SIGTTO Society of International Gas Tanker & Terminal Operators Ltd

Reduction of LNG Carrier Methane Emissions

First Edition

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SIGTTO

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The Society of International Gas Tanker and Terminal Operators (SIGTTO) *is a non-profit making organisation dedicated to protecting and promoting the mutual interests of its members in matters related to the safe and reliable operation of gas tankers and terminals within a sound environment. The Society was founded in 1979 and was granted consultative status at the International Maritime Organization in November 1983.*

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Introduction and Scope

1. Introduction and Scope

1.1 Introduction

This document is part of a series of documents supporting the shipping industry's environmental goals to reduce greenhouse gas (GHG) emissions. The main constituent of liquefied natural gas (LNG) is methane, a GHG, and it is vital that robust systems are in place to minimise the environmental impact of LNG transportation.

Building on the guidance in *Detection and Reporting of Fugitive Methane Emissions from LNG Carriers*,[1] this document outlines the main sources of methane emissions from liquefied natural gas carriers (LNGC) and provides guidance on ways to reduce them in the design and operation phases.

[1] SIGTTO – Detection and Reporting of Fugitive Methane Emissions from LNG Carriers.

1.2 Scope

All LNGC types, designs and operations have the potential to reduce methane emissions, and many of the considerations in this document are valid across trades. However, as the highest level of operational experience is available for large-scale ships, some of the guidance focuses on the technologies employed on these ships. These recommendations are not specific to storage or regasification units and LNG bunker ships, but shipowners and operators might choose to follow those applicable to them.

The guidance only covers methane emissions and does not consider other GHGs or air pollution emissions. For CO_2 emissions, see *Reduction of Gas Carrier CO_2 Emissions*.[2]

The level of technical detail assumes that the reader is familiar with the operation of an LNGC. Not all concepts are simplified or explained at an introductory level.

[2] SIGTTO – Reduction of Gas Carrier CO_2 Emissions.

2

Overview of Methane Emission Reductions

2. Overview of Methane Emission Reductions

The safety aspects of handling methane are focused on its flammability and ensuring that the gas stays in concentrations in the air well below the lower flammability limit (LFL). Environmental aspects require other considerations such as the size of the leak and its duration. From a safety perspective, measurement of leaks is normally in percentage volume of the LFL but from an environmental perspective leak detection is usually in parts per million (ppm).

Understanding the LNG shipping trade and environmental regulatory framework helps the industry and organisations focus efforts on the most effective areas to reduce these emissions. Figure 1 provides a summary of the structure of this document, which groups the emissions into three main categories: emissions due to ship design and construction (Chapter 3), emissions during operations (Chapter 4), and fugitive emissions (Chapter 5).

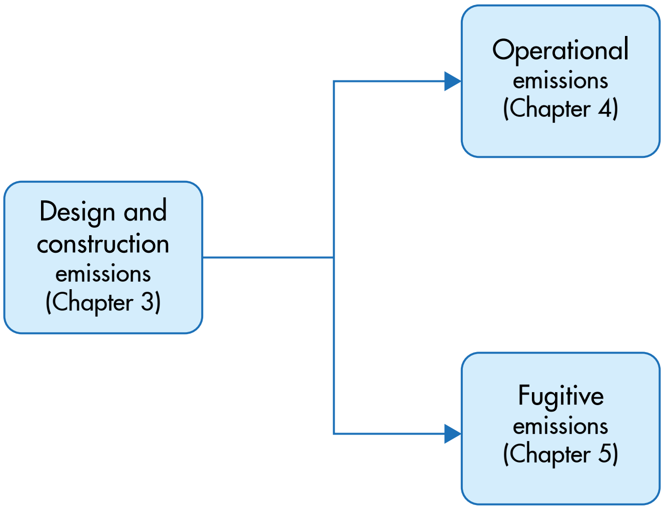

Figure 1: Emissions and document structure

An effective approach to reduce emissions at the design stage is to follow an iterative assessment process (see Figure 2) in which emissions are identified, eliminated or reduced and the design solution evaluated again. During operations, implementation of continuous improvement initiatives, including prevention of fugitive emissions, will reduce emissions.

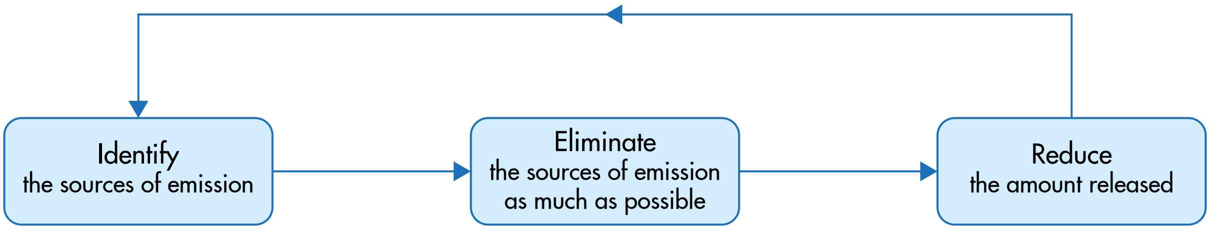

Figure 2: Emission reduction flow chart

LNGCs that can be retrofitted can gain the benefit of adapting to new methane management technologies. Adoption of any of the recommendations should be done without compromising safety. It is important to assess the implications of any change in the design of a ship or in the way the ships are operated.

