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Safety Precautions for the Use of LNG as Marine Fuel

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Abstract

International Maritime Organisation has changed the emission rates in the MARPOL Annex VI rules as of 2020 and reduced the sulfur rate from 3.5 percent to 0.5 percent and led the maritime sector to alternative fuels. Compared to other alternative fuels, liquefied natural gas (LNG) is an attractive option with almost zero emission rate, ease of access, availability of ports that currently supply LNG and low price in the fuel market. In addition, according to the life cycle assessment, which is a methodology created by ISO 14040: 2006 to examine the impact of a product on the environment, in order for a fuel to be environmentally sustainable, it has to be associated not only with low emissions during fuel combustion, but also with the entire fuel life cycle, starting with raw material extraction, fuel production, distribution and finally combustion. The life cycle environmental performance of LNG as a marine fuel has been observed to have its impact on climate change in the range of 20% to 5%, significantly reducing SO2 and NOX emissions compared to heavy fuel oil. Besides its environmental advantages, the most important handicap of LNG is potential hazards. Thus, the most important factor in the use of LNG is to take safety precautions. Within the scope of this study, the rules regarding the safe handling of LNG were examined.

1. Introduction

The energy need, which is indispensable in the age of mechanization, is directly affected by the increase in the world population, which causes more harmful gas emissions to occur every day (Mahmood et al., 2014). CO2, SOX, NOX and PM emissions caused by fossil fuels being the main source of energy reduce the quality of air day by day. Irreversible hazards to the environment and the health of humanbeings have made it necessary for international authorities to take precautions. Fuel efficiency and improvement studies, which started with the oil crisis in the 1970s, were regulated by the relevant authorities (Kalghatgi et al., 2018). With the Kyoto Protocol, which entered into force in 2005, efforts to take measures against greenhouse gases became the responsibility of all countries of the world with the Paris agreement in 2015 (Gilbert et al., 2018). However, maritime transport is not covered by these two conventions. The International Maritime Organization (IMO), an organization founded by the United Nations, changed the limit values in the Marpol Annex 6 Air Pollution Prevention Rules and created the Greenhouse Gas Strategy (Ji et al., 2020). Accordingly, while the limit determined in 2010 for sulfur emissions from fuel in the SECA (Sulphur Emission Control Area) area created according to Marpol Annex 6 Rule-14 was $< 1\%$; It was reduced to $< 0.1\%$ in 2015, and then the sulfur limit was reduced to $< 0.5\%$ globally, with the final regulation enacted in 2020 (Chu et al., 2019). According to the Green House Gas strategy published by IMO in 2020, it is desired that carbon emissions be reduced by at least 50% by 2050 compared to the rate in 2008 (IMO, 2020a). These emission limits in question encourage the maritime industry to seek alternative fuels. directed.

Alternative fuels have two important responsibilities. One is to reduce local pollutants; the other is that it shows a reduction in greenhouse gas over a considerable time. For this, it is important not only to compare the emissions that the fuel emits when it burns, but also the emissions it emits throughout its life cycle (Gilbert et al., 2018). Reducing carbon emissions and improving air quality can be achieved by the intersection of efficiency improvements such as the energy efficiency design index (EEID) and the use of alternative fuels (IMO, 2020a).

