MARITIME TECHNOLOGIES FORUM

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GUIDELINES FOR THE DEVELOPMENT OF LIQUEFIED HYDROGEN BUNKERING SYSTEMS AND PROCEDURES

Abbreviations and Definitions

Abbreviation	Definition
ASME	The American Society of Mechanical Engineers
DDT	Deflagration-to-detonation Transition
LH_2	Liquefied hydrogen
IGC Code	The International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IGF Code	The International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels
IMO	International Maritime Organization
LNG	Liquefied Natural Gas
MEPC	IMO's Marine Environment Protection Committee
MSC	Maritime Safety Committee
MTF	Maritime Technologies Forum
SGMF	The Society for Gas as a Marine Fuel
SIGTTO	The Society of International Gas Tanker and Terminal Operators
SMS	Safety Management System
STCW Code	The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers,1978

Executive Summary

The Maritime Technologies Forum (MTF) is a group of flag States and classification societies which aims to bridge the gap between technological progress and regulatory process. In relation to the adoption of liquefied hydrogen gas (LH_2) as a relevant fuel for the maritime sector, MTF carried out a study on the current technological progress, and potential regulatory gaps, relating to liquefied hydrogen with emphasis on the bunkering of the fuel.

IMO is currently working on the development of guidelines for the safe design of ships with hydrogen as fuel, with the target completion already at CCC10 in September 2024. Those guidelines will however focus on the ship installations and stop at the bunkering manifold on the ship. The details related to the bunkering operations are not part of the scope for that work. The goal with this work is to supplement CCC10 with input on the bunkering side of liquified hydrogen fuel safety.

This report discusses the potential use of hydrogen as a zero-emission fuel to meet the IMO Strategy on Reduction of GHG Emissions from Ships by 2050. It acknowledges the lack of experience in the maritime sector with hydrogen as cargo and fuel, and the increased risks associated with its use as a fuel compared to LNG. As of the writing of this report, there are no international standards covering the bunkering of liquefied hydrogen. However, information collected from ongoing developments in ISO for related areas, as well as the experience gained from the Norwegian ferry "Hydra", serves as the basis for the guidelines and recommendations of this report.

The objective of this project is to review barriers and enablers to safe bunkering operations of liquid hydrogen (LH_2) with focus on the ship-to-shore interface and to produce a framework for LH_2 bunkering guidelines. Experience with bunkering of hydrogen for ships is limited and the design, operation and regulatory approval processes are complex. The project has conducted a review of existing standards and experience that can be applied to LH_2 marine bunkering and proposed structure and main topics of importance for bunkering guidelines which can help to accelerate the development and standardisation of LH_2 bunkering procedures for ships.

Proposed draft guidelines are recommended to be further developed by industry.
The bunkering processes for LH_2 will need to be developed with the properties of liquefied hydrogen clearly in mind. This report provides a starting point for development of guidelines for bunkering of LH_2, and this work is recommended to be discussed at IMO and further developed by industry.

Experience from bunkering LNG as fuel cannot directly be re-used.
The properties of hydrogen, and in particular the very low temperature of liquified hydrogen, means that experience gained from bunkering arrangements for liquid natural gas, LNG, cannot be re-used directly. The bunkering process will be more complex than what is known for LNG, since no nitrogen can be present inside the piping systems when LH_2 is introduced, as this will freeze and clog the systems.

Extreme properties of hydrogen require careful material selection and more temperature insulation.
The potential risks associated with hydrogen properties such as extremely low temperature, flammability, explosivity, permeability can lead to damage to equipment and detonation. A careful material selection is required to prevent hydrogen embrittlement and leakage. The extremely low temperature also means that more extensive use of vacuum insulation for components and piping will be necessary.

More complex bunkering procedures may bring more automated processes.
Vessel-specific procedures for bunkering operations will be needed, and the added complexities with LH_2 bunkering may also lead to a need for more automated bunkering processes.

Inherent complexity of LH_2 systems requires high emphasis on training and safety management.
The added complexities will also mean that the need for crew training and certification is of even higher importance than for other bunkering processes. The Safety Management System should be updated to cater for the additional safety aspects with the liquified hydrogen bunkering, as outlined in another work carried out by MTF, 'Guidelines to develop and implement Safety Management System for alternative fuels onboard ships'.

