Hydrogen as a Marine Fuel

Background

Hydrogen is a colorless, odorless, and flammable gas; however, for the future purpose as a non-traditional marine fuel, it will likely be stored as either a compressed or refrigerated liquid (referred to as LH_2).

In the future, hydrogen may be used as part of a "dual-fuel" engine, meaning it is used alongside more conventional fuel oils, such as heavy fuel oils, marine diesel oils, and biofuels, within a vessel. Unlike other alternative fuels, LH_2 is currently not globally transported as a marine cargo; therefore, there is a dearth of experience in the handling, transporting, storing, and unloading of hydrogen. LH_2 has approximately 4.5 times higher energy density than compressed hydrogen gas, making LH_2 the more attractive form as an alternative fuel. Since 2023, several hydrogen-fueled vessels have been launched, including the world's first hydrogen-powered tug boat. These are typically smaller vessels, and the use of LH_2 has not been upscaled to the larger ocean-going commercial fleet yet. LH_2 does not have the industrial maturity of other fuels such as LNG, ammonia, or methanol.

Hydrogen Properties

- At ambient conditions, hydrogen is a colorless, odorless, and non-toxic gas.
- Hydrogen gas has a very low density and is typically liquefied cryogenically or compressed (at pressures between 250–700 bar) for storage and transportation purposes.
- In its liquid state, hydrogen has a specific density of 0.071 at -423.4 °F/-253 °C, making it less dense than water; however, it has a boiling point of -423 °F/-252.8 °C and will quickly evaporate if placed in ambient conditions.
- In its gaseous state, the specific density of hydrogen is 1.338 at -423.4 °F/-253 °C, making the saturated vapor heavier than air. The vapors will remain close to the ground until its temperature rises. At ambient temperature, the vapor specific gravity is 0.067, making these vapors significantly lighter than air, and the vapors will easily disperse in open or well-ventilated areas.

Flammability Hazards

- The Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL) range from 4%–75% by volume. It therefore can be considered highly flammable. Outside of this range, the hydrogen/air mixture will be either too fuel rich or poor to be flammable.
- The LEL-UEL range for hydrogen is much greater than conventional fuels such as diesel, which has a smaller flammability range: LEL-UEL range of 0.6%–5.5% by volume.
- Small hydrogen leaks can often form pockets of hydrogen gas which can create explosive environments due to its low LEL.
- As hydrogen is less dense and more volatile than LNG, the dispersion rate will be much quicker. As a result, hydrogen vapor clouds will have a significantly smaller flammability area than LNG.
- In an unconfined space, hydrogen vapors will rapidly mix and dissipate into the atmosphere, falling relatively quickly below the 4% LEL. Only small confined areas close to the hydrogen source would likely reach flammable concentrations. High concentration of hydrogen vapors displace oxygen in the air, decreasing oxygen availability, leading to asphyxiation of those present.
- When ignited, a flash fire is likely to occur, which will continue until all of the fuel has been consumed.
- Hydrogen flames are colorless, resulting in low visibility especially during daylight conditions.

Environmental Behavior

- When the temperature of LH_2 rises above its boiling point, or when the LH_2 is exposed to the ambient environment, it quickly vaporizes. As these vapors warm up to ambient conditions, the vapors will disperse rapidly into the atmosphere due to its extremely low density.

- If LH_2 is spilled on surface waters, it will first float on water and rapidly vaporize.
- Unlike in the case of LNG, it is unlikely that cryogenic pools will form on the water's surface from the difference in temperatures (>482 °F/250 °C) between the hydrogen and water under ambient conditions.
- If a release below the waterline occurs, LH_2 will rise to surface waters, due to its specific gravity, before rapidly boiling and volatilizing into the atmosphere.
- The vaporized hydrogen forms a vapor cloud; the footprint and height of this vapor cloud is dependent on the rate of the spill and the meteorologic and oceanic conditions at the time of the release.
- In lower wind conditions (<5 miles per hour [mph]), the vapor cloud footprint is smaller on the sea surface. It is then expected to rise and dissipate at higher altitudes (Figure 1, Top).
- In moderate wind conditions (>5 mph), the vapor cloud plume is likely to be pushed down onto the surface water, causing the vapor cloud's footprint to be more low-lying and spreading over a much larger surface area of the water (Figure 1, Bottom).

Response Monitoring

- Thermal imaging cameras and flame detectors are recommended for hydrogen fires; hydrogen fires are colorless and have low radiant heat, making them difficult to perceive in bright daylight and sense unless within close proximity.
- Protective equipment, for any hydrogen response operation, should include antistatic clothing, cryogloves, and a SCBA full face-piece operating under positive-pressure mode.
- For smaller fires, a carbon dioxide or halon extinguishing agent should be employed.
- If the fire is larger, it is recommended that the hydrogen is allowed to continue burning, as the leaking hydrogen vapors may travel and find another ignition source.

