RESEARCH ARTICLE

Studying the Impact of Proper Crew Trainings and Safety Procedure during LNG Bunkering

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Reducing emissions to air and introducing new propulsion technologies are key challenges for the worldwide transport sector, including shipping. The world's future fleet will have to rely on a broader range of fuels, propulsion solutions and energy efficiency measures. The development and analysis of the alternative fuels/energy sources and technologies are essentially important in reduction of greenhouse gases (GHGs) Emissions and for creating a sustainable world. Loading Liquified Natural Gas (LNG) into fuel tanks is a different process from loading Heavy Fuel Oil (HFO) due to some unique differences in the fuel characteristics. Ensuring safety during bunkering is the main task not only for the Engineers, but also for the Navigation Officers. It should be obvious that the bunkering operations should be carried out in a safe manner in accordance with all regulations, procedures and rules of Flag State, Port State, Container Terminal, Charterers and the Company. The purpose of this study is to improve the LNG bunkering procedure from the safety side to prevent gas leakage. Qualified Crew is essentially important for the new technologies on ships. Due to the rapid development of shipping industry, it must be paid much attention on the demand of the well-trained maritime manpower within the dynamic economies. The main types of drills that are carried out on the vessel were analysed using the example of the company Nordic Hamburg. In order to support the green direction by Nordic Hamburg Crewing, special training courses to train seafarers who provide sustainable shipping industry were integrated, especially dealing with: (a) oceans; (b) communities; (c) people; (d) transparency; (f) finance; (g) energy. The results of the study showed a high level of preparation for various types of danger during the acceptance of Liquified Natural Gas on board at containerships. The article draws conclusions about the necessity to improve the safety procedures for LNG bunkering and the correctness of the corresponding monthly alarms in order to be sure about the readiness of ship's crew for an emergency situation.

Introduction

International Maritime Organization (IMO) in 2018 adopted the initial strategy to cut down on and eventually eliminate greenhouse gases (GHGs) from the international maritime shipping industry. This changeover will require using fuels that contain less carbon and, ultimately, zero carbon. Liquified Natural Gas (LNG) contains less carbon per unit of energy than conventional maritime fuels, which means that burning it emits less carbon dioxide (CO_2). It is composed, in the main, of methane it is largely unreactive chemically.

Bunkering LNG into gas tanks is a dissimilar process from loading Heavy Fuel Oil (HFO) due to some unique differences in the fuel's characteristics:

1. LNG is transported as a boiling liquid, which means pressure and temperature influence and the behavior of the liquid.
2. LNG is a cryogenic liquid at temperatures of about -162°C, and therefore, this gas is hazardous to crew and any conventional steel constructions or piping with which it comes into contact.
3. LNG vapor can form volitive clouds in confined areas and is considered hazardous. This demands special handling of the vapor when bunkering.

Methods of bunkering LNG storage tanks have been expanded wherein there is no vapor emitted from the tanks, or the vapor is returned to the bunkering vessel or terminal. Hoses used for transferring gas must at the completion of bunkering be drained of LNG and the left-over gas vapors removed using nitrogen. Any liquid remaining in the pipes that is trapped between closed valves will boil and expand to fill the space available. If that space is narrow, the pressure developed by the expanding vapor can enhance to dangerous levels and cause the pipes to explosion or valves to be detrimental. Where there is a risk of natural gas

pressure build-up, such as LNG storage tanks and piping systems, relief valves are required to safely continence the excess pressure to be released as a final safety measure. Relief valves should be decently located so the hazardous zone created by the release of vapor is not near any operational areas aboard the vessel. In general, relief valves should tie into a vent mast which directs the gas away from all critical areas.

Due to LNG is bunkered at cryogenic temperatures, special procedures and equipment are required.

Any contact of staff with fuel will cause harsh frostbite. Spillage of even trivial amounts of LNG can cause structural problems. For example, unprotected normal structural steel can become embrittled by the cold liquid, leading to fracture. Break-away couplings, stainless steel drip trays, and special hose connections that seal before uncoupling are often used to protect from spillage.