3

Emissions Due to Ship Design and Construction

3. Emissions Due to Ship Design and Construction

The design of a ship significantly influences its methane emissions during its lifetime. This chapter provides recommendations to the shipowner, ship designer and shipyard to support them in selection of the technical solutions to be implemented.

3.1 Boil-Off Gas and Tank Pressure and Temperature Control

Gas carriers transport methane in liquid form because it is more efficient than transporting it in gas form. This requires adequate selection of cargo containment systems (CCSs) and methods of controlling tank pressure and temperature. Unmanaged boil-off gas (BOG) will increase the pressure and temperature of the cargo.

3.1.1 Boil-off gas and thermal insulation

Methane is the main constituent of LNG and is in liquid form at –162°C or below at atmospheric pressure. While LNG is stored in the cargo tanks it is warmed up by heat ingress from the environment, as shown in Figure 3, generating an equilibrium imbalance and causing the liquid to vaporise. These vapours are called boil-off gas (BOG).

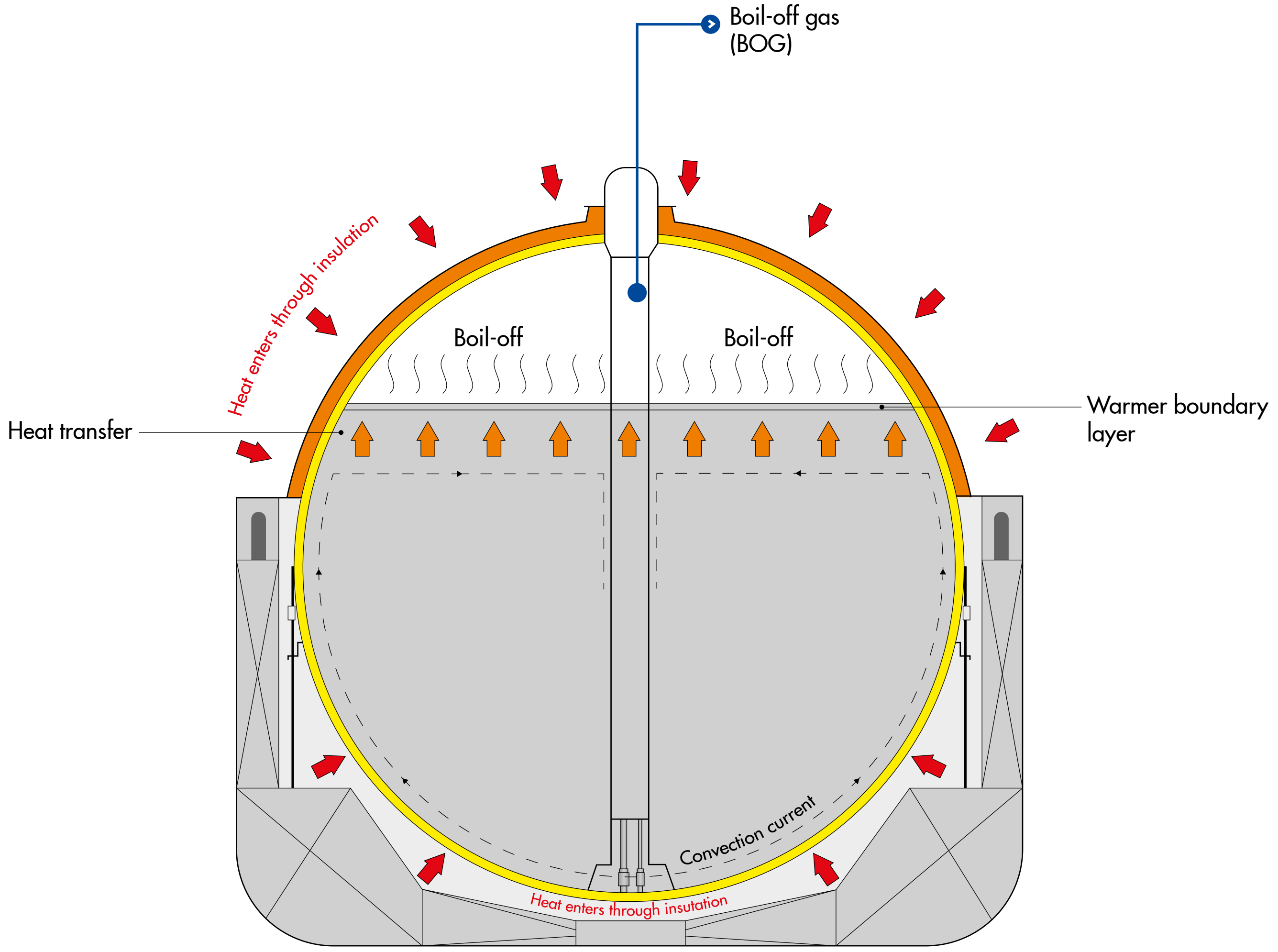

Figure 3: Heat ingress into the cargo tank

Tank insulation is fitted to minimise heat-flow into the cargo tanks and reduce the BOG. Materials with low thermal conductivity are preferred because they generate less BOG. The selection of the CCS should be made on the basis of a holistic assessment, taking into consideration the operating profile, the propulsion system, power generation requirements and minimisation of BOG production.