Helpful References

Le Masurier, A. 2024. Alternative fuels: a shift in the response paradigm? International Oil Spill Conference Proceedings, p. 346.

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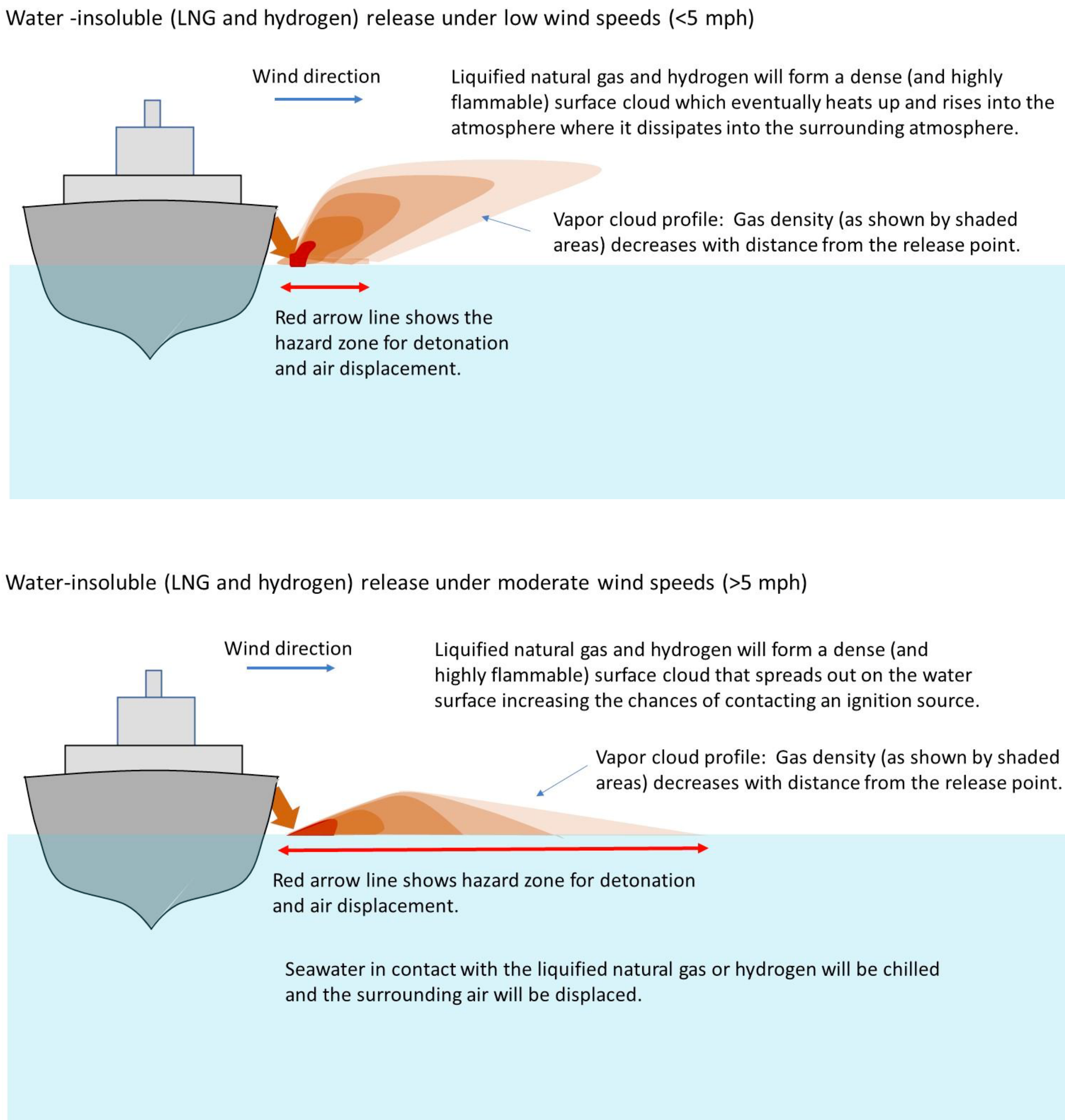

Figure 1. Comparative fate and behavior of LH_2 spill off of a ship in two conditions: **Top:** Low wind conditions (<5 mph). **Bottom:** Moderate wind conditions (>5 mph). Blue, orange, and red arrows indicate wind direction, hydrogen release direction, and extent of hazard zone increasing with wind speed, respectively. From Kass et al. (2021).