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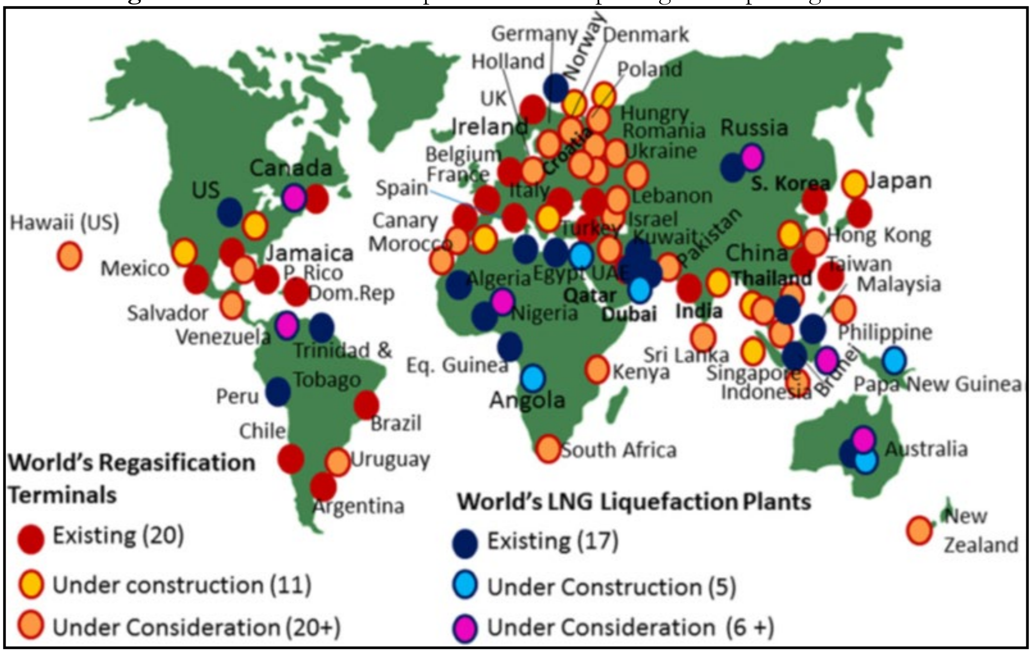
Heavy Fuel Oil (HFO) and Marine Dieseloil (MDO) make up 98% of marine fuels (Balcombe et al., 2019). Fuels such as low-carbon hydrogen, methanol and ammonia have not reached commercial maturity (Olmer et al., 2017). Battery electric technology, on the other hand, has not yet reached the desired kilometers even for land vehicles, no matter how much it has limited emission values, and it cannot go beyond short-distance use for vessels (Staffell et al., 2017). Since the industry is in search of a cost-effective, clean, reliable alternative energy, LNG stands out as the alternative fuel closest to providing the desired properties among alternative fuels (Ramachandran and Stimming, 2015).

In a study conducted by Lloyd Register with 4 shipowners in April 2011, it has been clearly demonstrated that the new emission limits will make LNG to be used as the fuel of the future (Kumar et al., 2011a). Compared to other marine fuels, LNG is estimated to reduce the sulfur emissions to almost 0%, while reducing carbon dioxide emissions by 10%-20%, nitrogen emissions by 80%-90%, and PM emissions by 98%-100% (Xu et al., 2015). As a result of the study by Lloyd Register, it was seen that the use of low-sulphur fuels is a short-term solution, and that LNG-fueled machines are a long-term solution instead (LR, 2012).

Natural gas is a fossil-based flammable petroleum-derived gas and is mostly discovered incidentally during oil exploration (Kılıç, 2014). LNG, which is formed by the liquefaction of natural gas through various processes, is a cryogenic liquid, mainly composed of methane, at -162°C (Foss and Parkway, 2012). The total world natural gas reserve is 6254.364 Tcf. (Ton cubic feet) Russia is the first in the world in terms of natural gas reserves, followed by Qatar in the second place (Ramachandran, 2015).

Figure 1. The world's most important LNG importing and exporting countries.



Reference: (Kumar et al., 2011b).

LNG; since its flammability rate is between 5% and 15% by volume during evaporation, it will be flammable when in contact with air in this range (Kumar et al., 2011b). This shows us the risks that may occur during fuel operations. If an explosion occurs after the slightest leak, the consequences will be quite devastating. Under these risks, IMO has created the IGC (International Gas Code) in order to carry out safe operations for LNG and similar low-burning gases (Vanem et al., 2008). In addition to these, various classification societies and authorities such as ISO have also created their own additional rules (IMO, 2020b). The main purpose of this article is to describe the advantages of using LNG as a marine fuel compared to other alternative fuels and to explain the precautions to be taken by defining the risks of hazard to the environment, crew, port and health due to the structural features of LNG during LNG bunkering operations.