Background and Objective

The Maritime Technologies Forum (MTF) is a group of flag States and classification societies which aims to bridge the gap between technological progress and regulatory process. MTF has been established to provide technical and regulatory expertise for the maritime industry. MTF's role is to publish research based on its members' expertise and offer unbiased advice to the maritime industry. The current research focuses on the common challenges that are faced by the maritime industry such as decarbonisation, alternative fuels and increased levels of automation therefore allowing safe adoption of new technologies. MTF's work can be found on our website: www.maritimetechnologiesforum.com.

The IMO Strategy on Reduction of GHG Emissions from Ships aims to reduce GHG emissions from international shipping as soon as possible and strive to reach net-zero GHG emissions around 2050 and recognizes that the introduction of new energy carriers (alternative fuels) and new energy converters (engines/fuel cells/batteries) is necessary to achieve the strategic targets. Such new fuels and energy converters will have to be devised, designed, tested, and implemented in commercial shipping in a safe manner.

Hydrogen is among the zero-emission fuels that may be highly relevant for commercial shipping to meet the 2050 targets. However, the maritime sector has little-to-no experience with hydrogen, both as cargo and as fuel. Research is still ongoing for the safe use of hydrogen as fuel and its potential wide use as a bunker fuel implies a shift from one-off operations with hydrogen to progressively extensive use, which increases the risks considerably.

The uptake of this technology relies equally on ensuring that the ship-to-shore interface is also factored in the regulatory development process and standardisation. This can involve high complexity in terms of risk management and mitigation but also from a planning and administration point of view.

For ports, hydrogen bunkering operations will require particularly careful attention. Detailed risk considerations will be significant for developing the right design protecting the ship, its personnel, and the environment.

IMO is currently working on the development of guidelines for the safe design of ships with hydrogen fuel, with the target completion already at CCC10 in September 2024. These guidelines will however stop at the bunkering manifold on the ship, and not consider in detail the matter of bunkering operations.

As of the writing of this report, there are no international standards covering the bunkering of liquefied hydrogen. However, information collected from ongoing developments in ISO for related areas, as well as the experience gained from the Norwegian ferry "Hydra", serves as the basis for the guidelines and recommendations of this report. An extract of the technical details of the bunkering arrangement for Hydra is found in Appendix 1.

The objective of this project is to review barriers and enablers to safe bunkering operations of liquid hydrogen (LH_2) with focus on the ship-to-shore interface and to produce a framework for LH_2 bunkering guidelines. Experience with bunkering of hydrogen for ships is limited and the design, operation and regulatory approval processes are complex. The project has conducted review of existing standards and experience that can be applied to LH_2 marine bunkering and proposed structure and main topics of importance for bunkering guidelines which can help to accelerate the development and standardisation of LH_2 bunkering procedures for ships. There is experience with the transport of liquefied hydrogen as cargo on the vessel Suiso Frontier, operating between Japan and Australia, and the project has also considered if there are relevant learnings to gain from that operation.

Introduction to the Guidelines

The structure of these guidelines can be summarised as follows:

1. Properties of Hydrogen
2. Regulatory Framework and Available Experience
3. LH_2 Bunkering System
4. Bunker Piping System
5. Bunkering Operations and Safety Equipment
6. Bunkering Procedures and Manuals
7. Crew Training and Certification

The format change in the document between Section 1 to 7 is intentional to provide the reader with a clear difference between the guidelines and the rest of the document.

Disclaimer

While the advice given in this report has been developed using the best currently available information, it is intended to be used solely as guidance. No responsibility is accepted by MTF or its members for any consequences resulting directly or indirectly from the adoption of any of the recommendations in this report.

1. Properties of Hydrogen

Flammability and Explosivity

Hydrogen, as a highly flammable fuel, mixes with oxygen whenever air is allowed to enter a hydrogen vessel, or when hydrogen leaks from any vessel into the air. Hydrogen is flammable over a very wide range of concentrations in air (4 – 75% vol in air). As a result, even small leaks of hydrogen have the potential to ignite. The wide flammability range of hydrogen also leads to larger flammable clouds compared to LNG, which has a flammability range of 5-17%, and hence will quickly reach a concentration that is too rich for ignition.