3.1.2 Cargo containment systems

Selection of CCS type and technology is based on the shipowner's choice and type of trade. Membrane and type A CCSs have a full secondary barrier capable of safely containing potential leakages through the primary barrier because of their inherent risk of leakage. The CCS manufacturer should assess the size and location of any credible defect to prevent CCS tightness being compromised. CCSs should include technologies to actively detect leaks.

The probability of structural failure of type B tanks is extremely low, and small leaks are only expected for the design of the secondary barrier. The risk of structural damage to type C tanks is so low that they do not require a secondary barrier.

3.1.3 Tank pressure and temperature control

The IGC Code prohibits the venting of cargo for tank pressure and temperature control except in emergency scenarios and provides requirements for methods of control. LNGCs use a combination of the following BOG control methods:

- Pressure accumulation
- reliquefaction of cargo vapours
- liquid cargo cooling
- thermal oxidation of vapours.

The pressure accumulation method allows pressure to build up within the system for a certain time and temperature increase. The operating procedures should consider the ship's operating profile and provide a sufficient margin to avoid pressure relief valve (PRV) release during normal operation.

Some LNGCs have reliquefaction or liquid cooling systems that can either be fully rated or partially rated when compared to the BOG rate. These systems allow tank pressure and temperature control without consumption of the full BOG.

Thermal oxidation[3] refers to the use of cargo as fuel in a gas combustion unit (GCU) or in a boiler. Cargo as fuel is extensively used because it is an efficient way to control tank pressure and temperature and, at the same time, provide fuel to the propulsion and power generation systems.

The use of the GCU is usually the last option to prevent an emergency such as venting due to pressure relief valve release. Some LNGCs consider such systems to be emergency equipment. Since methane has a higher GHG impact than CO_2,[4] the use of thermal oxidation is preferred over venting. Steam turbine methane emissions are low enough to render closer to zero[5]. Similarly, minimum unburned methane is expected from GCUs.

[3] IGC Code paragraph 1.2.52 – *"Thermal oxidation method means a system where the boil-off vapours are utilized as fuel for shipboard use or as a waste heat system subject to the provisions of chapter 16 or a system not using the gas as fuel complying with this Code."*

[4] See Intergovernmental Panel on Climate Change (IPCC) Global Warming Potential Values, Version 2.0, 7 August 2024.

[5] See Fourth IMO GHG Study 2020.

3.1.4 Reliability, availability and maintainability

The overall capacity of the combined methods should include a suitable margin for the operating profiles of the ship, such as laden and ballast voyages, cargo condition and cargo management, waiting time, and type of trade, without venting. It should consider equipment that is unavailable because of a single failure or because it is under maintenance.

3.2 Methane Slip from Engines

Methane slip refers to gaseous methane, used as fuel, that has not combusted and is discharged into the atmosphere via the engine exhaust. Methane slip is relatively higher at lower loads and reduction can be achieved through engine technologies, system design, integration with the LNGC systems or by a combination of them.

Methane leakage from the crankcase vent of trunk type engines is another potential source of emissions that should be considered.

3.2.1 Engine technologies

Methane slip is reduced using engine technologies such as:

- Combustion chamber design
- electronic controls and tuning
- high-pressure gas injection or
- exhaust-gas recirculation.

Some of these technologies may be applied either to newbuild engines or to upgrade existing engines. Other technologies, such as plasma reduction or oxidation catalysts, may become available in the future. The introduction of accelerants in the fuel stream, such as hydrogen, reduces the methane slip.

Methane emissions vary with the engine load and it is typically higher at low loads. These emissions differ depending on the type of engines[6] and can differ between engines of the same type.[7,8] Manufacturers should determine these emissions by testing at different running loads, and they should be certified in line with the relevant regulatory regimens such as the IMO.

Lessons learnt from testing can improve understanding of the engine's emission profile and should be detailed in the engine manual addressing operation and maintenance. Guidance on the operation at low loads eg manoeuvring can also be beneficial for the reduction of these emissions.

3.2.2 System design

Design of ship propulsion and power generation systems includes the dimensioning of engines, selection of engine technology and emissions performance and their configuration. BOG rate and voyage speed are the driving factors for propulsion, but other aspects related to system flexibility, such as waiting for discharge, should be considered. System design influences the methane slip during operation. A multiple engine

[6] Engine types refer to low-pressure, high-pressure or spark-ignited engines.