2. Methodology

In this article, literature review method was applied to analyze the risks that may arise during bunkering operations of using liquefied natural gas (LNG) as an alternative ship fuel and to determine the precautions to be taken. For the basic rules, the publications of the International Maritime Organization (IMO) and Classification Organizations were examined. For the use of LNG as an alternative fuel and risk analysis of bunkering operations, a literature search was conducted with the keywords "alternative fuel, LNG, bunkering operation" from Google Scholar, Sciencedirect, Academia.edu. A literature search was made in the YÖK database for theses. For the use of LNG as an alternative fuel and risk analysis of bunkering operations, a comprehensive literature review about "alternative fuel, LNG, bunkering operation" has been conducted. The aim of the study is not to determine the amount of LNG use as an alternative fuel in maritime transportation, but to determine the necessary measures for the safe use of LNG, which has a high potential to cause harm and is within the scope of dangerous goods, as fuel in ships. For this reason, rather than statistical data analysis, the method of researching and compiling the rules related to the safe handling of LNG and handling them in a holistic way has been discussed.

3. Findings

3.1. The Structure of LNG and the Stages of Obtaining It from Natural Gas

LNG is a cryogenic liquid created based on the process of reducing the volume 600 times by condensing natural gas at -162°C (Aneziris et al., 2020). It contains mainly condensed methane (CH4), ethane (C2H6), Propane (C3H8), sometimes butane (C4H10) and in addition to all of them, nitrogen, carbon dioxide (CO2), water and traces of helium, hydrogen sulfide, mercury (Jeong et al., 2020). It is clear, odorless, non-toxic and non-corrosive under atmospheric pressure. Its density is 0.4-0.5 Kg/L, so it will stay above the water in case of leakage (Ramachandran and Stimming, 2015). Since carbon steel will become brittle at cryogenic temperatures, aluminum and stainless steel tanks should be used when liquefying natural gas or storing LNG (Jeong et al., 2020). The heat of vaporization, which is the amount of heat required for a substance to pass from liquid to gas, is 501.6 kJ/kg for natural gas (Scurlock, 2016). Two main types of tank designs are preferred for LNG transportation. The first is spherical tanks independent of the main ship structure, and the second is prismatic shaped membrane-lined tanks mounted on the inner hull. While spherical tanks carry LNG between 50000-135000 m3 with 4-6 tanks, prismatic tanks can carry 160.000 m3 LNG with 4 tanks, each of which can carry 40.000 m3 (Coşkun, 2004). The tanks prevent the risk of fire by reducing the oxygen level with the inert gas system (Pitblado et al., 2004).

While LNG is being liquefied, it goes through certain stages, first of all, CO2 is decomposed, then the dehydration stage is started, mercury is separated, the first cooling is done, it is liquefied, nitrogen is removed and LNG is stored as the final product (Alfa Laval, 2021). After the liquefaction process, ships carrying LNG arrive at the port destination, and are stored there in special purpose tanks after being regasified from liquid state, and the natural gas is transmitted according to its purpose through the pipeline system (Aneziris et al., 2020).

3.2. The Structure of LNG and the Stages of Obtaining It from Natural Gas

LNG bunkering, by definition, is the transfer of LNG to dual-fuel machine ships that use LNG as fuel. Requires special infrastructure for storage, supply and transfer to the ship LNG bunkering operations are performed in 3 ways: Truck to Ship (TTS), Port to Ship (PTS) and Ship to Ship (STS).

- TTS is the transfer of LNG from a tanker truck to a ship connected to the quay or pier by establishing a cryogenic hose connection. In a standard TTS operation, 13000 gallons of LNG can be transferred in 1 hour.
- PTS is made by connecting the cryogenic pipeline from the storage tank at the land facility to the ship connected to the port facility with a flexible end piece or hose.
- STS is the transfer from the LNG bunkering ship to the ship that uses LNG as fuel. STS operation can be carried out in port or at sea (Foss and Parkway, 2012).