The flame speed of hydrogen is very high (265-325 cm/s), which also incurs the risk of detonation (DDT), quicker pressure peaks and higher explosion pressures. At the same time the required minimum ignition energy for hydrogen is very low, meaning that hydrogen can ignite with a weaker ignition source (as little as static electricity is sufficient for certain concentrations). Hydrogen is colourless and odourless therefore leaks are difficult to detect and same goes for the flame that is almost invisible to human eyes. Hydrogen gas is lighter than air and provides a fire and explosion hazard in confined spaces. While the risk of explosion in open air is lower, it should not be neglected.

Hydrogen Permeation and Embrittlement

As the molecules of hydrogen gas are smaller than all other gases, it will leak through many materials considered airtight or impermeable to other gases, by diffusion through the material itself. This property makes hydrogen more challenging to contain than most other gases. The properties of the hydrogen molecule will also incur the risk of hydrogen embrittlement to metallic materials. Higher risk of leakage through small crevices is also a direct consequence of the molecule size.

Cryogenic

The boiling point of liquid hydrogen is extremely low, which creates several specific additional challenges in the design of ships and associated bunkering systems. First, the materials must be suitable for the fuel temperature, but also, at -253°C, both oxygen and nitrogen will become solid. This means that nitrogen cannot be used as an inert gas in the same way as for LNG systems. If there is any N_2 left in the systems when liquid hydrogen is introduced clogging of filters and fouling of valves and other sensitive equipment may occur. It is also necessary to consider the risk of air condensation on the outside surfaces, to mitigate the risks arising from presence of concentrated oxygen such as cold effects on equipment and increased fire risk. The low temperature also means that it can cause severe frostbite and burns when in contact with skin. In case of liquid hydrogen leakage, surrounding structure may suffer brittle fracture if not constructed using low temperature material.

Hydrogen Dispersion

The dispersion properties of hydrogen when released from containment can be considered both positive for safety due to its buoyancy, and a safety risk due to the volumes and flammability range. In the case of a leakage of liquid hydrogen, the expansion ratio between the liquid and gas phase of 1:848 creates a very large volume of flammable gas. The expansion rate also means that liquid hydrogen leakages cause a considerably larger flammable cloud size compared with leakage of hydrogen in the gas phase, and while a higher storage pressure increases the expansion ratio of gaseous hydrogen, the expansion ratio of compressed hydrogen still remains well below liquefied hydrogen (Hydrogen gas stored at 250 barg typically has an expansion ratio of 1:240). Additionally, compared with LNG, the flammable cloud sizes are also exacerbated by the larger flammability range of hydrogen (4-75%).

However, as hydrogen also very readily disperses in air and is extremely buoyant, this property can be used to mitigate the explosive nature of hydrogen, by arranging the installations in open air to allow the rapid dispersion of hydrogen. This is a typical safety barrier for land-based installations with single walled piping and components.

Toxicity and Asphyxiation

Hydrogen is not toxic, but it can displace oxygen in the air, which can lead to asphyxiation.

2. Regulatory Frameworks and Available Experience

The bunkering of liquefied hydrogen is currently not covered by any international standards. There are however ongoing developments in ISO for:

- Design and testing of marine transfer arms for liquefied hydrogen (ISO 24132).
- Ships and marine technology test procedures for liquid hydrogen valve of hydrogen ships (ISO/AWI 21341).

There are also several hydrogen standards for land-based applications which could be used in the development of regulation for hydrogen bunkering, such as:

- ISO/TR 15916 for Basic consideration for the safety of hydrogen systems.
- ASME-B31.12. (2019) on Hydrogen piping and pipelines.
- ISO 13984:1999 on Liquid Hydrogen-Land vehicle fueling system interface.

The Norwegian ferry "Hydra" is at time of writing the only vessel in operation with liquefied hydrogen as fuel and has conducted bunkering operation approximately every 2nd week since April 2023. The experience gained from this project will be very valuable for the future LH_2 fuelled vessels.

3. LH_2 Bunkering System

Bunkering operations for ships and similar past experiences are almost completely absent for liquid hydrogen, however many different compressed hydrogen supply solutions are available with technologies from car and bus refueling systems. Taking into account the vast LNG bunkering experience will be highly recommended in the design of the LH_2 bunkering systems.

The onboard LH_2 bunkering system will comprise bunkering station located on either side of the vessel. Bunkering stations would have provision for one bunkering liquid line and possibly one vapor return line together with inert gas purging facility, associated relief/safety valves, safety systems, and a dedicated control station. The LH_2 is led by piping from the bunker station to the gas storage tank(s).

