Installation and Maintenance guidelines for LNGPac equipment

Wärtsilä Finland

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EXAMENSARBETE

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Titel: Installations- och underhålls riktlinjer för LNGPac utrustning

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Datum: 16.4.2024 Sidantal: 21 Bilagor: 4

Abstrakt

Detta examensarbete skrevs för FGSS-avdelningen vid Wärtsilä i Vasa. Examensarbetets bakgrund var behovet av detaljerade riktlinjer för montering och installation av processkritiska komponenter och annan processutrustning, bland annat kryogeniska fjäril- och kägelventiler samt förångare för hantering av flytande naturgas (LNG).

Syftet med detta examensarbete var att producera ett antal sammanställda dokument med riktlinjer och guider för montering och installation av utrustning som används i Wärtsiläs LNGPac. Dessa riktlinjer kommer att användas av Wärtsiläs interna samt externa arbetare som en checklista vid produktionen av Wärtsiläs LNGPac, dessa checklistor är då lätta att gå igenom när man utför slutgranskningen av produkten.

Grunden för riktlinjerna baserar sig på den tekniska beskrivningen framställda av tillverkarna av komponenterna och utrustningen samt grundläggande underhållsteknik, som sedan granskas ur ett ingenjörsmässigt perspektiv för att säkerställa dess legitimitet som riktlinje för produktionen av Wärtsiläs LNGPac.

Orsaken för dessa problem som tidigare har uppstått i tillverkningsskedet har analyserats noggrant och lösningarna presenteras i de fyra olika dokumenten med riktlinjerna som presenteras i bilagorna.

Resultatet av detta examensarbete blev fyra skilda sammanställda dokument med monterings- och installationsriktlinjer för komponenterna och utrustningen. Dessa riktlinjer kommer att hjälpa och säkerställa att installationen och monteringen av komponenterna och utrustningen sker enligt IGF-koden och tillverkarnas direktiv.

Språk: engelska Nyckelord: riktlinjer, guide, montering, installation

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OPINNÄYTETYÖ

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Päivämäärä: 16.4.2024 Sivumäärä: 21 Liitteet: 4

Tiivistelmä.

Tämä opinnäytetyö on kirjoitettu Vaasan Wärtsilän FGSS-osastolle. Opinnäytetyön taustalla oli yksityiskohtaisten ohjeiden tarve prosessikriittisten komponenttien ja muiden prosessilaitteiden, kuten kryogeenisten lautasventtiilien ja nesteytetyn maakaasun (LNG) hallintaan tarkoitettujen höyrystimien, kokoonpanoon ja asennukseen.

Tämän opinnäytetyön tarkoituksena oli tuottaa useita koottuja asiakirjoja, joista ohjeet ja oppaat löytyvät Wärtsilän LNGPacissa käytettävien laitteiden kokoonpanoa ja asennusta varten. Wärtsilän sisäiset ja ulkopuoliset työntekijät käyttävät näitä ohjeita tarkistuslistana Wärtsilä LNGPacin tuotannossa. Nämä tarkistuslistat on helppo käydä läpi tuotteen lopputarkistuksen yhteydessä.

Ohjeistuksen perusta perustuu komponenttien ja laitteiden valmistajien tuottamaan tekniseen kuvaukseen sekä peruskunnossapitotekniikoihin, joita tarkastellaan sitten teknisestä näkökulmasta sen legitiimiyden varmistamiseksi Wärtsilä LNGPacin tuotannon ohjeena.

Näiden valmistusvaiheessa aiemmin ilmenneiden ongelmien syitä on analysoitu huolellisesti, ja ratkaisut on esitetty neljässä eri asiakirjassa liitteissä esitettyjen suuntaviivojen kanssa.

Opinnäytetyön tuloksena oli neljä erillistä koottua dokumenttia kokoonpano- ja asennusohjeet komponenteille ja laitteille. Nämä ohjeet auttavat ja varmistavat, että laitteiden asennus ja kokoonpano tapahtuu IGF-säännöstön ja valmistajan direktiivin mukaisesti.

Kieli: Englanti Avainsanat: ohje, opas, kokoonpano, asennus

BACHELOR'S THESIS

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Abstract

This thesis was written for the FGSS department at Wärtsilä in Vaasa. The background of the thesis was the need for detailed guidelines for the assembly and installation of process-critical components and other process equipment, including cryogenic butterfly and globe valves and vaporizers for liquefied natural gas (LNG) management.

The purpose of this thesis was to produce several compiled documents with guidelines and guides for the assembly and installation of equipment used in Wärtsilä's LNGPac. These guidelines will be used by Wärtsilä's internal and external workers as a checklist in the production of Wärtsilä LNGPac, these checklists are then easy to go through when performing the final review of the product.

The basis of the guidelines is based on the technical description produced by the manufacturers of the components and equipment as well as basic maintenance technologies, which are then examined from an engineering perspective to ensure its legitimacy as a guideline for the Wärtsilä LNGPac production.

The cause of these problems which have previously arisen in the manufacturing stage has been carefully analyzed and the solutions are presented in the four different documents with the guidelines presented in the Annexes.

The result of this thesis was four separate compiled documents with assembly and installation guidelines for the components and equipment, these guidelines will help to ensure that the installation and assembly of the components and equipment take place according to the IGF Code and the manufacturers' directive.

Language: English Keywords: guidelines, guide, assembly, installation

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Preface

I would like to thank the FGSS department of Wärtsilä for the opportunity to write my thesis, it has been a valuable experience for me.

Many thanks to my supervisors, Björn Sandgärds from Wärtsilä and Leif Backlund from Novia UAS, without their support I would never have had the possibility to achieve my targets.

Abbreviations

Bar(g)	Bar at Gauge
BioLNG	Biomethane Liquefied Natural Gas
BOG	Boil Off Gas
BOR	Boil Off Rate
BS	Bunkering Station
CIP	Cleaning in Place
DN	Nominal pipe size “Diametre Nominal”
DW	Double Wall
ESD	Emergency Shutdown
FGPU	Fuel Gas Preparation Unit
FGSS	Fuel Gas Supply System. Department in Wärtsilä Marine Power
Genset	Generating Set
GH	Gas Heater
GHG	Greenhouse Gas
GVU	Gas Valve Unit
GW	Glycol Water
HC	Hydrocarbon
HFO	Heavy Fuel Oil
HMS	Heating Media System
HVAC	Heating, Ventilation and Air conditioning

IGC	International code of the construction and equipment of ships carrying liquefied gases as cargo
IGF	International code of safety for ships using gases or other low flashpoint fuels
IMO	International Maritime Organisation
LFO	Light Fuel Oil
LHV	Lower Heating Value
LNG	Liquefied Natural Gas
MDO	Marine Diesel Oil
MGE	Main Gas Evaporator
N_2	Nitrogen
NG	Natural Gas
PBE	Pressure Build up Evaporator
PU	Polyurethane
PUF	Polyurethane Foam
PUR	Polyurethane Rubber
SGMF	Society for Gas as Marine Fuel
TCS	Tank Connection Space
VR	Vapour Return

1. Introduction

This thesis is made for the Production subdivision of the FGSS department in Wärtsilä Marine.

The thesis contains multiple installation and maintenance guidelines of equipment that will be used in the design and production phase of Wärtsilä's LNGPac. These guidelines will help with problems encountered in previous LNGPac's, reducing costs and time by learning from the past and gathering useful information and instructions from Wärtsilä and their equipment suppliers.

