KYMENLAAKSO UNIVERSITY OF APPLIED SCIENCES
Maritime studies/ Marine engineering

Tarvi Vabar

Gas as marine fuel

ABSTRACT

KYMENLAAKSO UNIVERSITY OF APPLIED SCIENCES

Degree Programme in Marine Technology

VABAR, TARVI

VABAR, TARVI	GAS AS MARINE FUEL
Bachelor’s Thesis	37 pages + 2 pages of appendices
Supervisor	Lector Ari Helle
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This Bachelor’s thesis examined the technical possibilities of using natural gas as marine fuel for merchant fleet.

The main aim was to gather all relevant information on how natural gas can be used in maritime sector. Due to the protection of environment, remarkable numbers of requirements are set for maritime transport sector regarding the combustion of fossil fuels. The aim is to reduce or even eliminate harmful emissions. Among other options liquefied natural gas may be environmentally the best option, but not economically.

The study was based mainly on publications issued by engine developers, international organizations, legislation bodies and shipping classification societies.

It is proved that natural gas can be used as marine fuel. There are transporting, storaging and distributing facilities and engines that are safely using natural gas.

TIIVISTELMÄ

KYMENLAAKSON AMMATTIKORKEAKOULU
Merenkulun koulutusohjelma

VABAR, TARVI	Maakaasu merenkulun polttoaineena.
Opinnäytetyö	37 sivua + 2 liitesivua
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Avainsanat	Ympäristönsuojelu, maakaasu, kaasukoneet, merenkulku

Tässä opinnäytetyössä tutkitaan maakaasun käyttöönottomahdollisuuksia kansainvälisessa merenkulussa.

Tavoite oli kerätä kaikenlaista tietoa siiä, miten kaasua käytetään merenkulussa. Ympäristönsuojelu on aiheuttanut paljon uutta lainsäädäntöä, joka koskee fossiilisten polttoaineiden käyttöa laivoissa. Tavoittena nykyään on rajoittaa tai jopa eliminoida haitalliset päästöt, joita laivat tuottavat. Eri mahdollisuuksista maakaasu on ehkä paras valinta.

Tutkimustyö perustuu pääosin lähteisiin, joita ovat julkaisseet moottorien kehittäjät, kansainväliset organisaatiot, lainsäädäntöviranomaiset ja merenkulunluokituslaitokset.

Työstä käy ilmi, että maakaasua saa käyttää polttoaineena. On kehitetty kaasun kuljetustapoja, varastointia ja myös jakelujärjestelmia. On olemassa koneita, jotka voivat turvallisesti käyttää kaasua. Kaasun käytön määrä on kasvussa.

TABEL OF CONTENTS

ABBREVIATIONS

CNG	Compressed natural gas
LNG	Liquefied natural gas
MDO	Marine diesel oil
MGO	Marine gas oil
IFO	Intermediate fuel oil
IMO	International Maritime Organization
MEPC	Marine Environment Protection Committee
DNV	Det Norske Veritas
PBU	Pressure build-up unit
NG	Natural gas

1 INTRODUCTION

Merchant fleet carries about 90% of entire traded cargo worldwide. Sometimes, traded commodities need to be relocated over long distances. Total maritime trades have doubled by last two decades. The container trade has increased eight-fold. As population increases demand for maritime transport will increase as well.

Ships have been continuously modified. There are several incentives for that. First, size of ships has drastically changed. First cargo ship carried only few hundred tons of cargo and even more coal than cargo to heat up steam used in steam engines. Nowadays, vast oil carriers and container vessels are common. The larger vessel generates greater economy of scale. Probably ship size has reached the maximum. If a ship will be larger she also requires ports with a deeper draught.

Secondly, ship propulsion systems have been continuously under development and improvement. First, sail ships conceded their position to steamers and later on diesel-driven ships conquered the waters. The goal has been to make engines more efficient. This is also an economical incentive, because competition in maritime transport sector is high.