3.3. LNG Potential Hazards and Accidents

LNG is not a toxic substance, if it leaks into the water, no damage to the environment has been recorded since it stays above the water due to its density (Ramachandran and Stimming, 2015). However, there are risks during operations due to suffocation and cryogenic damage. The LNG storage tank may leak from the pump or pipe; storage tank may overturn, fuel tanker may overturn, liquid leakage may occur due to pressure causing rapid phase transition (RPT) explosion, vessels may collide (Woodward and Pitblado, 2010). Consequences of a possible leak can cause dispersal of LNG vapor, pool fire radiation, flash fire, fireball and explosion (DNV, 2014; ISO/TS, 2015). LNG vapor poses no risk as long as it is not ignited, but will cause suffocation to persons inhaling the vapor (Hightower et al., 2008). Although this is initially considered a risk to ship crews and port facilities, the consequences of a nearshore cryogenic explosion would be enormous. Except this; LNG can be separated into layers with different densities, and if these layers are mixed, a rapid vapor release occurs, this phenomenon is specifically called rollover (Sun et al., 2017).

If LNG leaks onto water or land, it is initially very cold (110 Kelvin), since the difference between the water temperature and the water temperature is approximately 175 Kelvin, heat transfer takes place according to the 2nd law of thermodynamics and a vapor film forms on the surface; If this vapor film breaks down, the LNG will heat up faster and a different form of transfer will occur. This phase transition is called Rapid Phase Transition (RPT) (Örtberg, 2017).

There are many LNG marine accidents that have taken place, but there has not been a major accident recorded at any coastal facility or at sea over the course of nearly 40 years (Coşkun, 2004). Common causes of accidents include collision, grounding or minor leaks during transfer (Cleaver et al., 2007). El Paso Paul Kayser (1979) ran aground at a speed of 19 knots and a speed of 12 knots on a LNG Taurus (1980), and there was no loss of cargo in either of these accidents (Bubbico et al., 2009).

In 2007, the US General Accountability Office (GAO) started a study on the consequences of a possible terrorist attack on a tanker carrying LNG. An expert team with Sandia National Laboratories created and tested computer models of the damage caused by large-scale LNG leaks between 2008 and 2011. In this research, to determine the physical characteristics of fires on water caused by LNG leakage; determining the cause of failure, probability of occurrence and hazards in case of tank damage; It is aimed to identify safety measures to reduce the risk of leakage (Cabioc'h et al., 2009). According to the results obtained, 40% of the LNG will remain in the tank in case of a possible major leak, which will cause serious cryogenic damage. The resulting heat flow will disrupt the structure of the ship, scrapping the ship. Risks that will cause large leaks or fire should be minimized with risk management strategies, ports should review their emergency management plans (USDE, 2012).

3.4. Rules and Regulations for LNG Bunkering Operations

Rules and regulations for LNG bunkering operations are classified into 5 groups. These; high-level rules, standards, class guidelines, industry guidelines and port rules. High-level rules include international rules and those of the European Union. Standards are ISO, CEN and NFPA standards, Class guidelines are the guidelines of IACS and classification societies; industry guides include guides and checklists published by organizations such as The Society of International Gas Tanker and Terminal Operators (SIGTTO): The Society for Gas as a Marine Fuel (SGMF), while ports have their own rules (Aneziris et al., 2018).

3.4.1. The International Rules by IMO

- International Convention for Safety of Life at Sea (SOLAS, 2009)
- International Code of Safety for Ships Using Gases (IGF, 2015): International Code Of Safety For Ships Using Gases Or Other Low-Flashpoint Fuels Constructions & Bunkering of LNG Fueled Vessels. Adopted by the maritime safety committee (MSC) in 2015, it is a set of rules specifying LNG and safety standards for ships using low flash point fuels, which have become mandatory within the scope of 2017 SOLAS chapter VII. (IMO, 2021).
- International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in bulk (IGC Code, 2014): International Code for The Construction and Equipment of Ships Carrying Liquefied Gases in Bulk Construction of LNG Carrier Vessels. In the 16th section of the IGC code, which was revised by MSC 370(93) in 2014 and entered into force in 2016, it aims to bring safety standards for ships using gas cargo as fuel, and it is mandatory to apply for such ships (IMO, 2020b).
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3.4.2. European Union Rules

- Seveso III Directive (2012): It contains the rules of the European parliament and council numbered 2012/18/EU that will ensure the prevention of accidents caused by dangerous substances and minimizing the consequences of their effects on the environment and human health. The rules are valid for facilities holding a minimum of 50 tons of LNG (less if there are other dangerous goods), excluding offshore LNG facilities and underground storages in particular. For facilities holding 200 tons (440 m3) or more LNG, there are obligations with special reporting (EPC, 2012).