[7] Kuittinen, N., Heikkilä, M., Jalkanen, J.-P., Aakko-Saksa, P. and Lehtoranta, K. (2023) Methane slip emissions from LNG vessels: review. In *Proceedings of the 30th CIMAC World Congress 2023* Article 629.

[8] N. Kuittinen, P. Koponen , H. Vesala , K. Lehtoranta (Received 27 March 2024) Methane slip and other emissions from newbuild LNG engine under real-world operation of a state-of-the art cruise ship.

configuration provides operational flexibility, particularly in scenarios where the power demands vary widely. This setup allows operators to run only the necessary number of engines to meet current power requirements efficiently, rather than running larger and less efficient engines at partial load.

Power shaft generators, or batteries, can be fitted to operate the main engine at higher loads, which enables reduced running time of 4-stroke auxiliary engines that may emit relatively higher levels of methane compared to 2-stroke engines. Some ship designs and operating scenarios might allow stoppage of a power generation unit, eliminating its methane slip emissions.

3.2.3 Alternatives to combustion engines

Ship design should allow for the shutting down of engines during low engine loads, which can help reduce methane slip. Energy can be supplied by other means, such as onboard energy storage, a battery energy storage system, or power sources such as fuel cells.

While in harbour, the engine loads can be low and outside the optimum range of operation. Shoreside electricity[9] may be used as an alternative to onboard engine power generation where it is available.

3.3 Other Design and Construction Considerations

This section includes aspects specific to some designs or equipment used in the cargo or fuel systems.

3.3.1 Cargo tank gas freeing

Tank entry is carried out periodically to inspect the CCS and in-tank equipment (eg pumps or instrumentation) to ensure that they remain fit for purpose and compliant with the statutory requirements. As part of the preparations, gas freeing of the tank is required.

Selection of high reliability or redundant equipment can avoid the necessity of tank entry to repair equipment or instrumentation failure. Another option, if available, is fitting non-intrusive instrumentation that can be removed or repaired without access to the tank.

3.3.2 Tank and dome construction

The CCS manufacturer should produce procedures for construction and inspection, including prevention of tank and insulation damage from, for example, dropped objects.

Tank domes and connections are customised equipment and should be designed to be robust to avoid leakage, see Figure 4. Openings and other bolted connections are more susceptible to leakage than welded joints. Testing of the bolted connection's tightness should be carried out during the first loading, after warm-up, and every time the connections are opened.

[9] See section 9.2 Cold ironing on *SIGTTO Liquefied Gas Terminals - Site Selection, Design and Operation of Marine Facilities.*

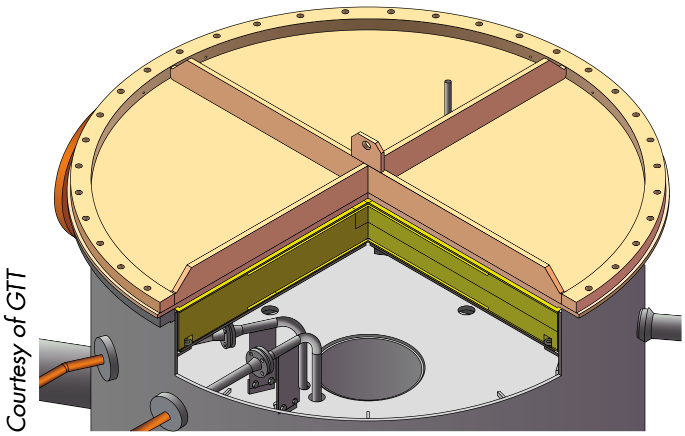

Figure 4: Tank dome design (bolted)

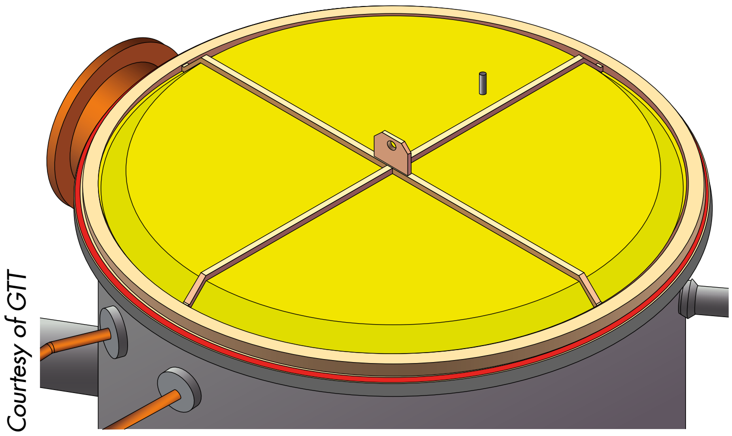

Figure 5: Tank dome design (welded)

3.3.3 Piping and valves

Flanged connections are more susceptible to leakage than welded joints. Reducing the potential for fugitive emissions can be achieved by minimising the number of flanges. Some valve designs can be welded to the pipeline. However, it is still essential to ensure that the piping and valves are accessible for inspection and maintenance, taking into account the size of the leak detection device, see Section 5.2.