Eventually, naval architects and marine engineers have new challenge. They have to build ships that are economically useful to ship owners but at the same time environmentally friendly. Ships consume vast amount of fossil fuels and produce enormous amounts of emissions that are harmful to environment. To reduce emissions, several actions are taken. New technologies have been implemented, such as common rail fuel oil system and exhaust gas cleaning system. Also, refineries have produced fuels that consist less sulphur. Reducing the speed of ship helps cut emissions. New ship designs reduce ship water resistance, thus less fuel is needed to achieve the same speed. Another option is to use fuel that does not consist sulphur and when combusted generates less emission. One of these fuels is natural gas.

2 FOSSIL FUELS IN MARITIME TRANSPORT

There are three types of marine fuel used in merchant fleet: distillate fuel, residual fuel and a mix of distillate and residual fuel called intermediate fuel oil (IFO). These are all very good energy carriers. All fossil fuels are different fractions of crude oil. The main differential properties are viscosity, density and consistent of impurities.

2.1 Intermediate fuel oil (IFO)

This type of fuel oil is very popular on the oceangoing vessels and also large vessels operating in short sea shipping market. The majority of vessels are equipped with two-stroke engines and medium speed engines that consume IFO. There are two grades of blended heavy fuel oil commonly available: IFO 180 and IFO 380. The 180 and 380 indicates oil's kinematic viscosity. The IFO 180 has a lower viscosity and fewer impurities. The popularity of this type of fuel can be explained by that it has lowest operating costs. However, additional capital costs are caused by treatment of fuel oil, for example heating, purifying and viscosity monitoring. (See annex 2).

2.2 Marine gas oil and Marine diesel oil

These are lighter fractions refined from crude oil. They have far less impurities and also sulphur content may be small as 0.1%. They are used in high-speed engines and are twice expensive than IFO. Also, they are stand-by fuel to heavy fuel oil to aid starting up machinery after servicing or after longer stand by periods. However, they do not require pre-heating systems or viscosity monitoring. Another advantage is cleaner combustion that is quite important factor these days. Annex 1 gives information about additives and chemical substances found in MGO/MDO.

3 EMISSIONS FROM SHIPPING

The fossil fuels have mainly been combusted in internal combustion engines to cope with energy demand. ”IMO second Green House Gas study 2009” found that world merchant fleet produced about 870 million tons of CO_2 in 2007. This portion contributes 3% of total CO_2 annual emissions.

There are three harmful emissions considered as pollutants: carbon dioxide, nitrogen compounds and sulfur compounds. Composition of exhaust gas is seen on figure 1.