- ADR Agreement – International Carriage of Dangerous Goods by Road (2017): This contract contains the rules for the international transport of dangerous goods. Based on IMO's International Maritime Dangerous Goods Code (of the IMO) for shipping (UN, 2017).

3.4.3. ISO Standards:

- ISO 20519 Ships and Marine Technology - Specification for Bunkering of Liquefied Natural Gas Fuelled Vessels: For LNG fueled ships, it specifies the standards for the equipment mentioned in the IGC code (ISO, 2017).
- ISO/TS 18683 Guidelines for Systems and Installations for Supply of LNG as Fuel to Ships: It provides a minimum standard for the design operation of facilities for LNG bunkering operations, whether shore facility or supply vessel, as well as training recommendations for ship crew and bunkering personnel for their mission roles during operations. Operations such as inerting, cooling and loading are within the scope of this standard (Sun et al., 2017).
- ISO/TS 16901 Guidance on Performing Risk Assessment in the Design of Onshore LNG Installations Including the Ship/Shore Interface: It guides the risk assessments to be made for the risks that will occur during the planning, design and operation of LNG onshore or coastal facilities (ISO, 2015).
- ISO/TS 28460 Petroleum and Natural Gas Industries -- Installation and Equipment for Liquefied Natural Gas -- Ship-to-Shore Interface and Port Operations: These are the standards created for terminal and port services such as pilotage, tugboats, mooring boats, terminal and port operators, fuel supply services required for the safe transfer of LNG carriers to the port area (ISO, 2010).
- NFPA 59A Standard for The Production, Storage, and Handling Of Liquefied Natural Gas (LNG): These are the standards that include minimum fire precautions and safety precautions for the location, design, construction, operation and maintenance of LNG facilities (NFPA, 2018).
- EN 1473 Installation and Equipment for Liquefied Natural Gas. Design of Onshore Installations: It is the standard established for the design, construction and operation of all facilities where the stages of LNG such as liquefaction, storage, gasification, transportation will be made (EN, 2021).

3.4.4. Class Guidelines

- International Association of Classification Societies – REC 142 LNG Bunkering Guidelınes: This document, which contains minimum recommendations for the safe conduct of LNG ship bunkering operations, includes the responsibilities, procedures, recommendations for equipment for bunkering operations, and how to conduct a risk assessment for bunkering (IACS, 2016).

3.4.5. Reports Publeshed by Other Classification Societies

- Guidance On LNG Bunkering To Port Authorities And Administrations (EMSA, 2018): This guide, which was created by the European Maritime Safety Agency (EMSA) to implement the Directive 2014/94/EU on LNG, aims to prevent environmental pollution and ensure safe operation in accordance with the requirements of European ports for LNG bunkering operations in parallel with other rules (EMSA, 2018).
- Bunkering of Liquefied Natural Gasfueled Marine Vessels in North America (ABS, 2015): It is a guide created in parallel with federal, state and local obligations for ships using LNG as fuel for North America and Canada, for shipowners and operators of such ships, as well as for obtaining project approval for LNG fueling facilities (ABS, 2015).
- Considerations for Proponents When Conducting QRA for LNG Bunkering SIMOPS (API PP142228-2 REV. 3): This guide, created by DNV Class, is a guide prepared for the quantitative risk assessment (QRA) to be made to LNG bunkering operations and simultaneous operations (DNV, 2016).

3.4.6. Industry Guidelines

- Society for Gas as Marine Fuel (SGMF)
- Bunkering Safety Guidelines (2017): It was created by the Society for Gas as Marine Fuel (SGMF) to explain the risk assessment approach, technical requirements and procedures for bunkering operations (SGMF, 2017).