Consideration should be given to hydrogen bunkering infrastructure, equipment and piping regarding hydrogen permeation, embrittlement, material compatibility, low temperature use (insulation), grounding (static) and hydrogen attack.

The bunkering station as a minimum will require:

- Manifolds, valves, coupling of dry-disconnect type and emergency release system appropriate for LH_2.
- A suitable gas and flame detection system with an alarm system combined with a shut-off and shutdown system.
- Emergency Shutdown System (ESD) arrangements.
- Control and monitoring system.
- Open bunkering stations are preferred solutions for hydrogen, but if semi-enclosed or enclosed solutions is the only option, ventilation will likely be necessary. Mechanical ventilation in connection with hydrogen has its additional challenges, as the ventilation system itself may create an ignition and explosion risk, if flammable concentrations are ventilated. Assessment of the risks involved will be required, and additional tests may be required to validate the designs.
- Drip tray beneath bunkering connections and a low-pressure water curtain to protect the hull from low temperatures.
- Drainage and inerting systems.
- Firefighting System

4. Bunker Piping System

Bunker pipes are sized according to the design flow rates through the system. The design flow rate is based on the LH_2 fuel tank capacity, pressure, temperature, and other factors such as vapour return capability, flow velocity limits and bunkering time window. The flow rate is also dependent on the achievable bunkering rate from the bunker vessel or shore facility. Some vessels may require a shorter bunker time than others depending on their operating profile. Depending on the size of the fuel tanks and frequency of bunkering, owners may wish to maximize the bunker rate. A vapor return from the receiving tank, back to the supplier's tank, will help achieve a higher flow rate.

Materials that may be directly exposed to hydrogen or hydrogen rich gases during normal operations are to be suitable for their application considering, but not limited to, hydrogen-specific metallurgical phenomena such as hydrogen permeation, hydrogen-induced cracking, stress corrosion cracking, hydrogen embrittlement and hydrogen attack.

Hydrogen embrittlement is a phenomenon that results in a significant reduction in material tensile strength, ductility, and fracture toughness. The initiation and severity of hydrogen embrittlement depends upon the interaction of materials used, the mechanical loading, and environmental variables. Such deterioration in properties in turn leads to accelerated fatigue crack growth and consequently shorter equipment life. Furthermore, if not properly accounted for, material degradation due to hydrogen can result in catastrophic unpredicted failure.

Full welded pipes will be preferred as hydrogen will be leaking through flanges. Special welding procedures and welder qualification will be needed.

LH_2 piping between bunkering connection and tank will need vacuum double barriers to prevent air condensation.

Hoses subject to tank pressure, or the discharge pressure of pumps or vapor compressors, should be designed for a bursting pressure not less than five times the maximum pressure the hose can be subjected to during bunkering. The means to prevent electrical arcing at the manifold is to be evaluated and addressed. Instead of bunker hoses, loading arms may be used for transferring LH_2 to the receiving ship. Loading arms generally consist of a rigid structure with swivel joints to allow for articulation of the LH_2 connection and relative movements between the receiving ship and the supplier, and may include a powered emergency release system. LH_2 fluid can pass through either a flexible hose supported within the arm or solid pipes with swivel joints. Loading arms will typically be more mechanically automated and eliminate some of the handling issues that are present with hoses, but loading arms can induce higher reaction forces on the bunker manifold that need to be considered in the design of the bunker station. Again, due to the lower temperature of the LH_2, the hose and connections will be required in addition to be designed to prevent and mitigate condensation of air constituent gases on the components' surfaces. This may be achieved by additional vacuum insulated double barriers or similar double barriers on sections of the hose not previously arranged with double barriers, as well as design considerations for loading arms and cradles to prevent damage from condensed air.

5. Bunkering Operations and Safety Equipment

Emergency Shutdown (ESD)

Having a means to quickly and safely shut down the bunkering operation by closing the manifold valves, stopping pumps, and closing tank filling valves, is essential to ensure safety. The ESD should be capable of activation from both the bunker receiving ship and the bunker supplier, and the signal should simultaneously activate the ESD on both sides of the transfer operation. No release of gas or liquid should take place as a result of ESD activation. Particular attention should be given to the fact that due to the properties of hydrogen (wide flammability range, low ignition energy, giving larger flammable clouds in case of a leakage) rapid reaction will be even more important for hydrogen compared with LNG systems. So, where LNG bunkering valves have a closing time requirement of 5 seconds, an even shorter closing time may be considered, if safely possible with the working pressure, for the hydrogen bunkering valves.

