YRKESHÖGSKOLAN NOVIA

Improvement of Vacuum Monitoring Systems

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DEGREE THESIS

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Abstract

This thesis was written for the Fuel Gas Supply Systems department at Wärtsilä. The purpose of this thesis was to do a comprehensive review of the vacuum monitoring skid and its equipment. The objectives include investigating rules and regulations set by De Norske Veritas (DNV) and exploring alternative vacuum valve options.

Relevant theory regarding liquefied natural gas and hazards with the gas, Insulation type, heat transfer, vacuum, vacuum heat transfer, humidity effect on vacuum, valves, International Marit Time and their IGF code, Classifications societies, classification society De Norske veritas and their rules for the equipment relevant to the thesis. At last, is the functionality and purpose of the Vacuum monitoring skid presented.

The result contains five different suppliers' offers, a review of the equipment, the acceptable vacuum grade, and a clarification of the rules from De Norske Veritas.

From the result, better alternatives of vacuum valves are found, and the plan is to start flushing the annular space before pumping the vacuum to reduce humidity and pump-down time.

Language: english
Key Words: vacuum, insulation, valve, DNV, Fuel Gas Supply Systems, Wärtsilä

EXAMENSARBETE

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Abstrakt

Detta examensarbete är gjort på uppdrag av avdelningen Fuel Gas Supply Systems vid Wärtsilä. Syftet med examensarbetet var att genomföra en omfattande undersökning av Vacuum Monitoring Skid och dess tillhörande komponenter. En undersökning av regler och föreskrifter fastställda av De Norske Vertias (DNV) på komponenterna, samt hitta ett nytt alternativ av vakuumventil.

Relevant teori om flytande naturgas och dess faror den medbär, isoleringstyper, värmeöverföring, vakuum, vakuumvärmeöverföring och fukt, ventiler, International Maritime och deras IGF-kod, klassificeringsällskap, klassificeringsällskapet De Norske Veritas och deras regler för utrustningen som är relevant för examensarbetet. Slutligen presenteras funktionen och syftet med Vacuum Monitoring Skid.

Resultatet innehåller offerter från fem olika leverantörer, en sammanfattning av utrustningen, den acceptabla vakuum nivån samt en förklaring av reglerna från De Norske Veritas.

Från resultatet har bättre alternativ av vakuumventiler hittats, och planen är att börja spola det annulära utrymmet innan vakuumpumpningen för att minska fuktigheten och pumpningstiden.

Språk: engelska
Nyckelord: vakuum, isolering, ventil, DNV, Fuel Gas Supply Systems, Wärtsilä

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Tiivistelmä

Tämä opinnäytetyö on laadittu Wärtsilän Fuel Gas Supply Systems osastolle. Opinnäytetyön tarkoituksena oli tehdä perusteellinen katsaus Vacuum Monitoring Skid ja sen varusteiden osalta. Tavoitteisiin kuului tutkinta De Norske Veritasin (DNV) asettamista säännöistä ja määräyksistä sekä vaihtoehtoisten tyhjiöventtiilivaihtoehtojen tutkiminen.

Asiaankuuluvaa teoriaa koskien nesteytettyä maakaasua ja sen vaaroja, eristyksen tyyppiä, lämmönsiirtoa, vakuumia, vakuumilämmönsiirtoa ja kosteutta, venttiilejä, Kansainvälistä merenkulkua ja heidän IGF-koodiaan, luokitusyhteisöjä, luokitusyhteisöä De Norske Veritasta ja heidän laitteeseen liittyviä sääntöjään, jotka ovat relevantteja opinnäytetyölle. Lopuksi esitellään Vacuum Monitoring Skid toiminnallisuus ja tarkoitus.

Tuloksena on viiden eri toimittajan tarjouksia, laitteiston arviointi, hyväksyttävä tyhjiön taso ja selvitys De Norske Veritasin säännöistä.

Tulosten perusteella paranneltu tyhjiöventtiili on löydetty, ja suunnitelmana on aloittaa renkaan tilan huuhtelu ennen tyhjiöpumpun käynnistämistä kosteuden ja pumpun alasoton ajan vähentämiseksi.

Kieli: englanti
Avainsanat: tyhjiö, eritys, venttiili, DNV, Fuel Gas Supply Systems, Wärtsilä

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1 Introduction

This thesis is written on behalf of Fuel Gas Supply Systems at Wärtsilä. The thesis work started in the autumn of 2023 and was finished in spring 2024.

In the introduction, I will go through the background, purpose, goal, limitation, and disposition.

1.1 Background

Wärtsilä Fuel Gas Supply Systems typically operates with a vacuum as insulation for double-wall pipes and double-shell tanks. It is mandatory to have double-walled pipe on pipes below deck and located outside of the Tank Connection Space (TCS) to prevent the formation of a hazardous zone. Vacuum-insulated double-walled pipes are used for Liquid natural gas pipelines, not necessarily all types of double-walled pipes.