- Simultaneous Operations (SIMOPs) During LNG Bunkering (2017): It was created by the Society for Gas as Marine Fuel (SGMF) to provide guidance on how to conduct other ship operations and port operations during the LNG bunkering operation (SGMF, 2018).

3.4.7. The Society of International Gas Tanker and Terminal Operators (SIGTTO)

- Guidelines for the Alleviation of Excessive Surge Pressures on ESD for Liquefied Gas Transfer Systems (2018): It was created by the Society of International Gas Tanker And Terminal Operators (SIGTTO) to explain Surge Pressure, identify potential hazards, and explain the benefits of the ESD system (SIGTTO, 2018).
- Liquefied Gas Handling Principles on Ships And in Terminals Handling Principles (2016): It is a guide created by the Society of International Gas Tanker And Terminal Operators (SIGTTO) to explain the principles of liquefied gas handling (Aneziris et al., 2018; SIGTTO, 2016).
- LNG Ship to Ship Transfer Guide for Petroleum, Chemicals and Liquefied Gases Ship to Ship Transfer (2013): It is a guide by the Society of International Gas Tanker And Terminal Operators (SIGTTO) containing the rules and procedures of LNG's STS transfer operations (Aneziris et al., 2018; SIGTTO, 2013a).
- LNG operations in Port Areas - Essential Best Practices for The Industry Operations in Ports (2003): It includes risk assessment methodologies, rules and procedures for LNG operations in ports by the Society of International Gas Tanker And Terminal Operators (SIGTTO) (Aneziris et al., 2018; SIGTTO, 2013b).

3.4.8. Port Rules

- Marmara Ereğlisi LNG Terminal Port Rules And Information: It is the guide published by BOTAŞ in our country, which includes port berthing, terminal contact information, safety and security rules to be followed for Marmara Ereğlisi LNG Terminal (BOTAŞ, 2020).

3.5. Safety and Risk Assesment of LNG Bunkering Operations

The International Safety Management Code (ISM Code), which is the safety-related rules of IMO, has been established for the safe conduct of operations on ships and the protection of the environment (IMO, 2020c). Along with these rules, a Safety Management System is established in order to create a safety culture, and measures to be taken in emergencies, accidents and dangerous situations are determined to minimize human-related accidents. By providing communication reports between the ship and the company, the maintenance behavior of the ship is followed, which minimizes the risks to the crew or the environment (IMO, 2021).

While performing the risk analysis, firstly the context is created, then the danger is determined, the error frequencies are determined, the results are evaluated and the risk is calculated (EPC, 2012). Quantitative risk assessment method is a widely known and accepted risk assessment method and it makes risk assessment with 5 questions (UN, 2017).

1. What could go wrong?=Define the hazard
2. How bad?=Result modeling
3. How often?=Frequency estimation
4. So what?=Risk assessment
5. What should I do?=Risk management

Hazard Identification Session (HAZID) methodology is used to identify the hazard. This method is an early hazard identification method. It is used to describe unusual situations that may occur during bunkering operations. In the outcome modeling section, in case of an accident, for example fire, its impact on humans and the environment is evaluated. In frequency estimation, the frequency of occurrence of the hazard is estimated using specific scenarios. Analysis of historical event data; Techniques such as fault tree analysis, event tree analysis, simulations are used (UN, 2017). Risk assessment classifies the risk as acceptable, tolerable or negligible. Risk management is to evaluate the measures to be taken to reduce the risk and recalculate the risk. For this, the ALARP (As Low as Reasonably Practical) method is used (EMSA, 2018).

The main purpose of the risk assessment of bunkering operations is to reduce the risks that may occur to people and the environment as much as possible and to collect information that helps to determine the safety and security zones where the operation will be carried out (ISO, 2017).