It is very demanding to design the LNGPac as cost-efficient as possible, leading to a more crowded space for equipment installation and maintenance. As the space for equipment in the LNGPac is to be kept as small as possible, we encounter a lot of issues which are now to be resolved.

1.1 Wärtsilä

Wärtsilä is a global leader in smart technologies and complete lifecycle solutions for the marine and energy markets. By emphasising sustainable innovation, total efficiency, and data analytics, Wärtsilä maximises the environmental and economic performance of the vessels and power plants of its customers. In 2023, Wärtsila's net sales totalled EUR 6.0 billion, with approximately 17,800 employees. The company has operations in over 280 locations in 79 countries around the world. (wartsila.com, 2024)

1.2 Delimitation

This thesis will be limited to the compiling of four guidelines for the installation and maintenance of equipment used in Wärtsilä's LNGPac. These guidelines will be limited to specific equipment used only at LNGPac.

The guidelines are divided into four categories.

The four categories of equipment are the following:

- Cryogenic and regular valves
- Evaporator

- LNG fuel pump
- Heating media pumps

1.3 Disposition

The thesis contains the following chapters:

- Chapter one introduces the reader to the subject and the background of this thesis.
- Chapter two contains the theory of LNGPac equipment.
- Chapter three explains the use of LNG as a marine fuel, basic properties, and fundamentals of LNG.
- Chapter four explains the installation and maintenance theory used in this thesis.
- Chapter five describes the method used to reach the goals of this thesis.
- Chapter six explains the results gained from solving the main issues.
- Chapter seven contains the conclusion of this thesis.
- Chapter eight contains a discussion of the conclusion and personal evaluation.

1.4 Problem definition and purpose

In the past there have been issues with space required for maintenance on the equipment used in Wärtsilä's LNGPac, e.g., piping and constructions occupying and blocking space required for maintenance.

The main purpose of this thesis is to compile several installation and maintenance guidelines that can be used in the manufacturing phase of the product. Ensuring that the installation of the LNGPac equipment and components are installed correctly according to regulations and manufacturer's directives.

By installing them correctly we can assure that they are easily obtained and there is sufficient room for future maintenance.

2. Pre-study

An introduction to Wärtsilä LNGPac and familiarize us with the problems encountered during and after the construction of LNGPac.

LNGPac is a complete fuel system for LNG fuelled ships, built to store, and process LNG to the gas consumers onboard. The LNGPac includes the bunkering station, LNG storage tank and related process equipment as well as the control and monitoring system.

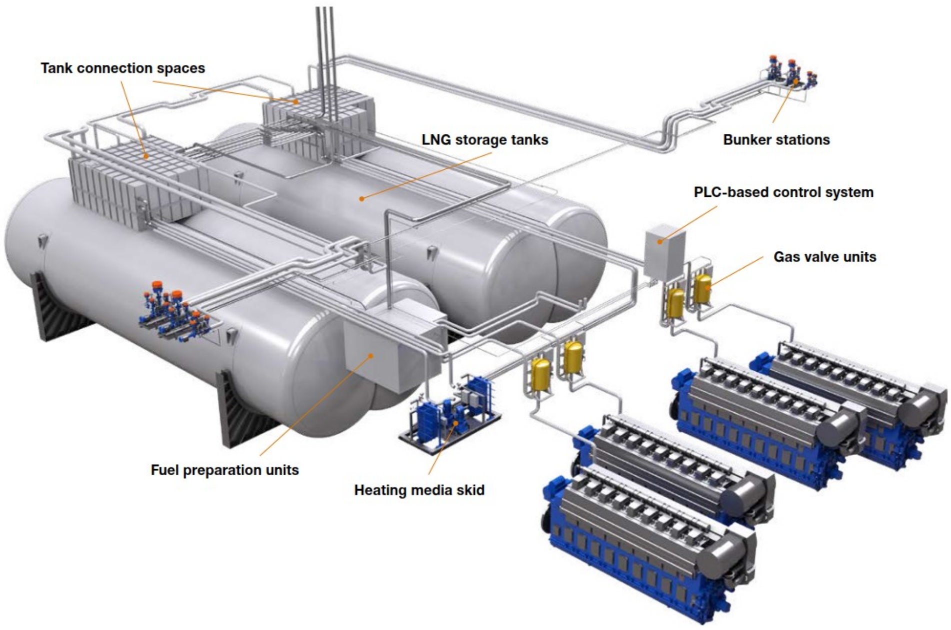

Figure 1. LNGPac system overview.

2.1 LNG fuel storage tank

The LNG fuel storage tank stores the liquefied natural gas. They are usually divided into four categories:

- IMO type-C vacuum-insulated cylindrical double-shell tank made from stainless steel.
- IMO type-C PUF-insulated cylindrical single-shell tank made from carbon steel.
- IMO type-C PUF-insulated bi-lobe tank made from carbon steel.
- Membrane tanks

The two types of insulations for cylindrical and bi-lobe tanks are:

- Double-shell perlite-filled vacuum insulation.

- PUF-insulation with a rigid reinforced top coating.

Figure 2. Double-shell vacuum-insulated LNGPac.

Figure 3. PUF-insulated single shell LNGPac.

Vacuum insulation is usually selected when the size of the tank is less than 300 m^3 due to a significant increase in costs in manufacturing compared to the PUF-insulated tank. The sizes of cylindrical and bi-lobe ranges from 25 m^3 up to 3000 m^3.

Membrane tanks are to be considered when the volume is above 1000 m^3 in one tank and especially if multiple tanks are required, membrane tanks are a solution to be considered due to their volumetric adaptation. Membrane tanks used as fuel storage for the gas consumers have been built up to 18000 m^3.

The cylindrical and bi-lobe type-C tanks must be designed to withstand temperatures continuously below -165 °C and pressures up to 9 bar(g). (Wärtsilä, 2020)

Criteria are a storage tank of type-C must follow according to (DNV GL, 2016):

- The tank must have a simple geometric shape, carrying loads mainly as membrane stresses.

- Tank is to be exposed mainly to static pressure, fatigue, and crack propagations, and in general, it is not to be critical.

- The structural strength of the tank can be easily calculated by simple formulas/methods.

2.2 Tank Connection Space

Every tank has its own TCS, connecting the tank to its components and systems that process the LNG.

As defined by the IGF code, the space surrounding all tank connections and tank valves is required for tanks with such connections in enclosed spaces. (International Maritime Organization, 2016).

The TCS must be provided with an extracting type of mechanical forced ventilation capable of at least 30 air changes per hour to reduce the risk of explosion in the TCS. (International Maritime Organization, 2016)

The processes inside the TCS can be divided into three types:

- **Pressure build-up-based systems, PBE**

  PBE is the most common one used for fuel gas supply since it is best suited for LNG volumes of less than 500 m^3 and because of its robust construction and design. The system is completely based on evaporation processes requiring no rotating equipment. The system still uses rotating heating media circuit pumps which provide heating power to the evaporators.