Several factors drive Wärtsilä's choice of vacuum insulation. Vacuum insulation offers many advantages, such as extremely low thermal conductivity, longer lifespan than other insulation, low maintenance, and easy detection of leaks. Despite these benefits, vacuum insulation requires valves, pressure sensors, and piping, which is very expensive compared to other insulation.

The primary motivation behind this investigation comes from several challenges faced by Wärtsilä with vacuum insulation. The vacuum pump-down time is long, creating operational inefficiencies and uncertainty surrounding class society rules. Additionally, the stability and clarity of the vacuum grade remain uncertain. Addressing these issues is crucial for optimizing the efficiency of Wärtsilä's Fuel Gas Supply Systems.

1.2 Purpose

The purpose of this thesis is to do an overall review of the existing design of the vacuum monitoring skid, with a special focus on finding a better alternative to the vacuum valve that is used for pumping the vacuum. Investigate class requirements for the equipment. Additionally, define system criteria for pipe preservation and vacuum grade.

1.3 Limitation

This thesis is specifically limited to the examination of vacuum-insulated double-walled pipes and their associated equipment, with the exclusion of the vacuum insulation double-shell tanks. The focus is on the equipment supplied as both skid and loose items, with the shipyard responsible for installation, excluding vacuum pumps.

The investigation for society rules is limited to DNV (Det Norske Veritas) and their rules for double-walled pipes and the equipment mounted on the skid, excluding regulations from other class societies. These limitations serve to narrow the scope of the study and to provide a more focused investigation of selected components.

1.4 Disposition

Introduction, the reader gets a small overview of what the thesis will contain. Background, purpose, goal, and limitation are discussed. Additionally, a brief introduction of Wärtsilä, their businesses, and the department this thesis is written for.

The second chapter presents the theoretical and technical theory. The purpose of this chapter is to give the reader information relevant to the subject of this thesis.

The third chapter describes the methods that have been used together with the theory to produce a result.

The fourth chapter will present the results, including the price and bore composition of each supplier, a review of the skid equipment, and the acceptable vacuum grade.

In the fifth chapter will the results be discussed. Different suppliers' offers, how to improve the vacuum pump downtime, and the vacuum grade are discussed.

1.5 Wärtsilä

Wärtsilä was founded in 1834 as a sawmill company. Now almost 200 years later Wärtsilä has developed and become a leading power source provider in the marine and energy market with 17500 employees in more than 240 locations in 79 countries. Their net sale in 2022 was 5.8 billion EUR.

Wärtsilä is a global leader in innovative technologies and lifecycle solutions for the marine and energy markets. Wärtsilä emphasizes innovation in sustainable technology and services for customers to improve their environmental and economic performance. (Wärtsilä, 2023)

1.6 Wärtsilä business

Within Wärtsilä there are three businesses: Energy, Marine, and Portfolio.

Energy aids customers in decarbonization by developing market-leading technologies. These cover future fuel-enabled balancing power plants, hybrid solutions, energy storage, and optimization technology.

Marine has a broad portfolio of engines, digital technologies, propulsion systems, hybrid technology, and integrated powertrain systems to deliver efficiency. Reliability, safety, and environmental performance are needed for customers. Marine also supports customers with lifecycle services related to exhaust treatment, shaft line, and underwater repair

The Portfolio Business unit operates autonomously, aiming to boost performance and unlock value through strategic alternatives such as divestments. The current portfolio includes Automation, Navigation & Control Systems, Marine Electrical Systems, and Water & Waste. (Wärtsilä, 2024)

1.7 Fuel Gas Supply Systems

This thesis centers around the Fuel Gas Supply Systems (FGSS) department within the Marine Power Business at Wärtsilä. Established in 2013, FGSS is a lucrative and expanding business line. The success is driven by the growing demand for environmentally sustainable, efficient, and flexible products. Specializing in tailor-made or standard LNG systems for any ship type, which is then integrated with the rest of the Wärtsilä portfolio.

FGSS offers LNGPac™, which includes modules such as LNG tank storage, bunker stations, process equipment, control, and monitoring systems (Figur 1). Additionally, FGSS offers Gas Valve Units, AmmoniaPac, and MethanolPac, with the latter gaining significant traction, especially in high natural gas prices. (Wärtsilä LNGPac)

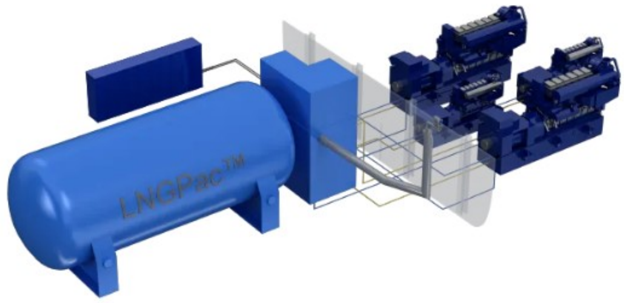

Figure 1. LNGPac

2 Theory

In this chapter, the following will be presented: a theoretical background of natural gas, explaining the transformation from natural gas into liquefied natural gas and the advantages of the gas in a liquefied state, examining the associated hazards with liquefied natural gas, which types of insulation type are used, and which heat transfers the insulation is affected by, particularly focused on heat transfer in vacuum-insulation double-walled pipes. General information about valves, such as where and what purpose they serve, and more specific information about relevant valves for this thesis. In the second part will the technical background be presented, with brief information about International maritime organizations, a summary of the purpose of the IGF codes, and their rules for ships using LNG as fuel, class societies' rules and regulations for vacuum insulation, double-walled pipes, and equipment mounted on the skid.