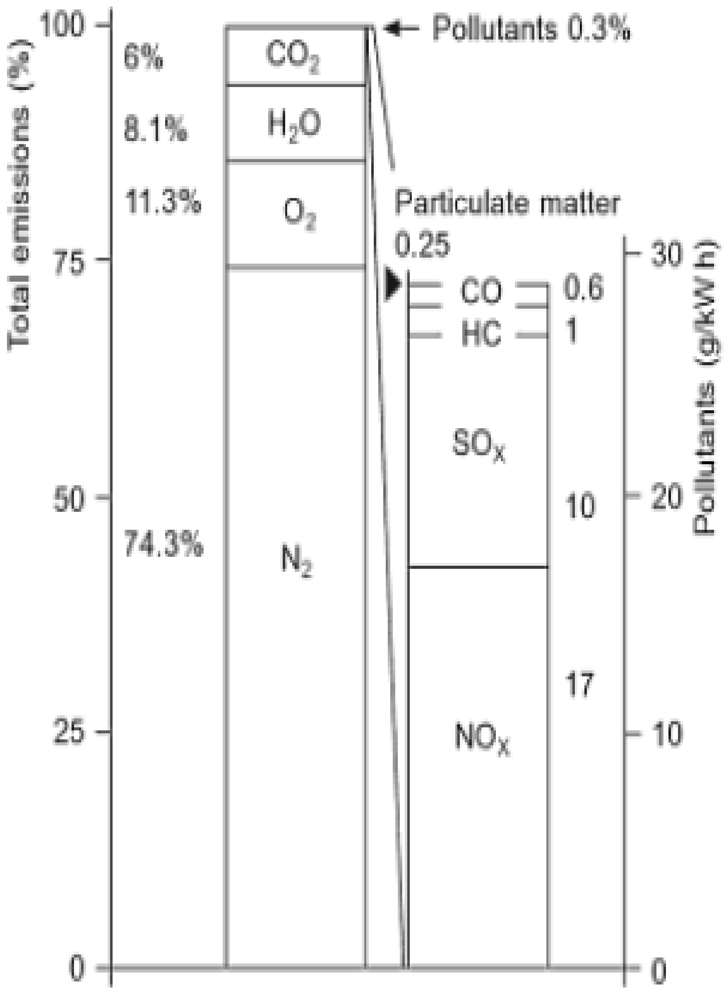

Figure 1. Typical composition of exhaust gas. (Woodyard 2009, 62)

3.1 Carbon dioxide

Carbon dioxide is colorless and odorless gas. In internal combustion engine it is a combustion product. For example handy-size bulk carrier emits about 70 metric tons of CO_2 a day while in operation. CO_2 emmisions can be reduced by literally using less fossil fuel. Nowadays internal combustion diesel engines have higher thermal efficiency factor than other heat engines. This means that less fuel is burned to achieve the same quantity of power compared to other heat engines. (Woodyard 2009, 63.)

3.2 Nitrogen compounds

This group contains all nitrogen-oxygen compounds: nitrogen monoxide, nitrogen dioxide and -trioxide. NO_x compounds are formed when there is lack of oxygen in high temperature. Also, longer combustion period forms more NO_x emissions. Therefore, two-stroke engines form more NO_x emissions. A 1 kg IFO needs for a full combustion about 10 kg pure oxygen. The ambient air contains 78% nitrogen and 21% oxygen. Subsequently 50 kg of unwanted nitrogen compounds are emitted when one kilogram of fuel oil is burnt. Nitric-oxides causing formation of acid rains that are harmful for ecosystems, thus to human being as well. Reducing NO_x emissions requires removal of conditions when NO_x are formed. There are several measures to cut these emissions: water sprayed directly to the cylinder, valve timing control, intake air humidifying, turbo cooling, Miller supercharging. Scheme to cut NO_x emissions is seen in Figure 2.