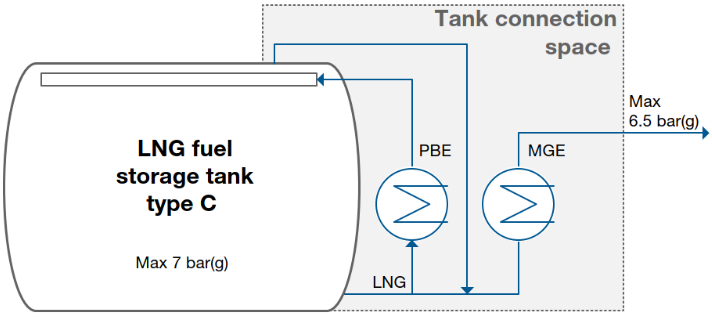

Figure 4. PBE based system.

The system uses two gas evaporators, PBE and MGE. Since the tank has a bottom connection, the LNG flows naturally through the PBE causing pressure build-up in the tank. By building up the pressure and keeping the required supply pressure in the tank, the LNG is fed through the MGE and vaporizes to the conditions required by the gas consumers.

- **Pump-based systems**

Pump-based systems use an LNG fuel pump upstream of the MGE either inside or outside the tank. This solution provides both advantages and disadvantages.

Advantages of the pump-based system:

- A stable pressure of the fuel gas supply can always be guaranteed and will not be affected by a collapse of pressure in the tank.
- The ability to supply 2-stroke dual-fuel consumers and high-performing 4-stroke dual-fuel consumers with high-pressure demands. This fuel supply system can achieve pressures up to 14 bar(g) after the MGE.
- The pump-based system uses a tank with lower design pressure, resulting in a lighter and less expensive fuel tank.

The downside of the pump-based system:

- At least one gas consumer is required on board, i.e., steam boiler or an auxiliary Genset. These gas consumers are needed to cope with the BOG generated at lower pressure levels.

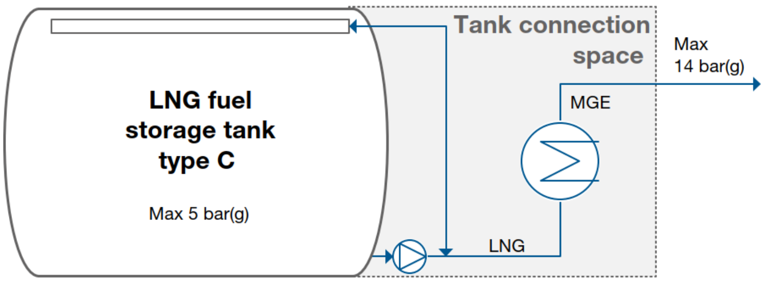

Figure 5. Pump-based system, simplified process diagram.

- **Pump-based systems with BOG compression**

This system is applied when large volumes of LNG are stored (greater than 1000 m^3). Due to high boil-off makes BOG management critical for self-dependence on longer voyages. BOG compressors are mandatory if membrane tanks are installed due to membrane tanks shall not exceed operating pressures above 0.7 bar(g).

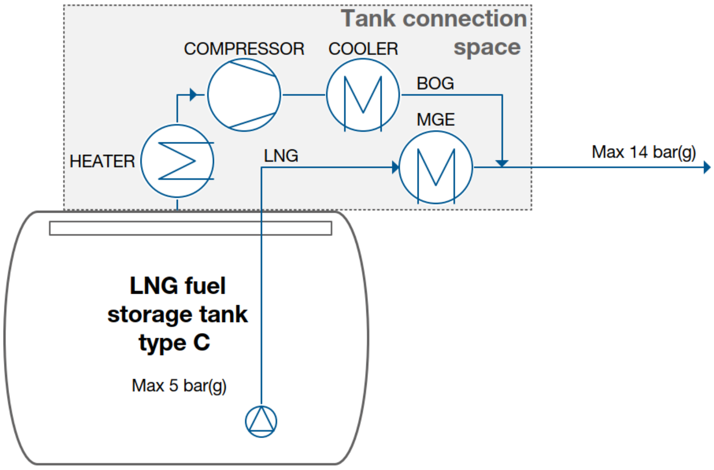

Figure 6. Pump-based system with BOG compression, simplified process diagram.

This system adds BOG in parallel with the LNG fuel pump(s), enabling the simultaneous feeding of forced NG and compressed BOG to the gas consumers on board.

The pump- and compressor-based system is much more versatile than the PBE-system due to its capability to control the tank pressure at any condition. (Wärtsilä, 2020)

2.3 Bunkering Station

The main interface between the receiving ship and the LNG supplier for the fuel transfer. The bunkering station consists of manual and automatic valves for bunkering LNG and usage of inert gas, i.e. nitrogen, instrumentation for pressure monitoring and a piping system. Designed according to the recommendations by SGMF. (Wärtsilä, 2020)

2.4 Evaporators and heat exchangers

Two types of heat exchangers are used in Wärtsilä's LNGPac:

- **Shell and Tube**

The shell and tube heat exchangers are usually very space-consuming due to their design, leading to a more crowded space.

- **Plate and Shell**

  The plate and shell heat exchangers are very compact compared to the shell tube heat exchangers.

The design of the plate and shell heat exchangers that Wärtsilä mainly uses is a combination of the traditional plate and shell heat exchanger technology and the traditional shell and tube heat exchanger, combining their advantages to a single plate and shell heat exchanger. (Wärtsilä, 2020)

2.5 LNG fuel pumps

When using pump-based systems, an LNG pump can be chosen from the three different alternatives available: (Wärtsilä, 2020)

- Submerged pump

  A submerged pump is a standard centrifugal pump submerged in the cryogenic LNG inside the tank. The main advantages of submerged pumps are:

  - Submerged pump requires less space above the tank for retraction of the pump.
  - Significant difference in costs compared to the deep well pump, more compact design.

  Disadvantages of the submerged pumps are:

  - Due to the electronic motor being submerged in cryogenic liquid, it is heating up the LNG and increasing the BOR. By increasing the BOR, the holding time of the tank is reduced.
  - The tank must be emptied and inert when maintenance is to be performed.
  - Shorter maintenance intervals, resulting in more frequent heating and cooling of the tank.

- Deep well pump
  - By using deep well LNG fuel pumps, the BOR is reduced due to the heat from the electric pump motor being produced outside of the tank, increasing the holding time of the tank.
  - When the deep well pump needs maintenance, it is possible to maintain the pump without emptying or gas-freeing the tank.
  - Maintenance intervals of deep well pumps are significantly longer than for submerged pumps.
- External pump
  - By definition, the external pump, i.e., a submerged or a deep well pump, is located outside of the tank in a vacuum-insulated cryostat. These are usually used in systems that use bottom tank penetrations.

2.6 BOG Compressor

In pump- and compressor-based systems, the BOG compressor is an important piece of equipment because the pressure accumulation cannot be guaranteed to be high enough to feed the gas consumers. (Wärtsilä, 2020)

BOG compressors that are LNG compatible are available in three different alternatives:

- Screw compressors
- Vane compressors
- Piston compressors

2.7 Gas buffer tank

By using a gas buffer tank, it is possible to reduce the pressure fluctuations in the gas supply lines to the gas consumers. Gas buffer tanks are required on high-pressure installations but are not necessary for low-pressure systems. The purpose of gas buffer tanks can be compared to compressed air storage tanks used in compressed air systems. Always ensuring high enough pressure and the ability to maintain constant flow without interruption. (Wärtsilä, 2020)

2.8 LNGPac piping

Cryogenic piping that is used in LNGPac can be divided into four types: (Wärtsilä, 2020)

- Forced ventilated DW piping with or without PUR insulation.
- Nitrogen pressurised DW piping with or without PUR insulation.
- PUR insulated single-walled piping.
- Vacuum insulated DW piping.