Valve leakage rates differ depending on the design of the valve and seal system. ISO 15848-1[10] and ISO 15848-2[11] provide information on the leakage rate for the seal systems and testing for validating the design. Open-ended valves, such as sampling and drain valves, should be limited as far as possible to reduce the risk of leaks across the closing isolating element. Blind flanges or caps are usually installed for safety reasons and they can reduce or avoid emissions from untight open-ended valve seats.

Cargo and fuel sampling and analysis should be designed to avoid venting by using, for example, closed-loop technologies.

[10] ISO 15848-1 Industrial valves – Measurement, test and qualification procedures for fugitive emissions – Part 1: Classification system and qualification procedures for type testing of valves.

[11] ISO 15848-2 Industrial valves – Measurement, test and qualification procedures for fugitive emissions – Part 2: Production acceptance test of valves.

3.3.4 Pressure relief valve discharge

PRVs are required for safety purposes but may be a source of fugitive emissions. When discharge from equipment or piping can be routed to the cargo tanks, or a buffer vessel, emissions are reduced. However, not all ship designs and systems, for example high-pressure equipment such as compressor discharge piping, allow this design solution without exceeding the over pressurisation allowed.

As an alternative to PRV, bursting discs can be installed in some systems with the benefit of eliminating the risk of fugitive emissions. Another possible option could be a combination of bursting disc and PRV.

3.3.5 Pressure and rotating equipment

Heat exchangers, pressure vessels, and the nozzles of other equipment should be able to withstand the maximum foreseeable piping loads to avoid leakage throughout the connecting surfaces. Equipment nozzles and piping should be installed within allowable alignment limits.

Compressors and pumps on deck should have seal systems specifically designed for the application. Some seal systems have features installed that detect a leak.

3.3.6 Purging of gas lines and reclaim system

For safety reasons, when consumers are not burning gas, these lines should be purged. In some ship designs it is feasible to reclaim the methane, rather than releasing it into the atmosphere, and store it in a suitable tank as compressed natural gas. Other measures can include the reduction of the volume of gas purged.

3.3.7 Gas trials

Serial gassing up and cooling down during gas trials can potentially limit the amount of gas released into the atmosphere. Such operation might require specific valve or piping arrangements.

On completion of the trials, LNG and methane should be transferred to other installations for processing or to the GCU.

4

Operational Emissions

4. Operational Emissions

Even the most modern and efficient ships need to be operated efficiently to reduce their methane emissions. This chapter provides recommendations to the shipowner and charterer during normal operation, maintenance and emergency activities.

4.1 Management Framework

Trading agreements and voyage planning impact the emissions of the LNGC and fleet. Agreements between shipowners and charterers should aim to establish the most efficient method to reduce emissions.

Charterers and shipowners can collaborate in estimating and optimising:

- The boil-off they will produce for the complete operation
- voyage instructions
- use of other fuels
- any cargo conditioning and heel requirements.

In the assessment, consideration should be given to the condition at loading and discharge, ship to ship operations, laden voyage, and waiting time. Other operations such as ballast voyages and anchorage might be outside the scope of the agreement between charterers and shipowners. As part of the Ship Energy Efficiency Management Plan (SEEMP), shipowners can include improvement plans for reducing emissions.

4.2 Cargo and Voyage

The voyage should be carried out according to the pre-established instructions. The operational procedures should reflect the assumptions and limitations of the design to reduce the emissions during operation. They should include the following aspects as a minimum.

4.2.1 Cargo management

LNG temperature delivered to gas carriers varies depending on aspects such as exporting terminal or cargo composition. Loading cold cargo, within the CCS safe limits, reduces the BOG.

In the event of a change to the voyage plan, an assessment should be made of the most energy-efficient way to manage the BOG, including the use of cargo as fuel and, if installed, reliquefaction or liquid cooling systems. This might include use of the GCU or boiler to avoid warming of the cargo to a level at which emergency venting is required. Venting of the cargo for conditioning should not be accepted.

Bad weather conditions and waiting time to discharge generate additional BOG. Effective voyage planning should aim to minimise impact and avoid delays.

4.2.2 Cargo containment systems

Although membrane CCS leaks rarely have safety implications, an effective way to assess its tightness is by the inert gas required to sweep the barrier spaces. Appropriate assessment should be carried out to control and reduce leaks to the atmosphere. Repairs should be carried out according to the recommendations provided by the CCS manufacturer.

4.2.3 Heating of cofferdams

To reduce heat ingress into the tanks, the temperature control set point of the cofferdams should be the minimum according to the gas carrier design and IGC Code paragraph 4.19.1.5 and 4.19.1.6, applying a margin for safety reasons.