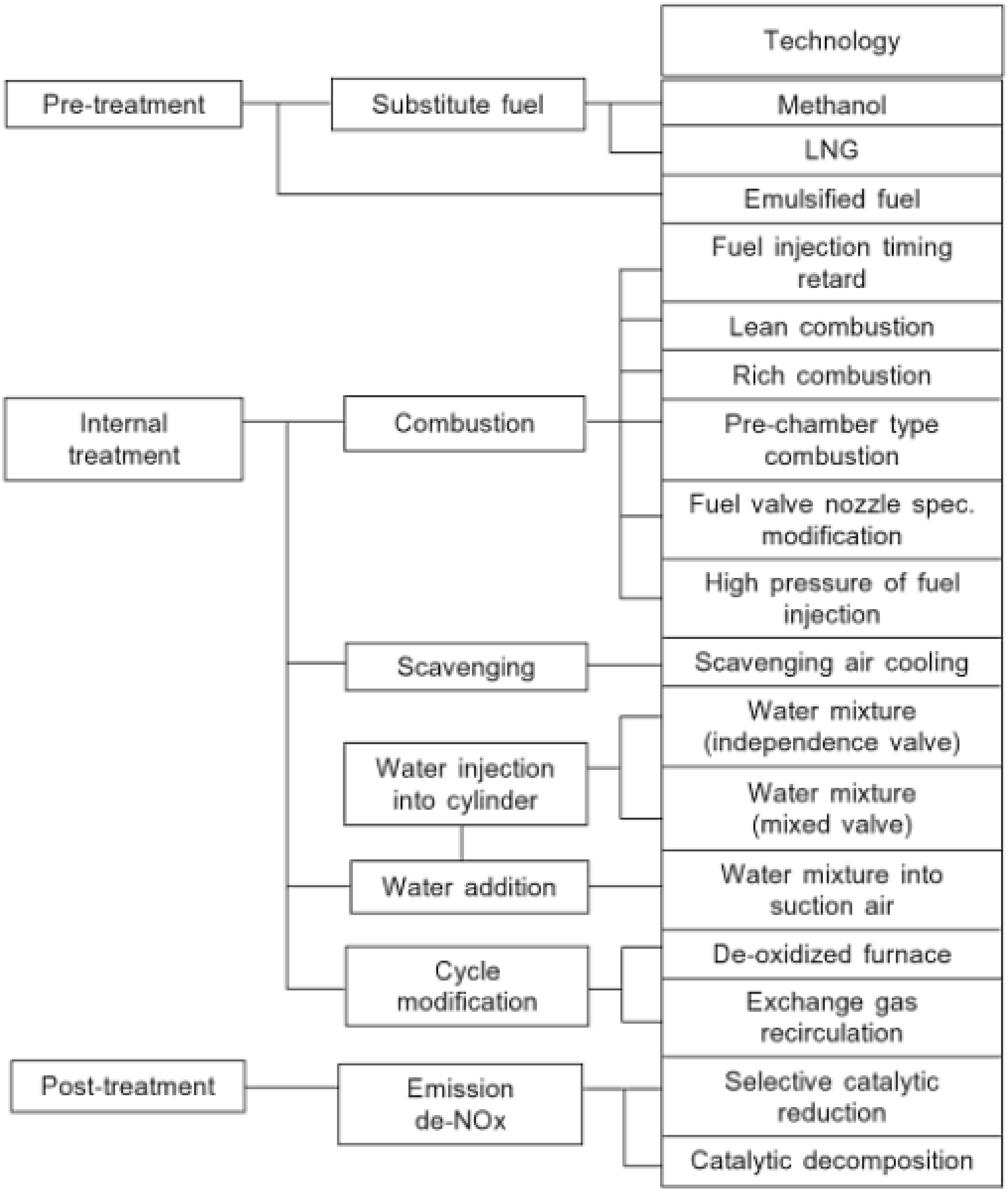

Figure 2. Methods of reducing NO_x emissions from marine diesel engines. (Woodyard 2009, 69.)

3.3 Sulphur

Some marine fuel oil is allowed to consist up to 4.5 % of sulphur. When this oil is combusted, SO and SO_2 are emitted. Gas containing sulphur is colorless, non-flammable but with distinctive odor. These compounds react with water and are very irritating to nature. There are two options currently to reduce SO_x emissions. One option is to use a scrubber plant where all exhaust gasses are washed with caustic soda and formed sludge is disposed in port facilities. This option is space demanding and noticeable investments shall be executed. Another option is to consume bunkers with relatively low sulphur content or completely sulphur free fuels (Woodyard 2009, 64.)

4 ENVIRONMENT PROTECTION

To cope with emissions, several organizations and committees have been established. Almost every country in Europe has some local legislation to protect environment. There are local and global conventions, committees and organizations to regulate the operation of the ships. The worldwide known convention is Marpol.

4.1 Marpol

The full name of the convention is” The Convention for the prevention of Pollution from Ships”. This IMO convention was first signed in 1973. Amended with Protocol 1978 in 1978 and finally came into force 1983. Now it has six annexes, the most important one is annex VI which came into force in 2005. Annex VI sets limits for emissions regarding sulfur and nitrogen compound consistence. Regulation 13 deals with nitrogen oxides. Limits are seen in Figure 3.