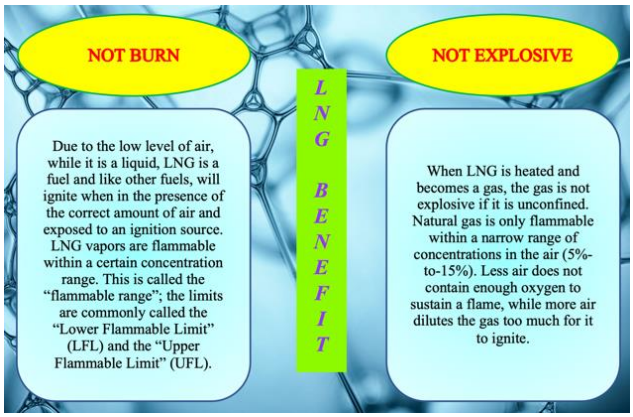

Fig. 1. Benefits of LNG.

Bunkering operations should be carried out in accordance with all procedures, regulations, and rules of Port State, Flag State, Company, Container Terminal, and Charterers.

In case of a highly unlikely event of an accidental spillage, LNG form of a gas cloud, that can extend to some distance from the LNG installation. This is one crucial difference between LNG and other maritime fuels. Managing the spread hazard requires a knowledge of the extent of the zone that might be affected and the measures that can be taken to reduce risks. The Hazardous Zone is a three-dimensional space in which a combustible or explosive atmosphere can be expected to be present frequently enough to require special precautions for the control of potential ignition sources [**1**].

The Safety Zone can be defined as the three-dimensional envelope of distances inside which most leak events occur and where, in exceptional circumstances, there is a recognized potential for a leak of natural gas or LNG to harm life or damage equipment/infrastructure. The purpose of the Safety Zone is to derogate the likeliness of harm to staff and damage to equipment by [**2**]:

1. Controlling spills and leaks.
2. Averting ignition and a subsequent fire or explosion.
3. Excluding non-essential crew to avoid additional injuries or deaths in case of an accident.
4. Guarding essential staff using Personal protective equipment (PPE) to derogate the likeliness of injury or death in the case of an accident.

According to above mentioned information, it is extremely recommended to familiarize all crew members with potential risks during bunkering. In this case, it is mandatory to provide special safety trainings (drills) where all opportunities to prevent hazard would be discussed. This paper presents analysis of common situations which could happened during LNG bunkering and gives the solution according to the sufficient trainings onboard the vessel to prevent dangerous situations.

Experimental

General requirements for the safety preparation before commence LNG bunkering

It is customary to divide main LNG bunker delivery procedures to LNG-powered vessels into four mostly recognized methods:

1. Ship-to-ship (STS) LNG bunkering
2. Truck-to-ship LNG bunkering
3. Terminal-to-ship LNG bunkering
4. Containerized (portable) LNG tanks used as fuel tanks

The first method procedure takes place between two vessels: LNG-powered vessel and LNG bunker delivering tanker (LNG bunker vessel) leading to Ship-to-Ship (STS) transfer operation. A specialized LNG bunker vessel should be fully equipped with all necessary STS LNG transfer equipment, mooring and fendering.

Master of LNG-powered vessel shall insure that enough mooring lines ashore to hold it, before Bunker vessel will come alongside for achieving LNG bunkering operations. It's inherent considerable that receiving vessel properly secured to berth taking in account additional load of bunker vessel. The fenders and mooring ropes shall be properly monitored during all process of bunkering (including approaching of bunker vessel).

During LNG bunkering, an LNG-powered seagoing ship shall switch on an all-round red light between sunset and sunrise and hoist the international signal flag 'B' between sunrise and sunset [**3**].

The integrated Alarm monitoring system should be monitored by engine and deck departments during LNG bunkering. In case of abnormal parameters observed the visual and sound alarm will be given inside/outside of Gas Handling Room (GHR).

Any irregular condition in the GHR will activate an alarm. All alarms are indicated as:

- sounding horn in engine control room (ECR) and Bridge;
- yellow/red flashing light on various locations in/outside GHR;
- flashing yellow/red symbol on the controlling monitors;

- sounding horns on various locations in the GHR if it is not reset within 30 seconds.

If given alarm potentially may escalate situation to dangerous for cargo operations and bunkering – all parties to be informed accordingly and LNG bunkering/cargo operation to be terminated immediately.