The LNG bunkering operation risk assessment should include preparing, testing and connecting equipment, LNG transfer and boil-off gas method, completion of fuel transfer and equipment disconnection, and simultaneous operations before the ship arrives, approaches or anchors (ISO, 2017). 3-stage checklists should be applied for risk assessment:

1. Control of things to be done before bunkering operations (before berthing)
2. LNG transfer information
3. Control of what will be done after the fuel operation.

Checklist before bunkering operations; determining the place and time where the transfer will take place, making the necessary reports to the authorities, training the personnel about the fuel transfer procedure and the use of equipment, the bunkering plan must be class approved, the lighting condition of the area where the transfer will be made should be good, fire equipment should be ready for use, air and wave conditions information and safety-related precautions to be taken before bunkering (ISO, 2015).

In the LNG transfer information section; It includes mutually agreed information for operations occurring during and simultaneously with LNG transfer. These are the temperature, pressure, density, transfer rate and physical unit of measurement required for LNG bunkering (ISO, 2015).

The checklist of what to do after the bunkering operation includes cleaning and disconnecting the hose, manifold, fixed pipelines; remote or manual valve closing control; reporting the completion of refueling of the port, terminal or bunkering vessel; It should include a record of the reporting of near misses, incidents or accidents (ISO, 2015).

3.6. Safety Precautions and Emergency Situations

According to the report prepared by EMSA, the LNG safety concept includes 4 stages. These are regulations, risk and safety, incident report and training. The safety measures enacted by the regulations determine the responsibilities for the safe execution of bunkering operations and the damages to the environment and people In the risk and safety section, measures to be taken against the risks that may arise from the structure of LNG, what to do in case of gas leakage, damage to personnel, ship-shore reporting, extra safety precautions to be found on ships, and most importantly, risks and precautions for new fuel caused by inexperienced crew are explained. With the reporting of LNG-related incidents or near misses, it is possible to learn from the incidents and increase safety measures, increase the accuracy of risk calculations, increase safety measures and improve equipment. Most of the accidents are caused by human error. Therefore, training is the most important part of LNG safety concept. Since LNG is a new fuel, it needs awareness training different from traditional marine fuels. For this reason, ship personnel and port personnel should receive training at certain intervals. (EMSA, 2018)

The responsibility of bunkering operations will be with the captain. The ship's radar must be turned off during operations (ISO, 2015). An area classified in accordance with ex-proof standards should be established on the ship and only responsible personnel should be allowed to enter it. In order to prevent ignition of LNG vapor, the electrical system in this area must be of high safety accordingly. The ship must have an ESD-Emergency Shut-Down system. This system makes the bunkering operation safe by stopping the liquid or gas transfer in case of emergency (Sun et al., 2017).

Checklists should be meticulously maintained and followed. There should be clearly visible hazard warning and instruction signs on the ship. Smoking and non-exposure lights should not be used during the bunkering operation. VHF radios used in reporting must also be of a nature not to cause fire (UN, 2017). The operation area should be illuminated. LNG transfer and gas detectors must be certified and their condition must be approved by the service (IAPH, 2015).

There should be an Integrated Automation System (IAS) computer system on board, all operational structures are connected to it and receive the signals sent by the system. (While the pressures of the tanks are managed automatically, when special tests are required, it can be switched to manual mode if valve control is desired to be bypassed.) (ISO, 2010).

Where the fuel station is, there should be an electrical and pneumatic cabin in the cold box, pressure gauges of the tanks in this cabin and transit solenoid valves that supply air to the actuators in the valves to facilitate manual tests. There are limit switches and solenoid valves on the ESD valves, pneumatic valves must be of the "Fail Close" type, which has the feature of closing itself in case of power failure or loss of service air (ISO, 2010).

Before bunkering, the ESD system should be tested and activated, and fire fighting equipment should be kept ready for use. In a possible emergency, the ship should be able to disconnect the hose in a short time, and an ax should be kept ready to cut the mooring ropes. If there is a ship-to-ship fuel operation, the ship's machine should be kept ready for immediate use (ISO, 2010).