4.2.4 Methane slip from engines

Running engines at their optimum conditions, which is at higher loads, reduces methane slip. However, for safety reasons, this might not be possible in operations such as manoeuvring and cargo transfer. Operating at low loads should be avoided as far as possible.

Onboard measurements, monitoring or assessment of emissions at different loads can be useful for improving the understanding of engine configuration and operation. These emissions may be certified in line with relevant regulatory bodies, such as the IMO.

4.2.5 Purging of fuel gas lines

Gas lines are purged due to engine changeovers from gas to other fuel or when engines are start and stopped. Recording the frequency of these purges provides documented indication of the quantity of emissions. Reduction might be possible through adequate planning.

4.2.6 Heel strategy

In heel out voyage, sufficient time should be given to maximise the quantity of cargo discharged from the cargo tanks.

Some existing LNGCs require venting when heeling out. Heel out voyages should, when possible, be limited to situations when tank inspection is planned.

4.2.7 Ship to ship cargo transfer

During ship to ship transfer operations additional BOG is generated mainly from cargo pumps and heat ingress from deck piping and transfer equipment. Transfer rates might need to consider the handling of excess BOG to prevent venting. Venting of the cargo to maintain cargo tank pressure and temperature during ship to ship operations should not be accepted except in emergency situations.

4.2.8 Piping, penetrations and valves

Small leaks from piping connections, penetrations and valves are fugitive emissions. However, as part of the normal operation of LNGCs, these sources of emissions should be frequently inspected visually and repaired. See Chapter 5 for the leak detection and repair (LDAR) campaigns.

4.3 Inspection and Maintenance

Effective planning of inspection and maintenance activities can reduce emissions.

4.3.1 Cargo tanks

When gas freeing cannot be avoided, means to recover the methane should be considered. The use of the GCU or boiler should follow operational procedures and should be used as much as possible rather than venting. Sufficient time to displace the methane reduces the amount diluted in the inert gas, which is vented to the atmosphere.

4.3.2 Equipment and pipework

Maintenance activities that require equipment or pipework gas freeing should be planned together to avoid multiple operations. Thermal oxidation methods should be prioritised onboard rather than venting.

4.4 Emergency Venting

Emergency venting procedures, including methods to prevent venting, should be available on board. Even when the GCU is not operational, venting should be avoided unless it is becoming a safety issue.

If venting does need to occur, controlled venting through manual operation, or by using the pressure control valves, such as a venting valve, provide better control of the quantity of gas vented. These methods can be used before PRV activation because they result in less methane being vented.

When a PRV is activated, the closing element (eg disc) lifts from its seat. When the PRV moves to its closed position, there is a risk that the moving element will fail to reset tightly resulting in a leak source. Controlled venting might prevent this. Operating and maintenance of PRVs[12] reduces the risk of malfunction and leakage.

[12] SIGTTO Recommendations for Relief Valves on Gas Carriers.

5

Fugitive Emissions

5. Fugitive Emissions

Fugitive emissions are leaks to the atmosphere caused by loss of tightness of an item that is designed to be tight.[13] This can be due to imperfections in mechanical components or small failures. Fugitive emissions are also caused by the gas carrier's normal operation through, for example, thermal expansion of components, wear in joints and ship movement and acceleration.

This chapter provides guidance to shipowners and service providers. It includes identification of the main sources of emissions and points to consider when implementing a leak detection and repair (LDAR) programme to ensure that these emissions are adequately managed.

5.1 Sources of Emissions

Figure 5 shows the typical sources of fugitive emissions.