Lastly, the vacuum monitoring skid is presented. The skid in itself and the purpose are described as well as equipment mounted on the skid, types of leakage that can occur, and what happens in the skid in the event of a leakage.

2.1 Natural gas

Natural gas, commonly referred to as NG, is a fossil fuel energy source. Natural gas contains many compounds. The largest component is methane, a compound with one carbon atom and four hydrogen atoms. Natural gas also contains small amounts of natural gas liquids, which are hydrocarbon gas and nonhydrocarbon gases, such as carbon dioxide and water vapor. (eia, 2022).

2.1.1 Liquefied natural gas

Liquid natural gas, or LNG, is natural gas that has been cooled to -165 °C, transforming it into a liquid state. In this state, the volume is about 600 times smaller than its gaseous state. The liquefaction process was developed in the 19th century and made it possible to transport natural gas to places pipelines don't reach and to utilize it as a transportation fuel. This advancement has also enhanced the flexibility and accessibility of natural gas as an energy source, which made LNG a vital component in the global energy market.

LNG can be transported either via pipelines or LNG carrier vessels. LNG pipeline infrastructure takes the LNG between liquefaction facilities and storage facilities, while the vessel transports it worldwide in tanks. (eia.gov, 2022)

2.1.2 Hazards with LNG

LNG is completely non-toxic and has a strong safety record for all common types of fuel. LNG is still hazardous. If spilled on the ground, it will boil rapidly and create a vapor cloud. The methane vapor will condense water vapor in the air, making the cloud visible. It stays close to the ground until it warms up, rises, and dissipates. The vapor cloud can be ignited, but only in an air-to-fuel proportion of 5-15%. Below 5%, the mix to lean to burn, and above 15%, the mix is too rich to burn. The auto-ignition temperature of methane is 540°C, which is significantly higher than gasoline at 257°C or diesel at 315°C. (Dodge, 2014)

Other potential hazards of an LNG spill include Boiling liquid expanding vapor explosion that occurs from rapid vaporization due to container failure. If LNG is spilled inside a contained area where the vapor cannot dissipate, high risk of fire if an ignition source is present. LNG is cryogenic, which can cause burns to the skin. Methane, which is odorless in LNG, can be asphyxiant in an enclosed space. When fighting a methane fire, water should not be used as it can intensify the fire. Dry chemicals must be used for firefighting. (Dodge, 2014)

2.2 Insulation and heat transfer types

Insulation is required for several reasons in LNG storage and transportation - to maintain the liquefied state, to minimize the heat influx to reduce boil-off, and to shield the surroundings from the effects of the low temperature. Insulation must possess a low thermal conductivity, the ability to withstand mechanical damage, and be unaffected by liquids or vapor (Seitov A, u.d).

2.2.1 Insulation type

Insulation material for cryogenic applications can be divided into three groups: foam, bulk-filled, and layered. These are:

Polyurethane is the most common foam insulation. Polyurethane has a thermal conductivity of around 0.02 W/m*K. The effectiveness of rigid foam can degrade over time with the high thermal expansion of the foam, which causes a tendency to crack at low temperatures.

Bulk-filled insulation requires an annular space with a vacuum, the annular space is filled with a powder that is either perlite, glass bubbles, or aerogel. Perlite is cheap, natural origin, and is the most used powder, with a thermal conductivity of 1-2 mW/m*K under vacuum pressure 0.1 Pascal. The Thermal conductivity varies based on the level of vacuum applied.

Multi-layer insulation, also known as superinsulation, offers the best thermal performance as low as 0.03 mW/m*K can be obtained in laboratory conditions. Superinsulation requires a vacuum level below 10^{-3} Pascal to be fully effective. This innovative approach involves numerous highly reflective shields strategically spaced apart by low-conductivity spacers (Lisowski, 2019).

2.2.2 Vacuum

A vacuum can be described as a space where there is no matter or where the pressure is below the surrounding atmospheric pressure and the particles are not affected by any processes ongoing in the space. Vacuum is measured in units of pressure, the pascal (Pa).

A vacuum can be created by using a vacuum pump to remove air from the space or by reducing the pressure using a fast flow of fluid. (Augustyn, 2024)

A common scheme of the vacuum range is the following: (Edwards Vacuum, u.d.)