Before commencing LNG bunkering should be done proper stability calculations by responsible person. Exceed vessel's movement during Simultaneous Operations (SIMOPS) can lead to damage of mooring ropes, bunker hose, fenders, or bunker vessel. Therefore, below operation limits to be fulfilled:

- Max heel during LNG Bunkering 1 degree.
- Max trim 2 m.

If the above paraments cannot be fulfilled, the LNG bunkering operation will terminate until vessel back to required parameters.

During LNG bunkering below requirements for communication equipment to be fulfilled:

1. Medium Frequency (MF) radio transmitting equipment shall be switched off and earthed while LNG bunkering. The main radio transmitting aerials shall be earthed.
2. Use of satellite communications equipment is permitted but shall be switched off in case of an emergency, gas release or on the advice from bunkering vessel.
3. Fixed Very High Frequency (VHF) radio installations, including the Automatic Identification System (AIS), shall be switched to low power - 1 Watt or less. If this option is not available, the equipment shall be switched off.
4. Only handheld VHF or Ultra High Frequency (UHF) radios having an output of 1 Watt or less and complying with the applicable standard, are permitted to be used during LNG bunkering.
5. Radars shall not be operated.

In case of breaching of security zone and possible dangerous, need to inform bunkering vessel immediately and LNG suspend operations.

The access control to Safety zones is responsibility of Chief Officer (CO). His responsibilities are the following:

1. Prohibit and control presence of naked lights, mobile phones, and other non-certified portable electrical equipment in Safety Zone.
2. To ensure that Safety posters placed at the gangway.
3. To ensure that access to the safety zone is granted to authorized staff only if they are fitted with personal protective equipment (PPE) with anti-static properties and certified portable gas detector.
4. To ensure that all safety requirements to SIMOPS activities are fulfilled.
5. Every visitor is instructed before boarding the vessel.
6. All unauthorized devices collected and stored in dedicated area.

During LNG bunkering operations, pressures in the fuel system should be kept within the regular operating range. Aboard LNG-powered vessels this may be achieved by burning excess vapor in the ship's machinery.

The design safety shutdown and interlock systems should be maintained carefully and tested regularly.

Actions should be taken in appropriate ways to avoid fuel gas system pressures reaching limits, pressure control valve opening pressure or relief valve lift conditions other than adjusting, inhibiting, over-riding of alarms and controls.

Improving LNG bunkering emergency response plan

The process of quick release of LNG vapor is spontaneous mixing-up of LNG from different densities in one storage tank. When there is short vertical mass or heat transfer, both layers settle their own convection currents. The lighter upper layer releases vapor and loses heat. Its density increases and get even to the lower layer one. The lower layer, which has a higher temperature, will roll over the upper layer resulting into the release of superheat and thereby generating large volumes of boil-off gas in a short period of time. An over-pressurization of the tank can occur, causing some structural damage. Historically, there were a few affairs of rollover occurring ashore and on-board LNG tankers. The La Spezia incident in 1971 is probably one of the most significant. In 2008, a Moss-type LNG carrier experienced an increase of pressure in some of the cargo tanks. This phenomenon is more likely to occur in large tanks [**4**]. However, there is a chance for this phenomenon to develop during LNG bunkering operation, if the receiving tank is partly filled with old LNG material (**Fig. 2**).

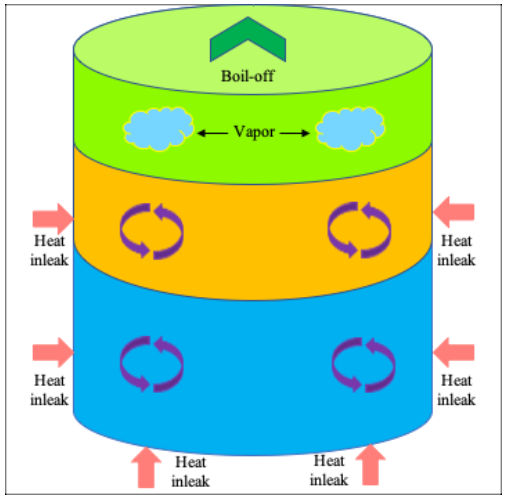

Fig. 2. A tank where stable stratification has taken place caused by a storage tank with liquids of different densities.