2.9 Cryogenic and non-cryogenic valves

Valves are crucial components which need to be selected carefully, globe valves are to be preferred when valve sizes are under DN 150, due to their reliability and low leak rates.

When using valves larger than DN 150, butterfly valves are to be used due to their significantly lower pressure drop compared to globe valves. (Wärtsilä, 2020)

Figure 7. Cryogenic globe valve.

Figure 8. Manually actuated butterfly valve

2.10 Heating medium pumps

Heating medium circulation pumps are found in the HMS, which circulates the heating medium and provides heating power to the LNG evaporators. HM pumps are critical components in the LNG process part of the LNGPac. If an HM pump fails to run, the consequences are insufficient evaporation of the LNG, disabling the full functionality of the process systems. (Wärtsilä, 2020)

2.11 LNG as a marine fuel

As we strive towards a decarbonised and cleaner environment, the need for sustainable fuels is increasing. In 2018 the global shipping industry emitted a total of 2.9% of the global GHG emissions caused by human activity and it is increasing every year since the global shipping industry is growing rapidly. The global shipping emissions represented a total of 1076 million tonnes of CO_2 worldwide. (European Commission, n.d.)

LNG is the type of transition fuel to be used now when we are rapidly and surely converting from fossil fuels to renewable fuels, as (Mokhatab, Mak, Valappil, & Wood, 2013) state, that LNG is decreasing the number of nitrogen oxides and is almost completely free from sulphur oxide which makes LNG a clean source of energy although it is still a fossil fuel. Vaporizing LNG and using it as natural gas generates very low particle emissions and significantly lower carbon emissions compared to other HC fuels (e.g., HFO, LFO and MDO).

LNG is described as a nontoxic, colourless, odourless, and noncorrosive cryogenic liquid with a boiling point typically around -162 °C, depending on its composition since every component has a different boiling point. Natural gas does not burn in its liquid state; LNG vapour has a window where it is explosive so-called LEL, and UEL. LEL stands for Lower Explosive Limit and UEL stands for Upper Explosive Limit.

Methane has a LEL of 5 Vol% and a UEL of 15 Vol% in air. (Cameo Chemicals, 2024)

LNG is often composed of lighter and heavier hydrocarbons such as methane (CH_4), ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), pentane (C_5H_{12}) and hexane (C_6H_{14}). Depending on the country of origin of LNG, the quality may vary a lot. Methane content can vary between 87 mol % to 99 mol %. (Mokhatab, Mak, Valappil, & Wood, 2013)

#	Peak Name	Channel	RT (min.)	Result (mol-	Norm. %	Area (uV/Sec.)
1	Nitrogen	Channel 1 - CP	0.5288	0.0630	0.0635	223
2	Methane	Channel 2 - CP	0.4145	95.3458	96.2183	693644
3	Ethane	Channel 2 - CP	0.5987	3.2861	3.3162	38022
4	Propane	Channel 3 - CP	0.2628	0.2956	0.2983	3506
5	i-Butane	Channel 3 - CP	0.3425	0.0560	0.0565	778
6	n-Butane	Channel 3 - CP	0.3598	0.0353	0.0356	505
7	i-Pentane	Channel 4 - CO	0.2035	0.0039	0.0039	126
8	n-Pentane	Channel 4 - CO	0.2288	0.0024	0.0024	89
9	n-Hexane	Channel 4 - CO	0.3317	0.0052	0.0052	29
	Totals			99.0933	100.0000	736922

Figure 9. Example of a general Gas Chromatograph result.

Engine knocking can be eliminated by having an on-line gas analyser which helps to always have engine parameters tuned to the correct methane number (ref. as MN).

It is very important to know the exact composition of the LNG since the MN is greatly affected by the heavier hydrocarbons, e.g., pentane and hexane. Hexane is a very heavy hydrocarbon, a straight chain alkane with six carbon atoms (C6) and with a low autoignition temperature (234 °C) compared to methane which is a light and simple hydrocarbon with a high autoignition temperature (537 °C), natural gas components with lower autoignition temperature significantly decreases the MN.

MN is calculated by ISO 6976:2016 standards, measuring the gas contents either by gas chromatography or on special occasions by an online gas analyser with either infrared absorption spectroscopy or tunable filter spectroscopy.

One of the perks of using LNG instead of NG as a fuel is that LNG is up to 600 times denser than NG, meaning it has a higher energy density. The density of LNG ranges between 430 kg/m^3 and 470 kg/m^3.

Another possible way to efficiently decarbonise the shipping industry besides using fossil LNG is the increased usage of BioLNG, which is produced by organic residues, e.g., waste from different local feedstocks, biowaste from households or biomass waste from the forest industry. These are then fermented in a biogas reactor.

Biogas is produced by microbes that feed on biomass and their digestion creates methane. Biogas usually contains methane, carbon dioxide and low amounts of hydrogen sulphide. The biogas is either used un-scrubbed in power plants or further refined by water scrubbing. After water scrubbing the methane content is between 95 - 98 Vol.%; after refining, the biogas can be cooled down and liquified to BioLNG for further transport or storage.

Synthetic methane or e-methane is an upcoming solution to decarbonize the shipping industry; synthetic methane is produced by low-emission electricity, water, and CO_2. The water is electrolyzed to hydrogen; by using the Sabatier method, hydrogen and carbon dioxide can be combined over a nickel catalyst to form methane. This, however, is a very inefficient method of methane production since the efficiency is around 50 - 60 % when accounting for the electrolysis of water to hydrogen.

3. Theory

Maintenance costs, as defined by normal plant accounting procedures, normally comprise a major portion of the total operating costs in most plants. On average, a third of these costs are wasted through ineffective maintenance management methods. (Mobley, 2004)

As (Mobley, 2004) states, industrial and process plants usually utilize only two types of maintenance management: run-to-failure, or preventive maintenance.

3.1 Run-to-failure

Since the Industrial Revolution, the term run-to-failure has been used a lot, this means that run-to-failure management is simple and straight forward. When a machine or equipment breaks, fix it.

When using the run-to-failure management philosophy, you do not spend any money on maintenance before the system or equipment fails and cannot be operated. Run-to-failure is a so-called reactive management technique, meaning no maintenance until necessary due to machine failure. This is, however, quite an expensive type of maintenance management; it needs large quantities of spare parts in your inventory and, in case of a machine failure, high labour costs and long machine downtimes, which results in low production availability. (Mobley, 2004)

The result is always the same: run-to-failure does always come with a higher cost, even by performing basic preventive tasks, such as lubrication, tension adjustments and cleaning of components. There are not many companies that utilize a true Run-to-failure management philosophy, meaning that they do not perform any preventive maintenance at all.

3.2 Preventive maintenance

Preventive maintenance comes by many definitions, but all preventive maintenance management programs or philosophies are time-driven, meaning the maintenance tasks are based on hours of operation. This can be illustrated with a so-called bathtub curve or the mean time to failure (MTTF).