- Low or Rough Vacuum (LV): Atmospheric to 1 mbar(a)
- Medium or Fine Vacuum (MV): 1 to 10^{-3} mbar(a)
- High Vacuum (HV): 10^{-3} to 10^{-7} mbar(a)
- Ultra High Vacuum (UHV) 10^{-7} to 10^{-12} mbar(a)
- Extreme High Vacuum (XHV) $<10^{-12}$ mbar(a)

2.2.3 Heat transfer in vacuum

In vacuum insulation, conduction heat transfer is prevented due to the absence of molecules. The lack of molecules serves as a natural barrier and effectively prevents any heat transfer through conduction. However, since a complete vacuum is impossible to achieve, there will be minimal remaining molecules, leading to a minimal degree of conduction.

Convection is also prevented because there is no heat movement in the vacuum space. If gas is present, then the gas would transport heat and convection would occur, but since a vacuum lacks all gas, heat transfer by convection cannot occur.

Radiation is the only mechanism of heat transfer that occurs even in the case of a full vacuum. Any object or material with a temperature above absolute zero emits energy in the form of radiation. The amount of energy released is dependent on its ambient temperature, but it is impossible to prevent all radiating heat loss from occurring. This can be minimized by coating the inside of the vacuum space with a highly reflective coating such as a thin layer of aluminum or stainless steel to prevent radiate heat loss as much as possible. (Wilson, 2022)

2.2.4 Humidity in vacuum insulation

Water vapor, in the form of humidity, is found in all air. The quantity may vary depending on temperature, atmospheric pressure, and the accessibility of water sources, but there will always be a certain amount present.

The presence of water vapor is the most common problem for vacuum technology. When the pump-down cycle proceeds to pressures below 10^{-3} torr, water vapor emerges as the dominant gas species among the partial pressures of the remaining gases still present in the chamber.

Any material exposed to air over some time will reach or be in the process of reaching some sort of equilibrium with the water vapor in the air. A porous material will continuously absorb water vapor until it becomes saturated. The saturated process involves two stages, a rapid saturation of the surface in the initial phase, followed by a slower stage where the water vapor slowly migrates from the surface into the bulk of the material. Each material possesses its own saturation rate and absorption mechanism.

Non-porous materials will absorb water vapor in molecular monolayers that remain on the surface. Water molecules will not only stick to the surface through weak bonds but also bond to each other with diminishing strength as the layer of sorbed molecules becomes thicker and more disordered.

A well-known and accepted procedure to produce a faster pumpdown time is to backfill the chamber with dry nitrogen. The nitrogen will sorb to the surface and provide a barrier layer to reduce the sorption of water molecules into the surface only under ultra-high vacuum where the surface is totally clean. Normally in high vacuum systems that are frequently cycled up to air, is nitrogen sorption minor because there is always a monolayer of water molecules on the surface. The faster pump-down of the vacuum is entirely traceable to nitrogen-filling virtual leak voids and barring water diffusion into those voids due to the small nitrogen-to-air interface area.

O-rings made of viton, which is the most used material used for sealing flanges, are heavily loaded with water during the manufacturing process. Because of this, the o-rings are a major source of water vapor within the chamber. The outgassing of water vapor can be done by pre-baking them under vacuum for weeks to months. (Danielson, u.d.)

2.2.5 Reducing outgassing in vacuum systems

Reducing outgassing, a process where gases or vapors are released from a material is crucial for maintaining a clean and controlled environment.

There are methods to reduce the outgassing of a material. Cleaning and handling is an effective method against gross and fine surface contamination. This method can reduce the outgassing rate anywhere from 50% to an order of five of magnitude, equivalent to a factor of 100,000 times. The cleaning process involves removing rust, grease, paint, or other gross contaminants. Removing fine contaminants such as oils, lubricants, and water. Mechanical polishing is an effective treatment for removing gross contaminants. Hydrogen can also be absorbed within the bulk of metals, which can be treated with electropolishing.

Another method for reducing outgassing is to purge and backfill the chamber with dry nitrogen. Nitrogen can effectively remove contaminations and reduce water vapor concentrations. (Leybold, 2022)

2.3 Valve

Valves are mechanical or electro-mechanical equipment that are used to control the flow of liquids, gases, and powder through pipes and tubes. Within the valve is some form of mechanical barrier such as a ball, plate, or diaphragm that can be able to change the flow of the media passing through. Some are designed to only be used as an on-off of the flow, such as gate valve and ball valve, then some valves are used for controlling the flow and pressure of passing media, such as globe valve and needle valve. (Kolstad, 2016)

2.3.1 Ball valve

A ball valve is a shut of valve that controls the flow of a media by using a rotary sphere with a bore. By rotating the ball 90 degrees, the medium can either be blocked or flow through. Ball valves are popular as shut of valves because they offer a long service and sealing life even if not being in use for a long time. (Kolstad, 2016)

Ball valves have three commonly used assembly designs:

One-piece which is the cheapest variant. The two parts enclosing the ball are welded together. The valve cannot be opened for cleaning or maintenance. Used for low-demanding applications.