The LNG bunkering Emergency Response Plan on vessels is divided into Contingency (Emergency) Procedures and appropriate Checklists. Procedures and Checklists will not release the Master from his responsibilities to follow international and national rules and regulations.

The best accident prevention is always preventive maintenance and training with equipment on board for eventual casualties. Therefore, all Contingency Procedures and their Checklists should also be subjects of training and drills to act in a controlled manner in case of a real emergency.

These contingency plans are to be used with the SOPEP (Shipboard Oil Pollution Emergency Plan), SSP (Ship Security Plan), Emergency Towing Booklet (ETB) or other guides as applicable.

Due to the risk of accidents and the potential consequences, it is required that LNG bunkering and LNG receiving vessels have contingency plans for dealing with emergencies. A contingency plan is a summary of individual emergency procedures. It shows emergency duties for both vessel's personnel. The contingency plans should be integrated with port and local authorities and agreed between both vessels prior to commencing LNG bunkering.

The following emergencies are covered by contingency plan:

a. Fire on board bunkering/receiving vessel
b. LNG leakage the deck or hull
c. Bunkering hose failure
d. Mooring line failure
e. Communication failure
f. Personnel injuries
g. Emergency departure procedure
h. Fender burst
i. Response for Operational Emergencies (Draining)
j. Response for Operational Emergencies (Purging)
k. Response for Operational Emergencies (Depressurization)
l. Blackout during LNG Bunkering
m. Emergency Shutdown (ESD) activation

The contingency plan determinates the responsibilities, actions and roles for personnel involved in the LNG bunkering operation and making maximum use of the resources such as knowledge, training and equipment of the parties that are straightly involved. The contingency plan contains from checklists which shall be regularly tested and reviewed. Copies of the plan shall be communicated to all parties involved in the bunkering operation including the planned emergency response team and be part of the training program. Port Emergency contact list shall be prepared and agreed with LNG Bunkering vessel / terminal and shall be posted closed to unnatural area.

In this paper made analyzed of the most probably common emergency situation on board and provided description of actions which should be done at this manner.

1. Fire on board

The major aim of firefighting is to prevent loss of life or injury. The next goal is to reduce loss of equipment and gas. Fire needs to have three components that are present to continue burning:

- fuel;
- oxygen;
- heat.

The most effective way of fighting with LNG fire is to shut off the fuel supply, in the form of LNG, at source to extinguish the fire by starvation. Cooling LNG fire is very difficult. Cooling media such as water and foam are much warmer than the LNG, so they will increase the rate of evaporation and so enlarge the fire. Nevertheless, if the leak has stopped, this will also reduce the duration of the fire.

Fire-fighting using water should be avoided, except for the cooling down of surfaces and for protecting other equipment or parts of the ship's structure. Water can also be used to deflect gas clouds from ignition sources. Fire-fighting vessels and tugs with water monitors can be used to cool down equipment and adjacent tanks.

LNG bunkering should not be performed without proper fire-fighting equipment in place throughout the duration of the operations.

2. Leakage during LNG Bunkering

The materials used in the deck construction are designed to withstand varying degrees of temperature. However, at temperatures below their specified limits, the steel will crystallize and become very brittle. It is essential that the spillage of LNG liquid onto the deck by overflowing the LNG tanks, and from any leakage at the loading manifold, is avoided at all costs. If leakage occurs from a valve, pipeline, metal arm or hose, operations through that item should be stopped until the cause has been ascertained and the defect has been rectified. If a hose, pipeline, or arm bursts or if there is an overflow or other spill, LNG bunkering operations should be stopped immediately and should not be restarted until the fault has been rectified and all hazards from the released LNG have been eliminated. In case of LNG leakage, occurs on board, the crewmembers shall immediately activate the emergency shutdown system to stop LNG transfer. The port authorities should be informed.

3. Bunkering Hose failure

If any leakage is detected, the transfer should be stopped immediately and not resumed until satisfactory checks and any necessary corrective actions have been completed. During LNG bunkering operations, additional safety precautions should be undertaken to avoid the risk of fire or explosion. At any time during LNG bunker operations there exists a possibility of either LNG liquid or vapor to escape the confines of the LNG tank or containment system, or at the bunker manifold, through either pipeline failure or other breach of the system. As such, an extreme fire hazard may follow, and by removing any possibility of ignition, the incident can be safely contained.

