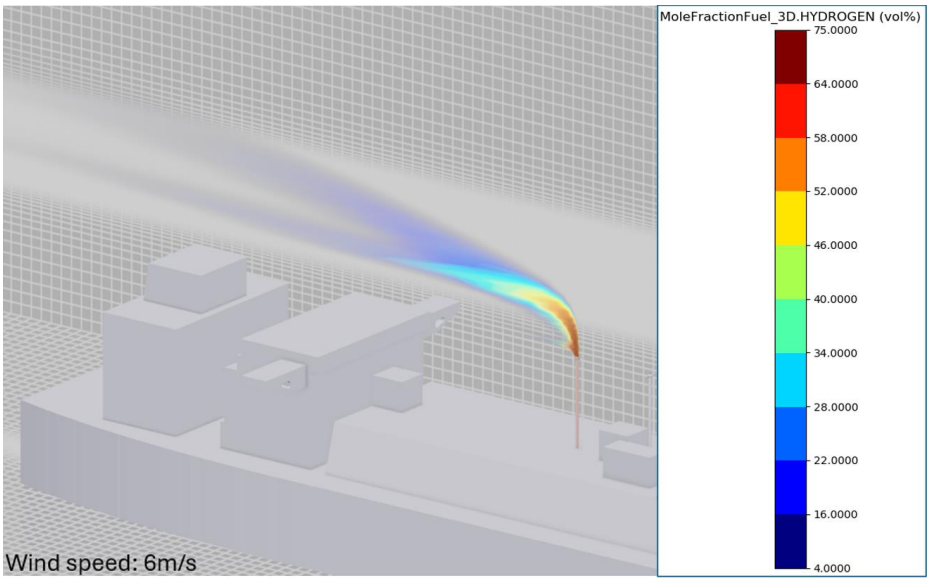

Fig. 4. 3D simulation of hydrogen dispersion from vent mast.

5 Conclusion

This study conducts a CFD analysis to investigate the dispersion of hydrogen gas emitted from the vent mast of an LH_2 carrier. The findings underscore the critical role of vent mast design, positioning, and velocity distribution in facilitating efficient hydrogen dispersion.

The analysis indicates that while hydrogen gas is expected to disperse rapidly upon release through the vent mast, it may initially accumulate in high concentrations around the mast, significantly heightening the risk of fire or explosion. This underscores the necessity of carefully determining the vent mast's placement and devising an appropriate operational strategy.

Moreover, this research highlights the substantial influence of wind speed on hydrogen dispersion patterns. The results reveal that dispersion range and velocity fluctuate considerably depending on wind intensity and direction, suggesting that even a well-engineered vent mast may still present unforeseen risks under certain environmental conditions.

The conclusions derived from this study contribute to the development of safety guidelines and regulatory standards for hydrogen carriers. By deepening the understanding of hydrogen dispersion mechanisms in marine environments, this research supports ongoing efforts to safely integrate hydrogen as a sustainable alternative fuel in the shipping industry.

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References

1. Shi, J., Zhu, Y., Feng, Y., Yang, J., Xia, C.: A prompt decarbonization pathway for shipping: Green hydrogen, ammonia, and methanol production and utilization in marine engines. *Atmosphere* **14**(3), Article 584 (2023).
2. Patel, P., Baalisampang, T., Arzaghi, E., Garaniya, V., Abbassi, R., Salehi, F.: Computational analysis of the hydrogen dispersion in semi-confined spaces. *Chemical Engineering Research and Design* **193**, Article 758–768 (2023).
3. Giannis, S., Salmeron-Perez, N., Spetsieris, N.: Challenges in realising composite liquid hydrogen cryogenic storage: A materials and standards perspective. Unpublished or forthcoming work (2023).
4. Machniewski, P., Molga, E.: CFD analysis of large-scale hydrogen detonation and blast wave overpressure in partially confined spaces. *Process Safety and Environmental Protection* **158**, 537–546 (2022).
5. Sun, R., Pu, L., Yu, H., Dai, M.H., Li, Y.: Modeling the diffusion of flammable hydrogen cloud under different liquid hydrogen leakage conditions in a hydrogen refueling station. *International Journal of Hydrogen Energy* **47**(55), 23200–23213 (2022).
6. Vyazmina, E., Jallais, S.: Validation and recommendations for FLACS CFD and engineering approaches to model hydrogen vented explosions: Effects of concentration, obstruction vent area and ignition position. *International Journal of Hydrogen Energy* **41**(31), 13887–13898 (2016).
7. Ustolin, F., Øygård Asholt, H., Zdravistch, F., Niemi, R., Paltrinieri, N.: Computational fluid dynamics modeling of liquid hydrogen release and dispersion in gas refuelling stations. *Chemical Engineering Transactions* **86**, 229–234 (2021).