Two-piece requires the valve to be completely removed from the pipe to be able to separate the two parts. The valve can be disassembled for cleaning, maintenance, and inspection.

Three piece are the most expensive assembly. The parts are clamped together by bolt connections. The advantage is that the valve can be maintained without removing the entire valve from the pipe. (Kolstad, 2016)

Ball valves have many advantages with high efficiency due to the size of the opening in the ball, with high recovery since they have a low-pressure drop and high flow capacity. Convenient usage as a result of a simple quarter-turn operation, lightweight and small. Low maintenance because the ball valve stem rotates without axial movement, which makes the valve stem to not easily wear or fail. Also depending on the assembly design, they are easy to replace or repair. The ball valve is also very robust with the ability to withstand high pressure and with a wide range of materials allowing for usage in a variety of environments.

The disadvantage with the ball valves is they are not suitable for thick liquids, which tend to clog inside the valve cavities, increasing the operating torque. (johnvalves, 2021)

Figure 2. Three pieced ball valve with butt-weld end connection

2.3.2 Pressure relief valve

A pressure relief valve is a safety device for protecting a pressurized vessel or system in case of an overpressure event. This occurs when conditions cause the pressure to exceed the designated design pressure or maximum allowable working pressure (MAWP)

Unlike other valves that require electronic or compressed air as a power source to regulate pressure, temperature, and flow, the pressure relief valve relies solely on the process fluid as its power source. So, in the event of a power failure system control becomes inactive, and the pressure in the system increases to dangerous levels, the pressure relief valve may be the only device that prevents a catastrophic failure.

The design of the pressure relief valve must be as simple as possible, have a predetermined set pressure, flow at a rated capacity at a specified overpressure, and close when the pressure in the system has returned to a safe level. The material of the valve must be compatible with many process fluids from air to corrosive media. It must be able to operate smoothly and stably on a variety of fluids and fluid phases. (Wermac, u.d.)

Figure 3. Pressure relief valve

2.4 International Maritime Organization

The International Maritime Organization (IMO) was founded in 1948 by the United Nations. The organization serves as a platform for governments to collaborate on regulating technical aspects of international shipping. The purpose of the organization is to promote high standards in maritime safety, navigation efficiency, and preventing and controlling marine pollution from ships. (IMO, u.d.)

2.4.1 IGF Code

The “International Code of Safety for Ships Using Gases or Other Low Flashpoint Fuels”, also known as IGF code, provides an international standard for ships, and other vessels covered by the IGC code, that operate on gas or low-flashpoint liquids as fuel.

The fundamental principle of the code is to establish mandatory criteria for the arrangement and installation of machinery, equipment, and systems for vessels using gas or low-flashpoint liquids as fuel. This aims to reduce the risks to the ships, their crew, and the environment, taking into consideration the characteristics of the fuels in use. (IMO, u.d.)

2.4.2 IGF code rules and regulations

In this chapter, I will list IGF rules and regulations for pipe functionality and design. The class societies adhere to these rules and interpret them in their own way.

The functional requirement for fuel pipe design is that fuel piping shall be capable of absorbing thermal expansion or contraction caused by extreme temperatures of the fuel without developing substantial stresses (As per 7.2.1.1).

Provision shall be made to protect the piping, piping system, components, and fuel tanks from excessive stresses due to thermal movement and from movement of the fuel tank and hull structure (As per 7.2.1.2)

Because of these rules, FGSS has designed its bunkering lines with bends to accommodate thermal expansion during bunkering. See Figure 2.