4. Mooring line failure

Lines, winches fenders, and other mooring gear should be visually checked for damage. Equipment should be replaced or mooring aborted if there are any doubts about safety and quality. Mooring lines should be under supervision during the bunker operation. Special attention

is to be given when the vessel is loading and discharging goods which could cause rapid vertical movement of the ship.

When the bunker hose is connected, inserted and tested, the LNG bunker transfer can be commenced. At the beginning, the manifold pressures and rate should be kept to a minimum and in accordance with the pre-transfer agreement. The temperatures should be monitored and verified. Once the LNG is confirmed to have reached the designated tank, and the system has been set to the normal operational transfer parameter, a visual inspection of the surrounding area should be made.

During the bunker transfer, one important element to be addressed is the management of the vapors. The displaced gas and the boiled-off gas will require to be either stored or transferred back to the bunker vessel via a vapor return line. The parameters associated with the vapors should be constantly monitored, depending on the method in use.

The manning level of the bunker station should be in accordance with the plan. Any necessary changes of personnel can be done following a proper hand-over procedure. All agreed items from the bunker transfer checklist, which will require verification, should be confirmed at regular intervals. The communication between both vessels should be periodically checked.

Training onboard to familiarize and prepare crewmember to emergency situations during gas bunkering

The requirements for seafarers' training, who are engaged in LNG bunkering operations are covered by the International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels (IGF Code), International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), and the industry codes and international guidelines, such as The Society of International Gas Tanker and Terminal Operators (SIGTTO), The Society for Gas as a Marine Fuel (SGMF), Oil Companies International Marine Forum (OCIMF) and ISO/TS 18683. Trainings, emergency exercises and drills should be conducted by the crew at regular intervals. It will be important that all newly joined key personnel take part at relevant drills and trainings on their vessel prior to bunkering. Their relevant duties and responsibilities should be understood.

As an example, the following should be considered as part of the training (IGF Code, Part C-1, Regulation 17):

1. Table-top exercise
2. Review of fueling procedures
3. Responses to potential contingences
4. Tests of equipment intended for contingency response
5. Reviews that assigned seafarers are trained to perform specific duties during fueling and contingency response.

All crew members should be familiar with different possibilities of accidents during gas bunkering. To prevent numerous consequences all participants must do appropriate actions. This paper provides regulations with necessary precautions which could be included in drills on LNG-powered vessels, based on above-mentioned information.

1. Fire on board (Fig. 3)

Recommendation procedure is the following:

1. Stop LNG bunker operations
2. Emergency signal sounded
3. Crew moved away from manifold area
4. Stop cargo/ballast/bunkering operations
5. Close valves and tank openings
6. Notification to terminal and port authorities

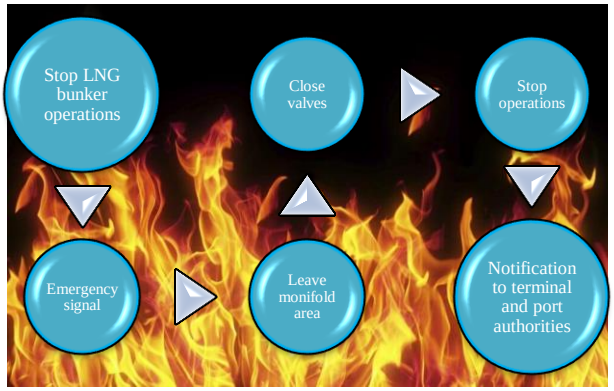

Fig. 3. Procedure in case of fire on board.