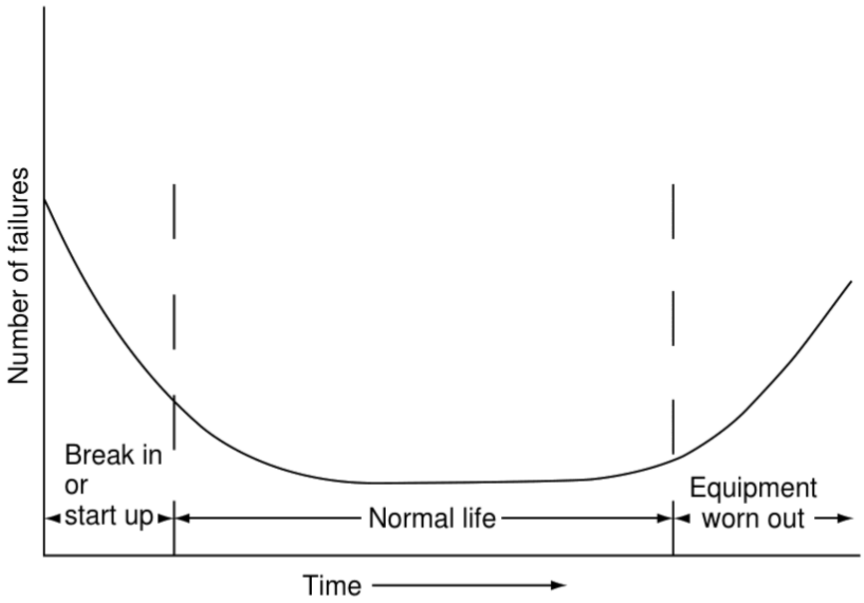

Figure 10. Bathtub curve (Mobley, 2004)

It can be seen by the bathtub curve, that there is a high probability of failure during the first weeks of start-up due to possible installation problems but remains relatively low for the expected lifetime of the equipment, gradually increasing over time. MTTF statistics are the basis of equipment repairs and scheduled rebuilds that most preventive maintenance management systems use.

Every type of preventive maintenance program has one thing in common: machines or equipment will degrade over time. By using scheduled guidelines with the known lifetimes of components, failure of components is easily avoided by scheduling maintenance in advance when the component is reaching its end of its lifespan. (Mobley, 2004)

3.3 Total productive maintenance

TPM originated from the introduction of preventive maintenance that was introduced in Japan in the early 1950s. Japan Institute of Plant Maintenance pioneered the development of maintenance management, and the management system was later perfected by the Japanese car and technology companies. (McCarthy & Nick, 2004)

Total productive maintenance (TPM) is an initiative for optimizing the reliability and effectiveness of manufacturing equipment. TPM is team-based, proactive maintenance and requires total participation by all employees, from top management to the shop floor. TPM addresses the entire production system lifecycle and builds a solid, shop floor-based system to prevent all losses due to failure. TPM objectives include the elimination of all accidents, defects, and breakdowns.

The characteristics of TPM are that it is not a short-lived, problem-solving, maintenance cost-reduction program that solves all problems without any downsides. It is a permanent corporate culture-changing process that improves and maintains the overall effectiveness of systems and equipment by utilizing the active involvement of operators and all other organization members. Each team of participants has their own objectives and parts to play, with safety as a cornerstone.

3.4 Maintenance matrix

By combining these maintenance philosophies with the manufacturer’s recommendations, we can compile simple and straightforward preventive maintenance matrices. In a perfect world everybody knows that planning and scheduling maintenance prior to failure of the machine or equipment reduces downtime and money.

When using standard and reliable machines and equipment, the machines and equipment have known lifetimes. This makes it easy to define service and component exchange intervals in a matrix format.

4. Method

The method of research has been analysing the existing documents of the LNGPac equipment and gathering new information and manuals from equipment suppliers. The main method of research is based on equipment related information gathered from suppliers to make the guidelines product specific and to support the statements from the suppliers with academic research.

The theory used must contain installation and maintenance fundamentals of the four main types of equipment that have been included in these guidelines. All theory and equipment information must be in accordance with the standards and regulations used at Wärtsilä. The main regulation that the design of the LNGPac is based on is the IGF Code.

5. Results, equipment guidelines

Separate guidelines have been produced for four different equipment used in Wärtsilä LNGPac, all original guidelines are listed in the appendices.

Here, they are presented in a very discrete form.

5.1 Valve installation and maintenance guideline

This is a general guideline for the installation and maintenance of different valve types that are being used in LNGPac (Appendix A) containing the following:

- **General installation guides:**

  This chapter of the guideline contains installation instructions for valves that do not have separate or individual installation instructions, i.e., dummies or temporarily used valves. It also contains instructions and preparation for welding of both globe valves and check valves, followed by a brief explanation of different ways to perform pressure and leak tests of the cryogenic and non-cryogenic valves.

  The important part of this section of the guideline is the space requirements for installation and maintenance of the valves. Presenting figures displaying minimum distance and space required for dismantling and installation of globe/ball valves and butterfly valves.

- **Installation of shut-off valves:**

  This chapter is split into two categories: cryogenic valves handling LNG and valves controlling NG and other gases (e.g., N_2, dry air).

  The main difference between these two types of valves is the inclination of the cryogenic valve must not exceed an angle of 45° from a vertical position. By not having the stem past an angle of 45°, it is made sure that no LNG can be trapped in the valves.

  Non-cryogenic valves that only handle gases can be installed with an inclination of up to 65° from the vertical position. In special occasions and if there is no other way to solve the space requirement issue, they can be installed with the stem horizontally if it is made sure that no crucial torque and stress is applied to the valve body and its connections.

- **Installation of check valves:**

  The rules for shut-off valves apply to the check valves as well, but the inclination of check valves should never exceed 45° from the vertical position whether it is a cryogenic or a non-cryogenic valve.

- **Installation of safety valves:**

  This chapter explains the fundamentals of safety valve installation, i.e., instructions on how to prepare the pipelines prior to installation and the importance of cleanliness of the tools, pipelines or equipment that is being installed when handling the most crucial component in the matter of safety, the safety valve. The safety valve prevents the system from damage if the process or equipment in the LNGPac malfunctions and proceeds to gain unwanted pressure.

  It also covers the space required for mounting and dismantling of the safety valves for maintenance.

- **Valve maintenance and inspections:**

  This chapter contains the two different types of leak testing: external leak testing and internal leak testing.

  It also consists of a maintenance matrix for valves used in LNGPac.

5.2 Evaporator installation and maintenance guideline.

A guideline containing installation and maintenance instructions for evaporators and heat exchangers used in Wärtsilä LNGPac (Appendix B) containing the following chapters:

- **General installation guides:**

  This chapter of the guideline contains general instructions on how to install the evaporators and heat exchangers used in Wärtsilä LNGPac, including information such as space requirements, clearance for maintenance and visual inspections.

- **Installation of the evaporator/heat exchanger:**

  This chapter contains instructions on how to install the two types of evaporators that Wärtsilä LNGPac uses. The two types are:

  - Plate & shell
  - Shell & tube

  The chapter also contains space requirements for installation and maintenance, pipe routing requirements, and preventive actions to be considered prior to installation.

- **Maintenance of the evaporator/heat exchanger**

  This chapter of the guideline contains the maintenance part of the evaporators/heat exchangers. Consists of planned cleaning procedures, troubleshooting, periodical inspections, and periodical maintenance.