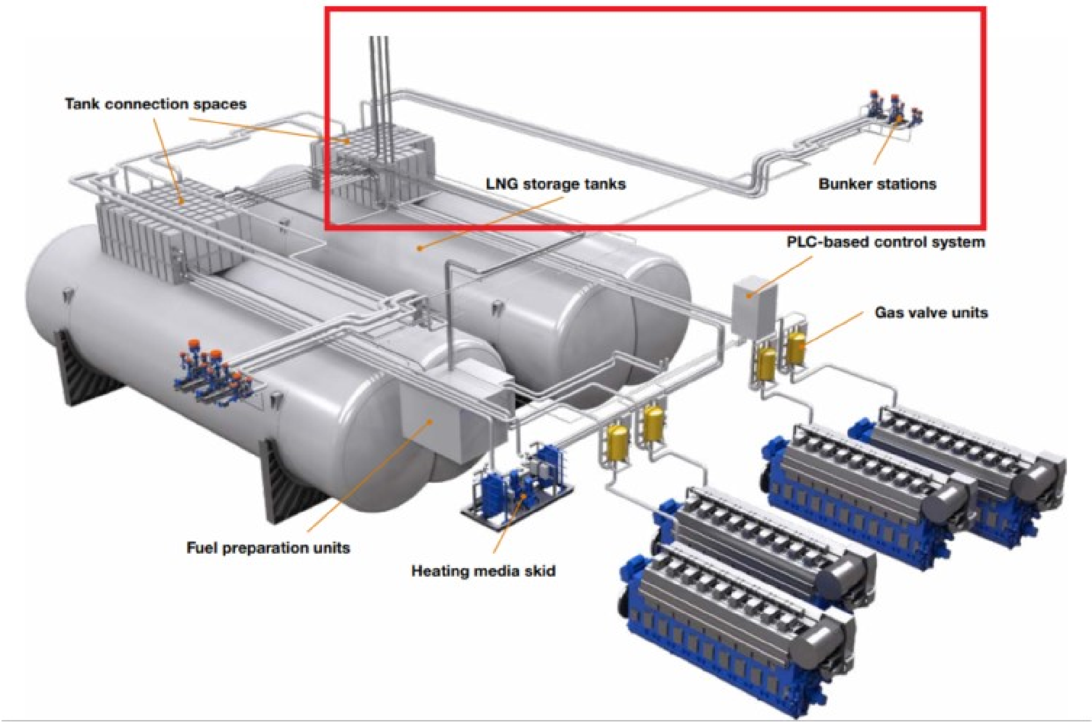

Figure 4. Overview of LNGPac. The bunkering line is highlighted.

Other functional requirements are:

If the fuel gas contains heavier constituents that may condensate in the system, a device for secure removal of the liquids must be installed (as per 7.2.1.3)

Low-temperature piping shall be thermally isolated from the adjacent hull structure, where necessary to prevent the temperature of the hull from falling below the design temperature of the hull material (as per 7.2.1.4)

Regulations for general pipe design:

Fuel pipes and all other piping needed for safe and dependable operation and maintenance shall be color-coded based on standards at least equivalent to those approved by the organization (as per 7.3.1.1). The primary color yellow indicates a flammable gas, while the secondary color violet indicates liquid gas.

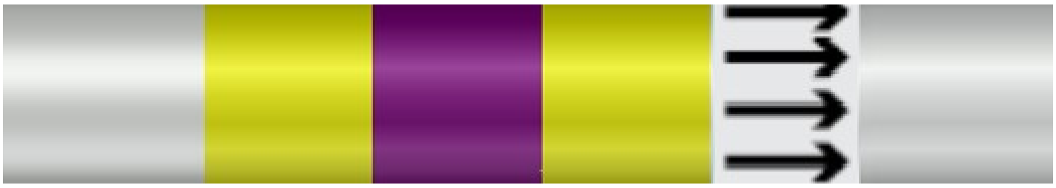

Figure 5. Color code indicating a LNG pipe

All pipelines or components that can be isolated in a liquid full condition must be equipped with a relief valve (as specified in 7.3.1.3)

Pipelines which may contain low-temperature fuel must be thermally insulated to an extent that will minimize condensation of moisture (as specified in 7.3.1.4)

2.5 Classification societies

A ship classification society is an independent, non-governmental organization responsible for establishing and maintaining technical standards governing the construction and operation of ships and offshore structures. With over 50 organizations globally engaged in marine classification, 11 of them form the International Association of Classification Societies (IACS). The collective standards of these 11 societies cover over 90% of the world's cargo-carrying ships. (EMSA)

Members of IACS are: (Marineinsight, 2022)

- American Bureau of Shipping (ABS)
- Bureau Veritas (BV)
- Croatian Register of Shipping (CRS)
- China Classification Society (CCS)
- Det Norske Veritas (DNV)
- Indian Register of Shipping (IRclass)
- Lloyd's Register (LR)

- Korean Register of Shipping (KR)
- Nippon Kaiji Kyokai (ClassNK)
- Polish Register of Shipping (PRS)
- Registro Italiano Navale (RINA)

2.5.1 De Norske Vertias (DNV)

DNV is a renowned independent authority in assurance and risk management. They are the world's leading classification society for the maritime industry after a merger in 2013 with Germanischer Lloyd (GL). DNV provides testing, certification, and technical advisory services across the energy value chain. DNV also holds a world-leading provider of digital solutions for managing risk and enhancing safety and asset performance in diverse sectors, including ships, pipelines, process plants, offshore structures, electric grids, and smart cities. (DNV)

2.6 DNV class rules for Double-walled pipes

Numerous rules exist for double-walled pipes, such as vacuum-insulated, ventilated, and pressurized double-walled pipes. Since my thesis centers around vacuum-insulated pipes, I will focus on rules regarding vacuum-insulated fuel pipes within this category.

DNV class rules regarding double-walled pipes can be found in DNV-RU-SHIP Part 6 additional class notations, chapter 2 propulsion, power generation, and auxiliary systems.

2.6.1 Fuel piping systems containing cryogenic liquids

Liquefied fuel pipes shall be protected by a secondary enclosure that can contain leakages. This requirement can be waived if the piping is located in a space that can contain leakages (as per rules 5.1.4.1).