2. LNG leakage (Fig. 4)

1. Stop LNG bunker operations
2. Emergency signal sounded
3. Crew moved away from manifold area
4. Start the fire fighting systems
5. Bunkering/Receiving vessels and shore emergency standard procedures must then be put into immediate operation
6. Ventilation systems are to be shut down where possible
7. Any personnel on the open deck must be suitably clothed in a fireman's outfit to avoid injury should the gas cloud that has been formed ignite

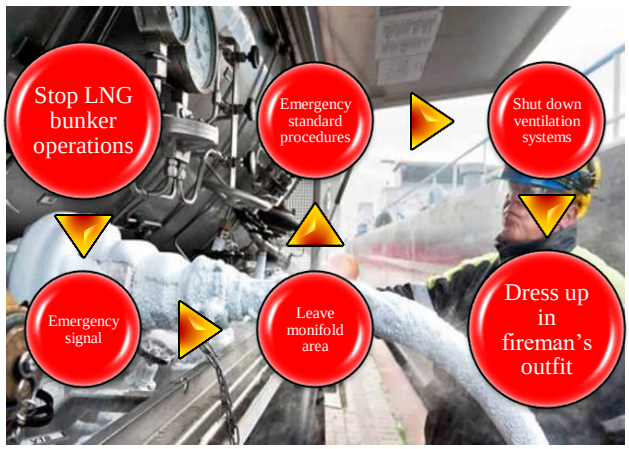

Fig. 4. Procedure in case of LNG leakage.

3. Bunker Hose failure (Fig. 5)

1. The alarm should be raised, Bunkering vessels and the container terminal informed immediately.
2. Bunkering operations should be stopped and all valves in the liquid line closed both on the Bunkering vessel and receiving vessel as necessary.
3. All accommodation access doors should be shut, and all ventilation shut down.
4. Ventilation systems are to be shut down where possible.

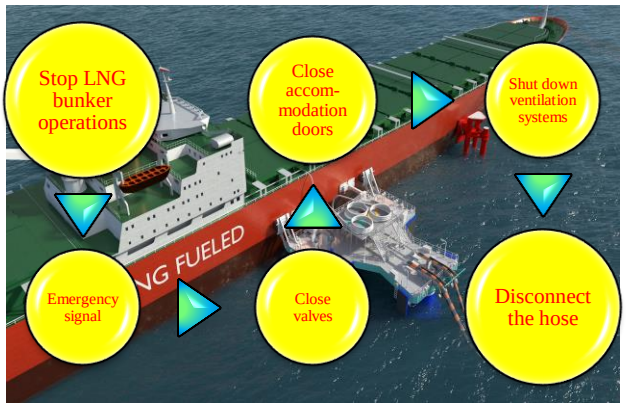

Fig. 5. Procedure in case of Bunker Hose failure.

4. Mooring line failure (Fig. 6)

1. The alarm should be raised, Bunkering vessels and the container terminal informed immediately.
2. Bunkering operations should be stopped and all valves in the liquid line closed both on the Bunkering vessel and receiving vessel as necessary.
3. Main engine to be brought to STBY Mode.
4. Bow thrusters must be ready for use.
5. STBY Crew at stations forward and aft.
6. Anchors must be cleared and ready for use.
7. Endeavour to run out extra mooring line.

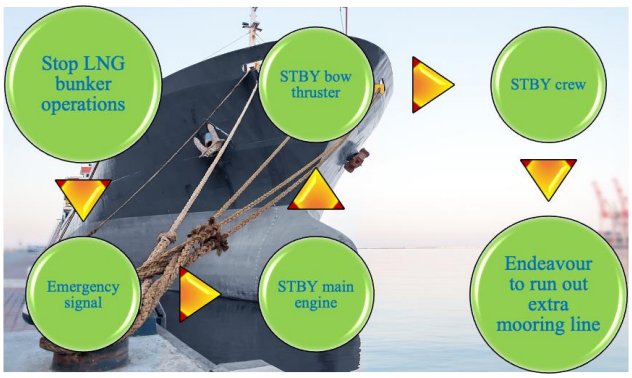

Fig. 6. Procedure in case of Mooring line failure.

To ensure that the bunkering operations are carried out in a safe manner in accordance with all regulations, procedures, and rules of above-mentioned requirements.

Results and discussion

In case LNG bunkering is carried out between two ships, the safety zones around the vessels should be agreed between them. If required, they should be coordinated with, and approved by, the terminal and local port authorities.