Typical reasons for activation of the ESD include the following:

- Leak detection
- Fire detection
- Manual activation from either the supplier or receiver
- Excessive ship movement
- Power failure
- High level in receiving tank
- Abnormal pressure in transfer system
- High tank pressure

Quick release of bunker connections in case of emergency is also to be provided.

Purging

For LNG bunkering, the IGF Code requires the bunkering system to be purged with inert gas (nitrogen) after bunkering. Nitrogen is not a directly suitable solution for cryogenic hydrogen (freezing point) without intermediate steps ensuring nitrogen does not come into contact with cryogenic hydrogen. The risk of keeping the hydrogen in the bunkering piping can be managed by other means, like reduction of the pressure, and monitoring, to keep the consequences of a leakage under control. For the Hydra ferry, hydrogen gas remains in the bunkering system between the bunkering operations, and this is also the solution applied in projects with compressed hydrogen. But the bunkering connection will need to be air/hydrogen free before connections and disconnections, so for this purpose, creating a vacuum and injecting a small amount of Helium gas is the solution chosen in the Hydra ferry. Such procedures introduce the need for vacuum pumps and helium storage, which for Hydra, is stored on the bunkering tower on the shore.

Personal Safety

All personnel involved directly in LH_2 handling operations should be equipped with personal protective equipment (PPE) suitable and certified for LH_2 use. PPE includes gloves, face protection and other suitable clothing to protect against LH_2 drips, spray, spills, and leaks. PPE is also required to protect against skin damage caused by contact with potentially cold pipes, hoses, or equipment. Although no standard exists for required PPE during bunkering procedures, guidance for LNG is provided by SIGTTO and others. Industry practice in shore hydrogen plants can be adopted to develop PPE requirements in regulations. In addition, additional PPEs such portable gas detectors and intrinsically safe portable IR/UV cameras can also be considered to aid in the early detection of leakages and hydrogen flames, that will otherwise be invisible to naked eyes.

Regarding bunkering operations, processes should be automated, reducing human intervention as much as possible. Areas to be avoided during bunkering should be marked accordingly.

Low Temperature Insulation

Due to the need for limiting the heat ingress to the LH_2 during the transfer, and additionally the risk of oxygen accumulation on the outside of surfaces that hold -253°C, better insulation is necessary for the bunkering connections and hoses compared with LNG. Vacuum insulation is generally the most efficient and safest solution for hydrogen.

Drip Tray

Drip trays are commonly used to contain LNG leakage and prevent damage to the ship's structure and the same will apply to LH_2. Drip trays should be sized to contain the maximum amount of leakage expected and made from suitable material, such as stainless steel.

The bunkering station drip tray should serve as protection from liquid hydrogen spills, but should in addition be designed to account for the additional aspect of condensation of air constituent gases. Due to the extremely low temperature of liquefied hydrogen, the main air constituent gases (nitrogen and oxygen) may freeze and/or condensate on surfaces of the bunkering connection and skid, and drip to the tray. This will likely not affect the dimensioning and placement of the drip tray(s), but may affect secondary considerations such as prevention of oxygen rich atmospheres below the bunkering connection.

Bunker Control Room

Bunkering control arrangements are to allow for remote operations from a safe location. At that location, monitoring with CCTV and display of the tank pressure and tank temperature should be available. High temperature and high-pressure alarm, automatic and manual shutdown are also to be indicated at this location.

Leakage Detection

Bunker stations are to be fitted with permanently installed gas detectors and low temperature detection (differential temperature may also be relevant). For the vacuum insulated bunkering piping, other solutions for rapid detection of leakages will be relevant, like pressure monitoring. Diversity in applied detection methods is generally recommended for hydrogen leakage detection.

Fire Detection

All bunker stations are to be fitted with permanent fire detection suited to detect hydrogen flames. Hydrogen flames are invisible and have low radiant heat therefore detectors' technology should be suitable for the specific fuel. Solutions such as thermal, infrared and UV cameras will be relevant.

Tank Levels

The filling limit of an LH_2 tank is the maximum allowable liquid volume in the tank, expressed as a percentage of the total tank volume. The filling limit is not the same as the loading limit. The maximum filling limit for LH_2 cargo tanks, and IGF Code LH_2 fuel tanks, is 98 percent at the reference temperature.