The piping system and secondary enclosure must be capable of handling the maximum pressure that may build up in the system in case of leakage. To achieve this, the secondary enclosure may require a pressure relief system to ensure that it does not exceed the pressure above their design pressure (as per 5.1.4.3).

The secondary enclosure must be constructed from materials capable of withstanding cryogenic temperatures (as per 5.1.4.4)

2.6.2 Hydrostatic testing (11.2.3)

Following the manufacturing process but preceding insulation and coating, a hydrostatic test must be conducted on the fuel piping. This test must be performed in the presence of a surveyor and should be done at a minimum pressure of 1.5 times the design pressure (as per 11.2.3.3)

After assembly on board, the fuel piping system is required to undergo a leak test using air or another appropriate medium. The test pressure needs to align with the applied leak detection method (as per 11.2.3.4)

Secondary enclosures for high-pressure fuel piping must undergo a pressure test, with the test pressure set to anticipated maximum pressure in the event of a pipe rupture, but a minimum 10 bar. For secondary enclosure for low-pressure piping, a tightness test is required (as specified in section 11.2.3.5)

2.7 DNV class rules for vacuum monitoring skid equipment

This chapter will focus on rules regarding valve testing and pressure sensors which are equipment mounted on the skid.

DNV class rules regarding valve testing can be found in DNV-RU-SHIP Part 5, chapter 7, Liqufied gas tankers. DNV class rules for the instruments can be found DNV-RU-SHIP Part 6 additional class notations, chapter 2 propulsion, power generation, and auxiliary systems.

2.7.1 Cryogenic Valves

Every valve type intended to be used at working temperatures below -55°C must undergo a design assessment and undergo the following tests under the observation of a society's representative (as specified in 13.1.1)

1. Valves of every size must undergo a seat tightness testing over the full range of operating pressures for bi-directional flow and cryogenic temperature. This testing, conducted at intervals up to the valves rated design pressure, should be fixed to the

leakage rate specified by the society. The satisfactory operation of the valve must be confirmed during the testing.

2. The flow or capacity of each valve size and type should be certified according to an established standard.

3. Components under pressure must be subjected to a pressure test at a minimum 1.5 times the design pressure.

4. Emergency shutdown valves made of materials with a melting temperature lower than 925°C should undergo type testing, which includes fire test conducted according to a standard approved by the society.

2.7.2 Pressure relief valve

The pressure relief valve must be prototype tested according to 2.1.5.1 in DNV-RU-SHIP Part 5, chapter 7. The test must include:

1. Validation of relieving capacity.

2. Cryogenic testing, when operating temperature exceeds -55°C.

3. Seat tightness test.

4. Pressure-containing components must undergo pressure testing at least 1.5 times the design pressure.

2.7.3 Pressure sensors

Instrumentation and electrical devices in contact with the fuel must be appropriate for zone 0, indicating the presence of liquefied gas. Temperature sensors must be installed in thermo-wells, while pressure sensors without an additional separating chamber should be suitable for installation in zone 0 (as specified in 8.1.1.8)

2.8 Vacuum monitoring skid

[Classified]

2.8.1 Factory acceptance test

A factory acceptance test (FAT) needs to be performed before delivery of the skid. The class society normally requires that the test be performed under their supervision to get class approval.

The factory acceptance test requires:

1. Visual inspection: Visual inspection of all major welding and dimensional check
2. Review of documentation: Review of documentation, test reports from manufacturing, and material certificates
3. Hydrostatic testing: Testing with water at 1.5 times the design pressure.
4. Gas leak test: Testing with air at 2-3 bar pressure for demonstration of tightness
5. Vacuum leak test: Vacuum leak test with helium

3 Methodology

Distinctions between qualitative and quantitative methods can be approached from various angles, primarily centered on the type of knowledge a researcher is aiming for and the methodologies employed to attain it. Quantitative methodologies relate to measurable properties such as size, quantity, or extent, typically expressed numerically. These numerical representations constitute quantitative data, enabling precise numerical descriptions. On the other hand, qualitative methodologies concern the inherent nature or characteristics of phenomena. Qualitative data, unlike its quantitative counterpart, surround non-numerical aspects like images or textual descriptions, which resist quantification. In essence, while quantitative data quantifies attributes like volume or magnitude, qualitative data clarify the essence or quality of phenomena. Both types of data are integral to comprehensive research endeavors, with the nature of collected data dictating whether it falls into the quantitative or qualitative domain.

Alternatively, distinguishing between quantitative and qualitative methods can also be approached by examining how collected data is processed. Quantitative methodologies typically employ statistical techniques for data analysis, leveraging numerical computations to derive insights. In contrast, qualitative methodologies rely on verbal or non-numeric modes of analysis, emphasizing interpretation and contextual understanding. However, regardless of the analytical approach adopted, the fundamental determinant remains the type of data collected, rather than the processing methodology applied. (Säfsten, 2020)

The research methods used in this thesis are mixed methods, where both quantitative and qualitative parts are combined to find a suitable solution and a result. The research methodology is summarized through the following stages:

- Interview with colleagues to specify what is required from the valve
- Examination of DNV classification rules
- E-mail request for quotation from suppliers
- Meetings with suppliers to gather information
- Analysis and evaluation of different suppliers' valves

4 Results

In this chapter, the results of this thesis are presented. Suppliers offers with price and bore comparison, results of equipment review, clarification from DNV, and the acceptable vacuum grade is presented.