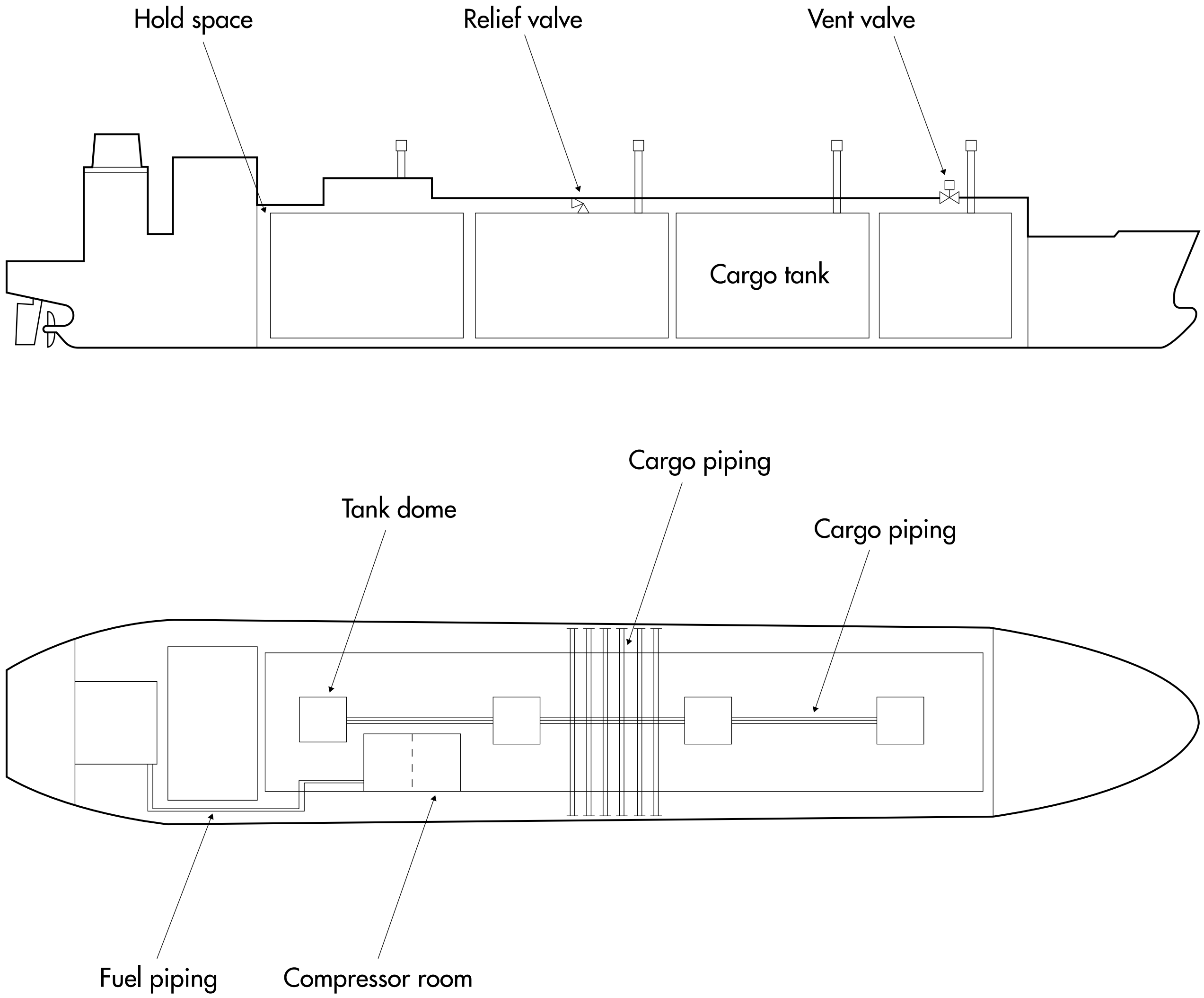

Figure 6: Areas to consider for sources of fugitive leaks

[13] See EN 15446 – Fugitive and diffuse emissions of common concern to industry sectors – Measurement of fugitive emission of vapours generating from equipment and piping leaks.

The following sections provide details on the main areas where leakage is more likely to occur.

5.1.1 Tank domes

Tank dome connections to the mating pipe can leak because of gasket failure, misalignment of two mating surfaces, or excessive piping loads.

5.1.2 Piping and penetrations

Flanged connections usually leak because of failure of the gasket, misalignment of two mating surfaces, or excessive piping loads. This includes piping, equipment nozzles, and other connections. Instrumentation connections and any other small size penetrations are typically threaded.

5.1.3 Vent and other valves

Valves leak through the stem packing or bonnet connection as a result of normal wear or failure of the packing or seal system. Valves open to the atmosphere, such as venting, manifold and drain valves, and valves for sampling and analysis, leak across the isolating element when the seat is worn out, damaged by debris, or not fully closed. Inspection doors are bolted flanges, which can also leak.

5.1.4 Relief valves

PRVs can leak when the closing element does not re-seat in the correct position or when the seat is worn out, damaged by debris or not fully closed.

5.1.5 Pressure and rotating equipment

Equipment nozzles and flanged connections usually leak because of failure of the gasket, misalignment of two mating surfaces, or excessive piping loads. Instrumentation connections and any other small size penetrations are typically threaded or compression fitted.

Compressors and pumps leak between the casing, which remains static, and the rotating shaft and seal systems are fitted to prevent this.

5.2 Leak Detection and Repair Programme

LDAR programmes should be implemented to identify leaks and establish a system for repairing them. Certain components have an inherent leakage rate within the tolerable levels of emissions for those technologies. Figure 6 shows an example of the process for LDAR programmes, which is explained in the following sections.