Communication

Communication between the receiving ship and the bunkering facility is always important, but it is even more critical when handling LH_2, because of the greater potential for hazardous situations during LH_2 bunkering. Written operational procedures, including the fuel handling manual required by the IGF Code, should be followed and understood between the person- in-charge on the bunkering facility and receiving ship. It is also expected that many of the processes in the bunkering operation will be automated.

Security and safety zones around the bunkering operation need to be set up to reduce the risk of damage to personnel and property from the LH_2 hazards, reduce the risk of outside interference with the LH_2 bunkering operation, and to limit the potential for expansion of a hazardous situation should LH_2 release take place. The determination of such security and safety zone can be established using a recognized and validated gas dispersion model to calculate the distance to the lower flammability limit (LFL) based on the maximum credible release to be agreed upon with the relevant port authorities for the planning of suitable areas for such an operation to be carried out.

Confirmation that both the bunker supplier and receiver can monitor the bunkering operation, and both can initiate an emergency shutdown of the complete transfer operation is of vital importance.

Radio equipment to be used in the safety zone during the operation should be designed for use in hazardous areas and should be intrinsically safe.

Vent Mast

Venting should be prevented under all normal operating conditions, except for emergency cases. IGF Code includes prescribed requirements for the vent masts locations however exact venting arrangements should be validated for the specific design upon gas dispersion simulation. As a minimum, both receiving ships and loading facility should be equipped with a venting mast.

Compatibilty

Compatibility studies should be carried out well in advance to confirm mooring and bunker equipment are compatible in design so the bunker operation can be conducted safely. At a minimum, the compatibility of the following equipment and installation should be assessed and confirmed:

- Communication/ESD systems
- Bunker connection and bunker station location
- The relative freeboard differences
- Transfer system specifications (e.g. type and size of hose connections), locations and loading on manifolds, and connection sequences
- Transfer system specifications (flow rate, temperature, pressure, etc.)
- Vapor return line, (if applicable)
- Nitrogen and/or helium line, if applicable
- Mooring arrangement/equipment
- Lifting gear and lifting appliances with sufficient SWL and outreach for bunkering hoses and equipment
- Personnel transfer arrangement
- Hazardous (flammable)/safety zones

6. Bunkering Procedures and Manuals

Vessel-specific procedures for the bunkering operation should be developed to include any unique characteristics or features to the bunkering facility and receiving vessel or location.

A specific hydrogen bunkering plan should be developed to ensure the safe and effective operation of bunkering processes. This plan should demonstrate and document all proof of compliance with the regulations of all relevant authorities, industry practices, and vessel Safety Management System (SMS) requirements. The bunkering plan should include, but not be limited to, the following:

- Purpose, objective, and safety policies
- Compatibility assessment
- Risk management
- Organization planning
- Communication
- Management of change
- Emergency procedure
- Training
- Operations, procedures, and checklists (include SIMOPS if applicable)

Before each bunkering operation, a coordination meeting should be carried out between ship's crew and bunker ship's or terminal's crew to discuss the bunkering plan.

Simultaneous operations as Hydrogen bunkering while unloading containers or other cargoes, or landing passengers will be depending on Port authorities. Safety distances and procedures will be required and studied during risk assessment.

7. Crew Training and Certification

Crew training and competence will be similar to LNG, as both are dominated by flammability and cryogenic concerns but, the depth of cryogenic temperatures, invisible flame and flammability of hydrogen, compared to LNG, will certainly have an influence in emphasis in the detailed training program as explained in the SGMF introduction of hydrogen as a marine fuel (2023).

Conclusions

IMO is currently working on the development of guidelines for the safe design of ships with hydrogen as fuel, with the target completion already at CCC10 in September 2024. Those guidelines will however focus on the ship installations and stop at the bunkering manifold on the ship. The details related to the bunkering operations are not part of the scope for that work. The goal with this work is hence to supplement CCC10 with input on the bunkering side of liquified hydrogen fuel safety.

As of the writing of this report, there are no international standards covering the bunkering of liquefied hydrogen. However, information collected from ongoing developments in ISO for related areas, as well as the experience gained from the Norwegian ferry "Hydra", serves as the basis for the guidelines and recommendations of this report.