An emergency action plan should be established in which the ship's personnel know their duties in an emergency. In this plan, it should be explained who will do what in case of LNG fuel leakage, how to respond to a gas fire, how to use the equipment, how to establish an alarm system and communication with the port or other authorities (Aneziris, 2021). The crew of the ship should be prepared for emergencies by performing regular drills in accordance with this plan (DNV, 2014). How to make safe reporting during on-board training must be explained (NFPA, 2018). As personal protection equipment, leather gloves should be used against cold burns, protective glasses should be worn in places where there is a possibility of contact with cold gas, and there should be no metal in the shoes against the possibility of sparks. Ear protection should be used for noise originating from the safety valve. (ISO, 2010).

In case of LNG fuel leakage, the bunkering operation must be stopped immediately and the vents must be closed. The port should be informed (ISO, 2010).

Trays with stainless steel features located under both manifolds are designed to remove the leaking fuel from the ship in the opposite direction in case of leakage. As the amount of spillage increases, the probability of experiencing RPT will increase. The vapor cloud size will expand due to the rapid cooling of the LNG. If cold LNG comes into direct contact with the ship, it will damage the hull structure. The larger the leak, the greater the damage (SMTF, 2013).

3.7. Role of Port Authority in Bunkering Operations

The port authority has 4 important duties in LNG bunkering operations. These are hosting, regulating, operator and community management (Wang and Notteboom, 2015).

The role of hosting basically includes the preparation of infrastructure and facilities suitable for bunkering (Wang and Notteboom, 2015).

Regulatory role; It includes following the implementation of the operational rules, especially the IMO rules regarding LNG bunkering, following the emission limits, pollution monitoring and risk assessment by creating a LNG bunkering checklist. Operator role; It includes the efficient delivery of LNG bunkering services and operations and assisting private sector bunkering companies. Community management role, on the other hand, includes the promotion of the use of LNG as a fuel, and the solution of problems that occur around and outside the port (EN, 2021).

4. Conclusion

LNG is the cleanest energy source among fossil fuels, as it is an alternative fuel that reduces local pollutant emissions to almost zero and GHG gases to 10%-20%. Although it is not a toxic substance, due to its cryogenic properties, rapid phase transfer (RPT) can occur in case of a leak, causing pool fires radiation, flash fire, fireball and explosion. An explosion will cause damage to the ship and the crew will inevitably suffer. In addition to these, it will cause cold fires in case of contact with pipes and suffocation if inhaled. The purpose of this study is to show the safety fuel precautions to be taken when LNG is used as fuel.

It is seen that there are many regulations regarding the safety measures to be taken when using LNG as an alternative fuel on ships. For this reason, it can be said that the most important method in preventing accidents is to carry out operations in accordance with safety measures.Regardless of the method of the bunkering operation (STS, PTS, TTS), a risk assessment should be made first and 3-stage checklists should be used for this. These lists will serve as a guide for safety precautions to be taken.

An emergency action plan should be created, the crew should be trained in this regard, and they should be well prepared and prepared for their role in emergency situations with regular drills. Training should focus on safe reporting. Communication is the most important element to prevent accidents. Explain how to use personal protection equipment.

During bunkering operations, fire response equipment should be kept ready for use, VHF handheld radios, flashlights, electrical system in the bunkering operation area should be ex-proof, and an emergency shutdown system should be present on the ship. Bunkering operations should be monitored with the IAS system and valves should be tested before operation.

Safety will always be the most important issue for maritime industry. Since new fuel systems are quite different from conventional fuel systems, a long process will be required for the personnel to adapt to it. For this, the trainings should be more frequent and the main purpose of this training should aim to adopt the safety culture.Further field research and experiments on the practical usage of LNG as the main fuel of bunkering operations will yield more solid results about the practical results of the efficient usage of this specific fuel type. Therefore, the making the use of LNG in the real life settings will give the fields researchers the chance to collect data from the already-happening scenerios.

Finally, another point is that although there are many guides published by different organizations regarding the safe use of LNG in ports and ships, it is seen that a specific code and/or guideline for ships that will use LNG as an alternative fuel has not yet been issued by IMO. In order to ensure uniformity in practice, Flag States, especially IMO, should do the necessary work to ensure the safety of life, property and environment related to LNG-related accidents.

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