  The periodical inspections and periodical maintenance are listed in a matrix, with an interval ranging between six months to ten years.

5.3 LNG pump installation and maintenance guideline.

A guideline containing the essential instructions for installation and maintenance of the LNG fuel pumps used in Wärtsilä LNGPac. (Appendix C)

- **General installation guides:**

  The usage of three different types of LNG pumps makes the general installation guide quite brief, the major differences in appearance and design of the different types of LNG pumps makes the installation procedures so different compared to each other.

- **Installation of LNG pumps:**

  LNG fuel pumps are crucial components and shall always be installed according to the manufacturer’s installation instructions, but this guideline is also to be taken into consideration prior to installation.

- **Maintenance of LNG fuel pumps:**

  The maintenance intervals of the LNG pumps are listed in a matrix with intervals ranging between annual to ten years. The matrix includes all types of LNG pumps used in Wärtsilä LNGPac.

5.4 Heating medium pump installation and maintenance guideline.

This guideline contains the necessary instructions for the installation and maintenance of the heating medium pumps used in LNGPac. (Appendix D)

- **General installation guides:**

  This chapter of the guideline contains necessary checks to be done prior to installation, space requirements for installation and maintenance.

- **Installation of heating medium pumps:**

  This chapter emphasizes the usage of the manufacturer's installation instructions to ensure you get the expected lifetime out of the circulation pumps.

- **Maintenance of the pumps:**

  A matrix consisting of the maintenance intervals has been produced to list all points of maintenance needed for the heating medium pumps. The heating medium pumps are almost maintenance free, requiring only bearing lubrication but crave visual inspections quite often.

6. Conclusion

The theory for the guidelines follows the preventive maintenance principles, crosschecking the manufacturer's installation and maintenance guides with academic installation and maintenance theory.

In conclusion, the goal of this thesis was to compile several guidelines to minimize the issue with insufficient space to install and maintain the components used in the LNGPac, these guidelines will help a lot during the production phase.

The critical components are evaporators and cryogenic valves, which must be taken into consideration during installation to ensure that they can be repaired or replaced without any major issues. From an engineering point of view, I can say that we have eliminated the worst issues regarding space insufficiency with the LNGPac equipment and components.

7. Discussion

It has been a very interesting topic to write about; I have gotten a deep dive into the world of installation and maintenance of different types of equipment and components. This is a topic that hits very close to home due to my earlier experience in the plumbing and HVAC industry.

I am very familiar with the practical part of installation and maintenance, so I have been very glad to take part in the theory behind these guidelines that I have accomplished, it feels like I have grown both academically and personally from this thesis.

A further development of these guidelines would be a 3D-modeling tool of space requirements for each component that can be used in the design phase of the LNGPac. This is something we already discussed in the early stages of the thesis content planning, but we concluded that it would take a massive amount of time to develop an automated function for space requirement modelling in, e.g., Siemens NX or Autodesk's Inventor and Navisworks.

But as the components are getting more standardized over the years, the possibility to develop this kind of modelling tool would be quite straightforward, if we still use the same manufacturers of the equipment and components that we are using today.

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Appendix A

1. Introduction

LNGPac is a complete fuel system for LNG fuelled ships, consisting of bunkering station, storage tank (IMO type C) and gas feed system to the engines. This document is a guideline on how to install and maintain the valves needed to control the process.

2. General installation guides

All valves shall be installed in such a way that they are easily accessed and not interfering with anything close by the valves. The valves shall be installed with enough clearance for maintenance and visual inspection.

One of the most important steps is the cleanliness of the valves prior/during the installation. All dirt left in the components will eventually flow somewhere in the system and potentially cause damage to valves or other critical equipment that is used to control the process.

When installing the valves ensure the following:

- Pay attention to the arrow showing the flow direction to ensure correct orientation of the valve.
- Butterfly valves to be installed in preferred flow direction to assure best sealing and lower torques when the differential pressure is applied on the shaft side of the disc.
- Remove protective caps or covers before mounting.
- Use only clean and suitable tools when mounting.
- Connect pipelines in a force-free and torque-free manner.
- Always use suitable transport and lifting equipment for the mounting.
- The valve must be protected against dirt and damage during construction work.
- Tighten flange bolts according to recognized standards and Wärtsilä guidelines.
- All welding of valves to be done with approved welding procedure specifications (WPS).

General instructions before welding of globe valves and check valves.

Only to be used if there are no available installation instructions from the supplier or manufacturer.

- Loosen and remove the bolts holding the bonnet to the body (globe valve must be in a fully open position).
- Remove bonnet and seal.
- The used seal shall be disposed.
- Protect valve body from welding beads, scale and other contaminations.
- Weld the body into place.
- Insert a new seal.
- Mount the bonnet and **be careful not to damage the seal!**
- Mount the bolts and tighten them to specified tightening torque in a criss-cross pattern.

After valves has been welded, pressure test to be performed.

- Pressure test always to be performed according to specified procedure, never to exceed 1.5 times the design pressure.

Butterfly valves not to be tested with water, test according to specific procedure.

Pressure test and leak test of cryogenic butterfly valves are to be done with nitrogen or other suitable medium e.g. dry air, using water or other fluids as a medium for butterfly valve pressure/leak test may cause damage to the valves packing and seat.

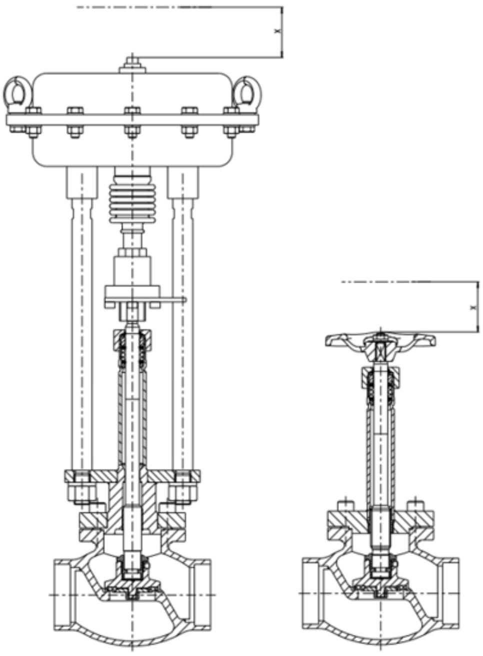
General information about space requirements for installation and maintenance.

Figure 1 and 2 is showing the general space requirements for installation and maintenance of globe/ball valves and butterfly valves.

It is important to respect the space needed for maintenance; unnecessary work can be avoided if the system is designed correctly with enough clearance to the valves. Ensure there is enough space around the valves installed position to allow the removal and refit of the headwork/valve.

The clearance required at the bottom of the valve is equal to the space required above it.

Minimum distance X, space needed to dismantle the valve.



Maintenance space	
DN	X
10	100
15	100
20	100
25	100
40	120
50	120
65	150
80	170
100	180
150	230
200	280

Figure 1. Space requirements for installation and maintenance of globe valves.

Minimum space requirements for butterfly valves.