To provide a framework for the considerations necessary to implement LH_2 as a fuel, the report provides detailed information on the properties of hydrogen, including its extremely low temperature, flammability, explosivity, permeability, and embrittlement effects on metallic materials. The potential risks associated with these properties, such as damage to equipment, detonation, and asphyxiation are also listed for consideration.

The report further provides a detailed description of the expected required functions and design considerations for an LH_2 bunkering system, including the bunkering station layout, piping system, safety equipment, and necessary functions and procedures. It emphasizes the need for careful material selection to prevent hydrogen embrittlement and leakage, and the need for vacuum insulation due to the cryogenic nature of LH_2. A key aspect that differentiates the bunkering systems for LH_2 from bunkering of LNG, which is the closest comparable system, is that LH_2 is colder than the freezing point of Nitrogen, which vastly increases the complexity of the bunkering connection and necessitates several additional ancillary systems.

Key observations:

- The properties of hydrogen, and in particular the very low temperature of liquified hydrogen, means that experience gained from bunkering arrangements for liquid natural gas, LNG, cannot be re-used directly.
- The bunkering process will be more complex than what is known for LNG, since no nitrogen can be present inside the piping systems when LH_2 is introduced, as this will freeze and clog the systems.
- The material choices, need for more insulated components and piping will also be slightly different. All in all, the development of vessel-specific procedures for bunkering operations, maybe more automated bunkering procedures, will be necessary.
- The added complexities will mean that the need for crew training and certification is of even higher importance than for other bunkering processes.
- The Safety Management Systems should be updated to cater for the additional safety aspects with the liquified hydrogen bunkering, as outlined in another work carried out by MTF, 'Guidelines to develop and implement Safety Management System for alternative fuels onboard ships'.

Conclusion

Concludingly, the bunkering processes for LH_2 will need to be developed with the properties of liquefied hydrogen clear in mind. This report provides a starting point for development of guidelines for bunkering of LH_2, and this work is recommended to be discussed at IMO and further developed by industry.

References

1. IMO, "The International Safety Management (ISM) Code".
2. IMO, "The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), 1978".
3. IMO, "International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels (IGF Code)".
4. IMO, "International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)".
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Acknowledgements:

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Appendix 1
Hydra Bunkering: Extract of Information from Linde 'Basis of Design'

Onshore Bunkering Equipment

Bunkering is done by truck, so the below description are for the shore systems between truck and ship, main components:

- Vacuum insulated process line (DN50)
- Cryogenic, vacuum insulated flexible hose, supported by a loading arm
- Female part of quick connect coupling attached to the loading arm of the bunkering system (male counterpart on the ship)
- Parking station for female part of bunkering coupling to an additional male coupling, for safe storage, and for functional check and cool down prior to bunkering
- Purging/vacuumization single wall lines
- Vacuum pump for purging purposes
- Vent mast for a safe release of hydrogen or He to the atmosphere
- Expansion tank, collecting the liquid hydrogen when depressurizing the process line after end of bunkering
- Air heated vaporizer downstream of the expansion tank and upstream of the vent mast for ensuring that only warmed up gaseous hydrogen enters the vents mast

The equipment is installed on a skid, mounted on wheels, to ensure easy transportation to the quayside.

Connection

The bunkering connection is an LH_2 quick coupling. The female part is attached to the loading arm of the bunkering tower, and male part (receptacle) is attached to the tank system of the ship. Both parts are vacuum insulated to limit freezing during the operation. Additionally, an integrated emergency release system is included, to protect the loading arm in case ship is drifting away. The spring loaded ejector is placed at the interface of the loading arm with the female part of the coupling.

Process Description

Bunkering processes are mainly done by several automatically run sequences, and the following list is not including all actions:

- Bunkering first tightness test – to be performed after commissioning or repair when no trailer is attached, and the quick coupling is in parking position
- Bunkering – procedure for intended operation/unloading of LH_2 distribution equipment, e.g. LH_2-trailer
  - Tightness test
  - Cool down and cold keeping
  - Filling (includes purge with He for segments in contact with air)
  - Filling end (LH_2 flow is stopped, QC coupling is purged and slightly pressurized at the end with He Valves closed in defined sequence and coupling disconnected. Couplings put in parking position, purge with He)
  - LH_2 removal-controlled relief of hydrogen to vent mast
- Bunkering unit stop – leads to a safe stop of the bunkering procedure for intended and unintended operations
- Bunkering unit depressurize – leads to a safe depressurization for intended and unintended operations

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