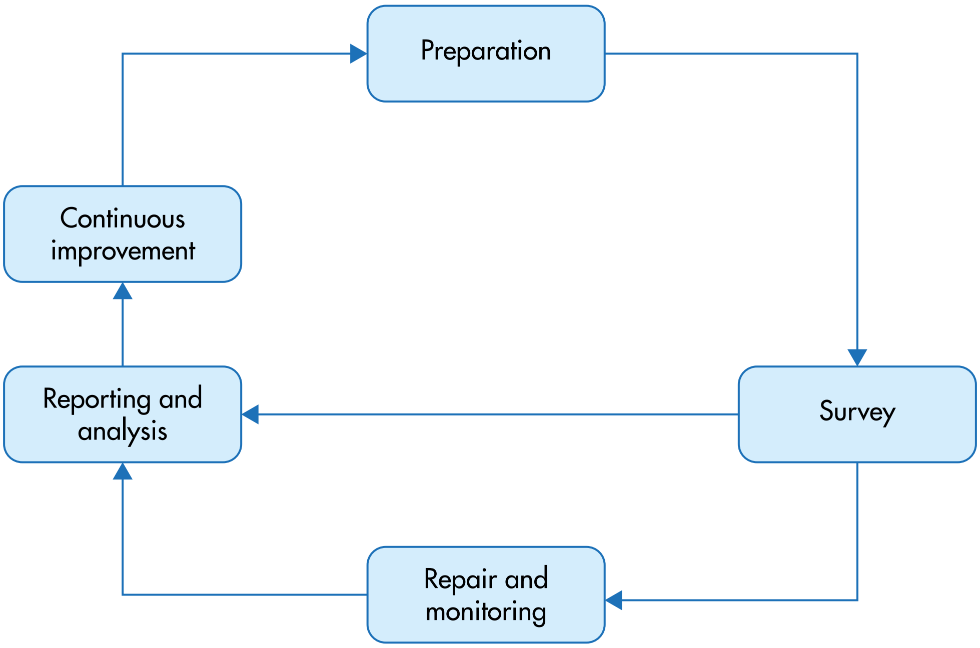

Figure 7: Leak detection and repair (LDAR) programme flow chart

5.2.1 Preparation

Identification of the targeted systems and equipment can be done extensively through a risk-based approach. It is expected that the risk of leakage is higher in high-pressure or large pipelines and so they should be inspected more frequently. Similarly, certain equipment, or equipment components, and pipework subjected to high levels of vibration or ship movement are more likely to leak.

Procedures should be created for the:

- Sources of emissions targeted
- measurement methodology
- detection device
- training and qualification of personnel
- quantification of leaks
- gas leakage criteria or threshold for repair
- time frame for repair.

The decision to repair should consider that the equipment should meet the acceptable leakage criteria after the work is carried out. These criteria should be based on recognised industry standards. If these are not available, it should be considered that certain components have inherent tolerable leakage rates for the applicable technology.

Suitable detection devices should be used in the LDAR programme such as optical gas imaging, a tunable diode laser absorption system and ultrasonic or flame ionisation detectors.

Survey and measurement planning can be time or condition based. For the former, the frequency of measurements should be established.

Another approach is to apply a variety of leak detection techniques combined at different intervals including, for example, frequent large-scale surveys combined with less frequent inspections of components and continuous monitoring.

5.2.2 Survey

Operators should be competent to carry out the campaign and follow the written procedures. They should be familiar with the detection devices used and the LNGC technology and equipment. Detection devices should be calibrated.

Records should be kept of the surveys carried out including the equipment and systems inspected, the location of any leak and actions taken. This might be incorporated within the quality assurance and quality control system.

5.2.3 Repair and monitoring

Any leak should be repaired according to company procedures. A component is only considered successfully repaired after it has been monitored and shown not to leak above the leak detection criteria. If leaks are not immediately repaired, they should be entered into a leak monitoring system or adequately registered in the planned maintenance system. An LDAR programme is not designed to replace any maintenance programme required for the ship's equipment or systems.

5.2.4 Reporting and assessment

Issues identified during the survey campaign should be closely monitored with the aim to find out the root cause of the failures. When it is identified that certain equipment or, for example, a certain valve or seal system type or model is prone to leak, all those items in the fleet should be investigated.

5.2.5 Continuous improvement

The inspection and maintenance programme should be reviewed periodically to improve the efficiency of the process and the overall reduction of emissions.

Annexes

Annex 1 – Glossary of Terms and Abbreviations

BOG Boil-Off Gas

CCS Cargo Containment System

CO_2 Carbon Dioxide

GCU Gas Combustion Unit

GHG Greenhouse Gas

IMO International Maritime Organization

ISO International Organization for Standardization

LFL Lower Flammability Limit

LDAR Leak Detection and Repair

LNG Liquefied Natural Gas

LNGC Liquefied Natural Gas Carrier

NOx Nitrogen Oxides

PRV Pressure Relief Valve

SEEMP Ship Energy Efficiency Management Plan

Annex 2 – Reference List

- SIGTTO – Detection and Reporting of Fugitive Methane Emissions from LNG Carriers
- SIGTTO – Reduction of Gas Carrier CO_2 Emissions
- IMO – International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)
- Intergovernmental Panel on Climate Change (IPCC) Global Warming Potential Values, Version 2.0, 7 August 2024
- Kuittinen, N., Heikkilä, M., Jalkanen, J.-P., Aakko-Saksa, P. and Lehtoranta, K. (2023) Methane slip emissions from LNG vessels: review. In *Proceedings of the 30th CIMAC World Congress 2023* Article 629. https://cris.vtt.fi/files/85067970/CIMAC_paper_629.pdf
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