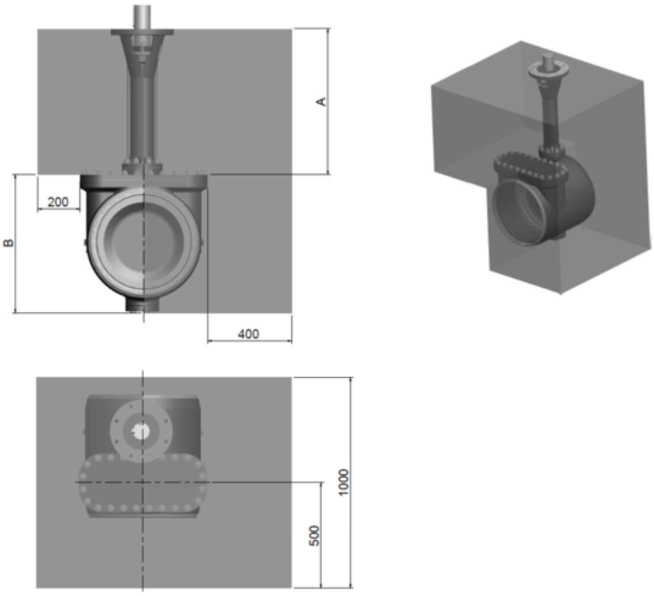


Figure 2. Space requirements for installation and maintenance of butterfly valves.

3. Installation of shut-off valves

Always ensure enough maintenance space for the shut-off valves before installing.

For valves controlling LNG:

Valves controlling LNG may never be mounted with an inclination past 45° due to risk of LNG getting trapped.

When mounting the shut-off valve ≤ DN150 in a horizontal pipeline, an inclination of up to 45° from the vertical is possible.

When mounting the shut-off valve ≥ DN200 in a horizontal pipeline, a vertical position of the stem is recommended but an inclination of up to 45° from the vertical is possible.

Installing large actuated valves in an inclination causes unnecessary stress to the valve body and connections due to the torque caused by the weight and angle of the actuator.

For valves controlling NG and other gases (e.g. N_2):

An exception to the inclination up to 45° rule can be made when the valves are controlling gas in systems which are not in contact or do not handle liquified gases.

In special occasions, an inclination up to 65° is possible. It must be assured that the inclination does not affect operation capability of the valve.

4. Installation of check valves

Check-valves handling LNG may never be mounted with an inclination past 45° due to risk of LNG getting trapped.

If available, use manufacturers installation instructions before welding the check valve, if there are no instructions available use the general installation guide.

When mounting the check valve ≤ DN150 in a horizontal pipeline, an inclination of up to 45° from the vertical is possible.

When mounting the check valve ≥ DN200 in a horizontal pipeline, a vertical position of the closing body is preferred but an inclination of up to 45° from the vertical position is accepted.

5. Installation of safety valve

Pipe system leak test should not exceed 35 % of design pressure.

Safety valves to be removed or blinded during pipe system pressure test.

Connect pipelines in a force-free and torque-free manner.

Follow manufacturers guidelines when installing safety valves.

If the safety valve is fitted with a handle there needs to be space for operating it.

Before installation of the safety valve, inspect and make sure that no foreign matter e.g. desiccant agents, rust, spatters and slag has entered the safety valve.

Protective caps/sheets shall be kept on the safety valve until mounting, minimizing the risk of exposure to foreign objects.

Remember to remove protective caps/sheets before installation of the safety valve.

Make sure that the safety valve can be mounted and dismounted after installation, general rule of space required height wise for Leser safety valves used in LNGPac is the height of the safety valve + 200 mm ensuring that the safety valve can be removed without any issues.

Make sure that the safety valve can be mounted and dismounted after installation, general rule of space required height wise for Fukui safety valves used in LNGPac is the height of the safety valve + 300 mm ensuring that the safety valve can be removed without any issues.

Space requirements around the safety valve is by the general rule, the radius from the centre of the inlet flange to the outlet flange ensuring that the safety valve can rotate freely without interfering any piping or components around.

6. Valve maintenance and inspections

Leak tests are done at operating pressure of the system.

- External leak testing is done with the valve in in open position and pipe pressurized to operating pressure. All connections and stem sealings to be checked for leaks using leak detection spray. No visible leaks (bubbles) allowed.
- Internal leak testing is done according to a system specific procedure. It is done so that the piping is pressurized one section at the time and pressure is monitored and noted. After one section is tested the valves are opened and the next group of valves are to be tested and monitored repeatedly until all valves are tested.

The two commonly used standards for allowed leakage over the seat of cryogenic valves are the following.

- BS6364: Allowed leak rate is $100\, mm^3/s \times DN$
  e.g. Cryogenic DN300 valve: $100\, mm^3/s \times 300 = 30\,000\, mm^3/s = 1800\, ml/min.$
- API 527: As per table below.

Acceptance Criteria per API 527 = Leakage Rate in Bubbles per minute
for Testing with Air

- Soft Seat = 0 Bubble per minute (no leakage)
- Metal Seat = Not exceed leakage rate in Table

Set Pressure at 15.6 °C (60 °F) MPa (psig)	*Orifice Diameter ≤ 18 mm (0.7 in)* Leakage Rate (Bubbles /min)	*Orifice Diameter > 18 mm (0.7 in)* Leakage Rate (Bubbles /min)
0.013 – 6.896 (15 – 1000)	40	20
10.3 (1500)	60	30
13.8 (2000)	80	40
17.2 (2500)	100	50
20.7 (3000)	100	60
27.6 (4000)	100	80
34.4 (5000)	100	100
41.4 (6000)	100	100

Table 1. API 527, Leakage rates

Minimum requirements for valve maintenance intervals listed in the table below.

Table of inspection and maintenance intervals for valves used in LNGPac.

	During start-up	Every 3 months	Annually	2 years	5 years	10 years
Correspondence to - Design drawing - Specifications - Type approval - Marking	X	-	-	-	-	-
Suitability	X	-	-	-	-	-
Visual inspection	X	-	X	X	X	X
Correspondence to technical data	X	X	X	X	X	X
Leak-tightness - valve external - valve internal	X	-	X	X	X	X
Opening and closing of the valve	X	X	X	X	X	X
Static pressure test with clean water or other suitable liquid.	-	-	-	-	-	X
Visual inspection of the system component for cracks, inadmissible changes in shape or leak.	-	-	-	-	-	X
Functional test of ESD valves	X	X	-	-	-	-

Table 2. Table of inspection and maintenance intervals for valves.

Appendix B

1. Introduction

LNGPac is a complete fuel system for LNG fuelled ships, consisting of bunkering station, storage tank (IMO type C) and gas feed system to the engines. This document is a guideline on how to install the evaporators used in the process.

2. General installation guides

Evaporators shall be installed in such a way that they are easily accessed and not interfering with anything close by them. The evaporator shall be installed with enough clearance for maintenance and visual inspection.

- The evaporator shall have a free path through the TCS and hatches to ensure the possibility to replace the evaporator.
- Pay attention to the arrow or indicator showing the flow direction.
- Remove protective caps or covers before mounting.
- Use only clean and suitable tools when mounting.
- Connect pipelines in a force-free and torque-free manner.
- All piping connected to the evaporator shall be carefully designed in order not to transmit any stresses or forces to the system during operation or stand still.
- The temperature contractions and elongations must be taken into consideration before mounting the evaporator.
- Always use suitable transport and lifting equipment for the mounting.
- The evaporator must be checked prior to installation, making sure no dirt or moisture has gathered on the inside of the evaporator. It is important that the evaporator is completely dry and free of dirt.
- The evaporator must be protected against dirt and damage during construction work.