The readiness of both vessels with respect to the transfer should be discussed and all operational parameters established and agreed. Below is an example of items to be considered:

1. The weather and sea criteria, and limits for aborting the operation.
2. The condition of the jetty/anchorage/traffic.
3. The moorings and fendering should be inspected, assessed, and confirmed by the responsible personnel.
4. The compatibility of both vessels should be verified and confirmed.
5. The main and emergency means of communication should be agreed and tested.
6. Bunker line connection, pre-cooling, inerting, cooling down, vapor management, and rates of transfer during the initial, bulk, and topping stages. Visual inspections for leaks of the transfer hoses and equipment should be carried out during the cool-down.
7. Smoking regulations and other fire prevention measures.
8. The compatibility and testing of the Emergency Release System (ERS) and Emergency Shutdown System (ESDS) should be performed and confirmed.
9. An agreement should be obtained, and restrictions imposed, with respect to potential simultaneous operations, such as cargo transfer, passenger movement, vehicles on ferries, other oil bunkering, stores and provision supply, personnel transfer and other activities that may distract or engage key shipboard personnel during LNG bunkering activity.
10. Other limitations by the receiving and delivering vessels with respect to the LNG bunkering activity.
11. Initial pre-cooling of the LNG transfer systems of both vessels. This can be completed either with the use of nitrogen or with LNG. During this activity, there are risks of cryogenic hazards, introducing oxygen in confined spaces, and boil-off-gas (if inerting with LNG).
12. Grounding, inerting and leak testing of the transfer hoses.
13. Filling sequence.

The LNG bunkering requires all personnel engaged with the operation to be knowledgeable and familiar with their own vessel's equipment and systems, the nature of the bunker fuel, and the hazards associated with the activity, including:

(a) Vapor dispersion and remote flash fire
(b) Rollover
(c) Rapid phase transition
(d) Boiling Liquid Expanding Vapor Explosion (BLEVE)
(e) Cryogenic damage to steel

(f) Asphyxiation
(g) Low temperature
(h) Sloshing
(i) Ship-to-ship transfer associated hazards – collision/allision, mooring failure, cargo transfer hose failure, fatigue and availability of personnel, concurrent operations and others.

Proper certification of personnel as well as a continuous training and development with respect to LNG bunkering operations should be established by appropriate training companies. Procedures should be provided in order to avoid complacency, high workload and fatigue, unfamiliarity, and poor communication.

All drills were carried out with good seamanship practices at LNG-powered vessels of Nordic Hamburg Company. The results of this training were summarized in this paper and showed that sufficient requirements were included in guidelines for each crewmember. All stuff has high knowledge of actions in case of emergency situations during LNG bunkering due to the qualified planned drills from Nordic Hamburg Company.

Conclusion

LNG Bunkering is a very safe procedure; associated risks are "mitigated" by zones. LNG's hazards are different (e.g., volatility, cryogenic conditions) from traditional fuel oil and all personal involved in LNG Bunkering operations must clearly understand the risks involved with LNG bunkering. Any type of incident can be successfully managed/resolved if the basic principles are well understood. The following hazards may arise during handling LNG: leaks and accidental spills; cryogenic hazards; LNG fire and explosion; boiling liquid; LNG vapors; contamination of the bunker lines and/or connections, etc. Prevention is crucial, with measures such as using the proper/right type of equipment and training in all available scenarios holding a pivotal role.

This paper proposes the concrete actions in case of different emergency situations during LNG bunkering. The specific actions in all drills onboard vessels developed by Nordic Hamburg Company should be implemented in good seamanship practice.

The proposed prevention actions and activeness in case of emergency further safety regulations, such as using Personal protective equipment, at ports and port areas for LNG bunkering should be developed. Further study of the problem of ensuring the safe operation of the LNG-powered vessels is relevant.

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Conflicts of interest
There are no conflicts to declare.

Keywords

LNG-powered vessel, LNG bunkering, training, safety procedure.

Supporting information

Supporting information are available online at journal website.

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Authors biography

Ihor Surinov is a PhD student at the National University "Odessa Maritime Academy", Third Officer and member of editorial board of journal "Shipping & Navigation" and International Scientific and Technology Conference "Navigation, Shipping and Technology". For present Mr. I. Surinov has 21 published articles, including 3 papers with Scopus index as well as 1 paper with Web of Science index. Also, 3 patents were presented by Mr. Surinov. His PhD thesis includes the theme of this research project and inbound / outbound at ports with special matrix's system.

Graphical abstract