4.1 Suppliers offers

[Classified]

4.1.1 Price comparison

[Classified]

4.1.2 Bore size comparison

[Classified]

4.1.3 Vacuum monitoring skid modification

[Classified]

4.2 Acceptable Vacuum grade

[Classified]

4.3 Review of other equipment

[Classified]

4.4 Clarification from DNV

[Classified]

5 Discussion

After analyzing the supplier's offers for vacuum valves, supplier one: 's gives a good alternative because it meets every requirement except the bore size. The vacuum pump-down time with this valve takes over a week.

To significantly improve the pump downtime, we should use a method to reduce humidity within the annular space. This can be achieved by flushing the space with nitrogen before initiating the vacuum pumping process. Flushing the annular space could reduce the pump-down time by a couple of days. I would recommend using this valve in projects with a very low budget.

For projects with a high budget, I would recommend using supplier two:s option 2 valve. The valve meets all the requirements, and its performance is proven as it's an upgrade from option 1 of the valve. The 3 mm increase in bore size, combined with flushing the system can make the pump-down time significantly improved. The only downside is that the valve needs a change of position, see Figure 12. For these two valves, FGSS will not have to change the opening pressure of the pressure relief valve.

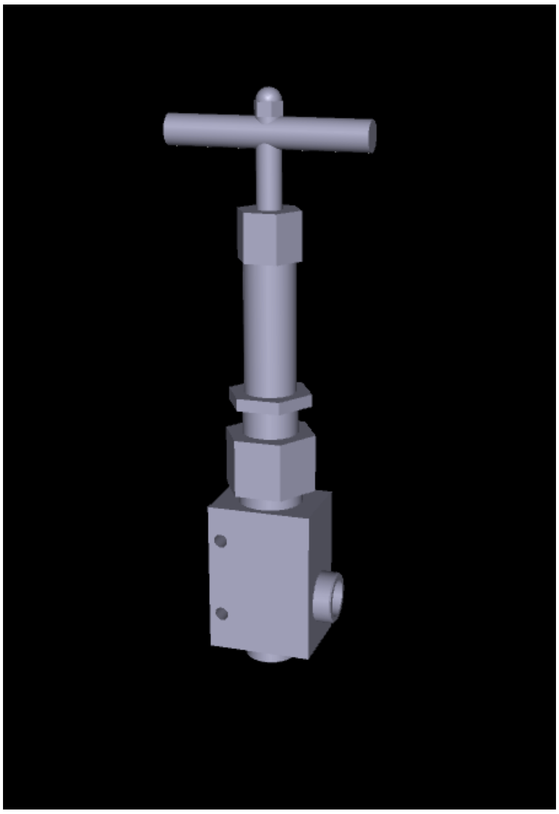

Figure 6. Supplier 2, option 2 valve

Supplier Six could be a good alternative to use in all projects. It would work for both low and high-budget projects since it has a good price. The valve has a conductance molecular flow of 50 liter/second^{-1}. The conductance is the flow of gases on a molecular level, and this term is typically used in vacuum systems.

This valve meets all the requirements except the pressure range of up to 10 bar. Following DNV’s clarification that the pressure could be lowered, a new challenge emerged. This is because, according to their rule (11.2.3.5), the outer pipe is required to undergo pressure testing.

Then the valve would not be able to withstand this high pressure. A solution for this would be to remove the valve during the pressure testing of the secondary enclosure. A blank flange would be used to block the pipeline. This valve could for now only be used at projects with DNV as class society.

Figure 7. Supplier 6 valve

The vacuum grade could be improved, as I have researched other pipe manufacturers that can provide a vacuum grade of 0.5 pascal, which is ten times better than our currently acceptable vacuum grade. However, since the insulation grade for our pipes is not so critical, considering that there will only be LNG in the inner pipe during tank refilling. If there were a constant flow of LNG in the pipe, then a higher vacuum grade would be necessary.

Since neither the supplier six:s valve nor the flushing of the annular space has yet been tested, I would propose future research on this subject. A suggestion would be to do a similar investigation into rules for other class societies regarding the vacuum valve and the vacuum monitoring skid. This could potentially allow the supplier's six:s valve to be utilized for all class societies.

I have learned a lot from this thesis, and the subject has been interesting. I believe that the objectives have been fulfilled and the requirements from DNV for the equipment have been

clarified. I want to thank FGSS for allowing me to write this thesis from them. A special thanks goes to my team at mechanical engineering and my manager Björn Hatt, for their support and guidance.

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