3. Installation of the evaporator/heat exchanger

Enough clearance must be provided around the evaporator body to ensure the possibility to perform maintenance of the evaporator and surrounding equipment such as safety valves, shut-off valves, instrumentation, etc.

The evaporators shall be installed in such a way that they are possible to be dismantled and removed through the hatch of the TCS, this means a clear path between the installation location and the hatch. Enough clearance shall be provided to ensure the possibility of hoisting the evaporator out of its position.

If a heating media pipe system is routed above or around the evaporator it must be connected by flanges so it can be dismantled to free up space for the evaporator.

The evaporator and the piping connected to the evaporator shall be installed in such a way that it can easily be drained.

Ensure that all connections are marked and connected according to the GA drawing provided by the manufacturer.

All pipe connections (i.e. inlets/outlets) of the evaporator must be equipped with shut-off valves.

All piping connecting to the evaporator shall be flushed prior to installation.

Before connecting any piping, make sure all foreign objects have been flushed out of the piping system that should be connected to the heat exchanger.

4. Maintenance of the evaporator/heat exchanger

If CIP is planned for heating media side additional connections for cleaning medium circulation needs to be added as well as isolation valves upstream and downstream of the unit.

Always follow manufacturer's instructions regarding maintenance of the evaporators and heat exchangers. Each manufacturer has their own procedure of evaporator and heat exchanger cleaning which needs to be followed.

If a decrease in performance or a distinguishable pressure drop is noticed, the evaporator/heat exchanger must be cleaned either by chemical or mechanical methods. Leaving the evaporator uncleaned may lead unnecessary wear on the heat transfer surfaces on the tubes, leading to partially blocked tubing causing either overcooling or overheating. This may cause leaking joints, fractured tubing or damage the sealings of the evaporator.

Periodical inspections for evaporators and heat exchangers.

<u>Plate & Shell</u>

Recommended periodical inspections of Plate & Shell heat exchangers:				
	Every 6 months	Every 2.5 years	Every 5 years	Every 10 years
Visual inspection of the heat exchanger, to be checked for leaks and external deviations in shell structure.	X			
External inspection of the evaporator/heat exchanger.		X		
Internal inspection of shell chamber with endoscope for rust, cracks and debris.			X	
Pressure test.			X	
Internal pressure test.				X

Shell & Tube

Recommended periodical inspections for Shell & Tube heat exchangers:				
	Every 6 months	Every 2.5 years	Every 5 years	Every 10 years
Visual inspection of the heat exchanger, to be checked for leaks and external deviations in shell structure.	X			
Chemical or mechanical cleaning of the evaporator		X		
Internal inspection of shell chamber with endoscope for rust, cracks and debris.			X	
Pressure test.			X	
Internal pressure test.				X

Appendix C

1. Introduction

LNGPac is a complete fuel system for LNG fuelled ships, consisting of bunkering station, storage tank (IMO type C) and gas feed system to the engines. This document is a guideline on how to install the LNG pumps used in the process.

2. General installation guides

Before installation it must be assured that:

- Length is correct according to installation drawing.
- The dome gasket is put on the dome flange before the pump is positioned in the tank.
- Manufacturers lifting instructions that has been provided in their manual to be strictly followed.

LNG pump shall be installed in such a way that they are easily accessed and not interfering with anything close by them. The LNG pump shall be installed with enough clearance for maintenance and visual inspection.

- Pay attention to the arrow or indicator showing the flow direction.
- Remove protective caps or covers before mounting.
- Use only clean and suitable tools when mounting.
- Connect pipelines in a force-free and torque-free manner.
- Always use suitable transport and lifting equipment for the mounting.
- The pump must be protected against dirt and damage during construction work.

3. Installation of LNG pumps

Enough clearance must be provided around the LNG pump to ensure the possibility to perform maintenance of the pump and surrounding equipment such as safety valves, shut-off valves, instrumentation, etc.

Ensure that all connections are marked and connected according to the GA drawing provided by the manufacturer.

All piping connecting to the LNG pump shall be flushed prior to installation.

4. Maintenance of the pump

If any sensor causes an alarm or a warning, it is crucial that the cause is investigated. In case of a faulty sensor, it must be replaced accordingly.

Service and maintenance			
Inspection	Annually	5 years (25,000 hrs)	10 years (50,000 hrs)
Inspection of the lube oil level through the inspection glasses.	X	X	X
Check for vibrations or abnormal noises.	X	X	X
Integrity and tightness of all the connections (screws, bolts, etc).	X	X	X
Visual inspection of leakages from sealing elements.	X	X	X
Disassemble base arrangement to perform visual inspection.	-	-	X
Disassemble intermediate pipe/drive shaft to perform visual inspection.	-	-	X
Disassemble pump cylinder and do the visual inspection.	-	-	X
Renew all gaskets and O-rings.	-	-	X
Replace wear rings.	-	-	X
Replace all carbon bearings.	-	-	X
Replace static seal.	-	-	X
Replace main bearing arrangement.	-	-	X
Replace canister.	-	-	X

Replace oil filter.	-	-	X
Replace lubricating oil.	-	-	X

Appendix D

1. Introduction

LNGPac is a complete fuel system for LNG fuelled ships, consisting of bunkering station, storage tank (IMO type C) and gas feed system to the engines. This document is a guideline on how to install the heating media pumps used in LNGPac.

2. General installation guides

Before installation it must be assured that:

- Pipes connecting to the pump are carefully cleaned.
- Check that the motor bearings are greased.

Heating media pumps shall be installed in such a way that they are easily accessed and not interfering with anything close by them. The heating media pump shall be installed with enough clearance for maintenance and visual inspection.

- Pay attention to the arrow or indicator showing the direction of rotation and install it accordingly.
- Remove protective caps or covers before mounting.
- Use only clean and suitable tools when mounting.
- Connect pipelines in a force-free and torque-free manner.
- Always use suitable transport and lifting equipment for the mounting.
- The pump must be protected against dirt and damage during construction work.

3. Installation of heating media pumps

Always use manufacturers installation instructions when installing the heating media pumps.

Enough clearance must be provided around the heating media pump to ensure the possibility to perform maintenance of the pump and surrounding equipment such as safety valves, shut-off valves, instrumentation, etc.

All piping connecting to the heating media pump shall be flushed prior to installation.

Ensure that connections are aligned before installing.

Make sure that bearings are greased before start-up.

4. Maintenance of the pump

If any sensor causes an alarm or a warning, it is crucial that the cause is investigated. In case of a faulty sensor, it must be replaced accordingly.

The lubricant of the ball bearings must be of high-quality lithium grease.

Ball bearings shall be lubricated after the first 1000 operation hours.

Service and maintenance				
Inspection	Every 3 months	Annually	Every 4,000 hrs	Every 8,000 hrs
Lubricate ball bearings	-	X	X	X
Check for vibrations or abnormal noises.	X	X	X	X
Integrity and tightness of all the connections (screws, bolts, etc).	X	X	X	X
Visual inspection of leakages from sealing elements.	X	X	X	X
Check the condition of shaft seals.	X	X	X	X
Check suction and discharge pressure.	X	X	X	X
Internal inspection of the pump.	-	-	X	-