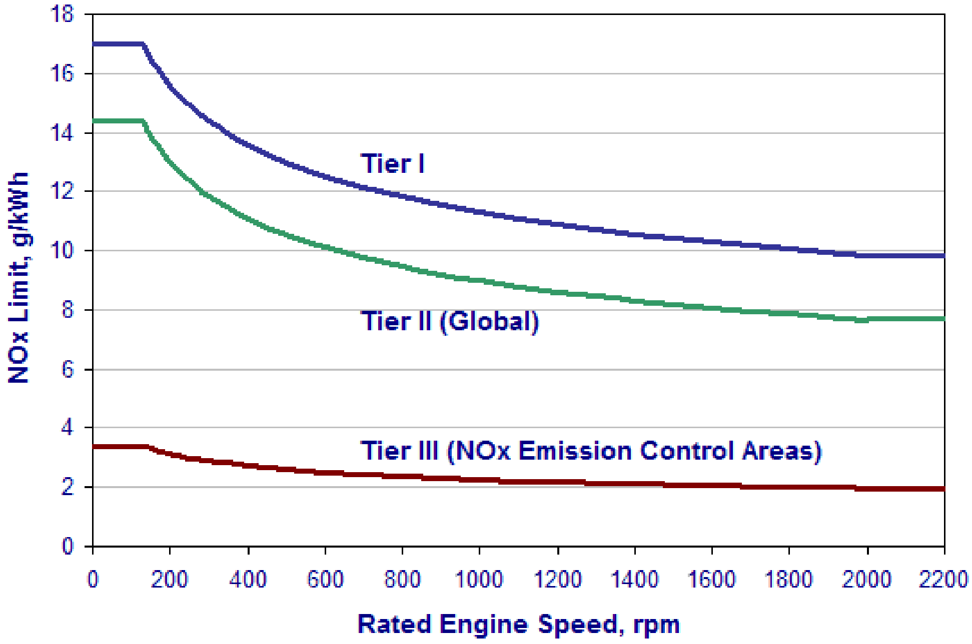

Figure 3. MARPOL Annex VI NOx Emission Limits

Regulation 14 sets limits for sulphur in fuel oil. Special fuel quality provisions exist for SOx Emission Control Areas (figure 5). The sulfur limits and implementation dates are listed in figure 4. By 2015 fuel sulphur content in SECA can be up to 0.1%.

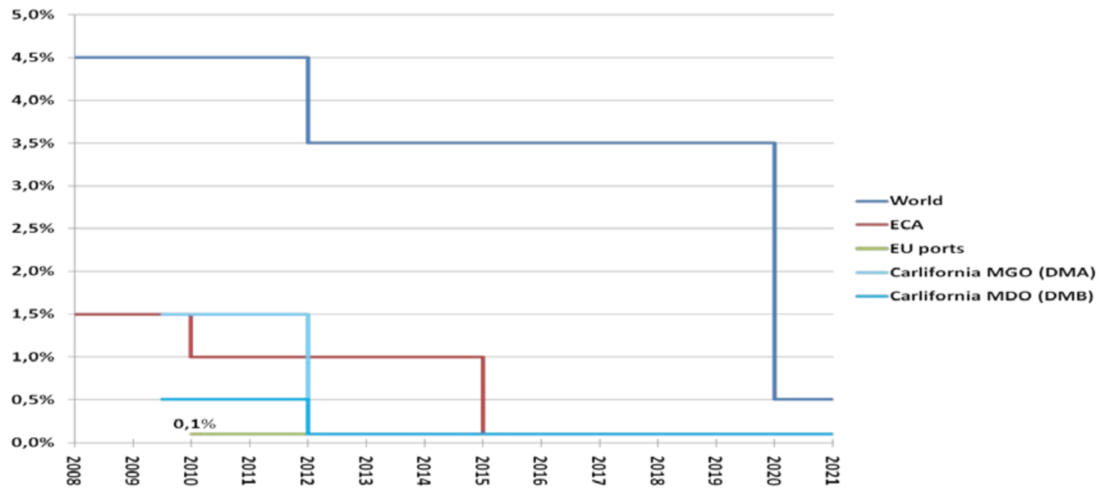

Figure 4. Sulphur emission regulation. 2010. Colfax corporation.

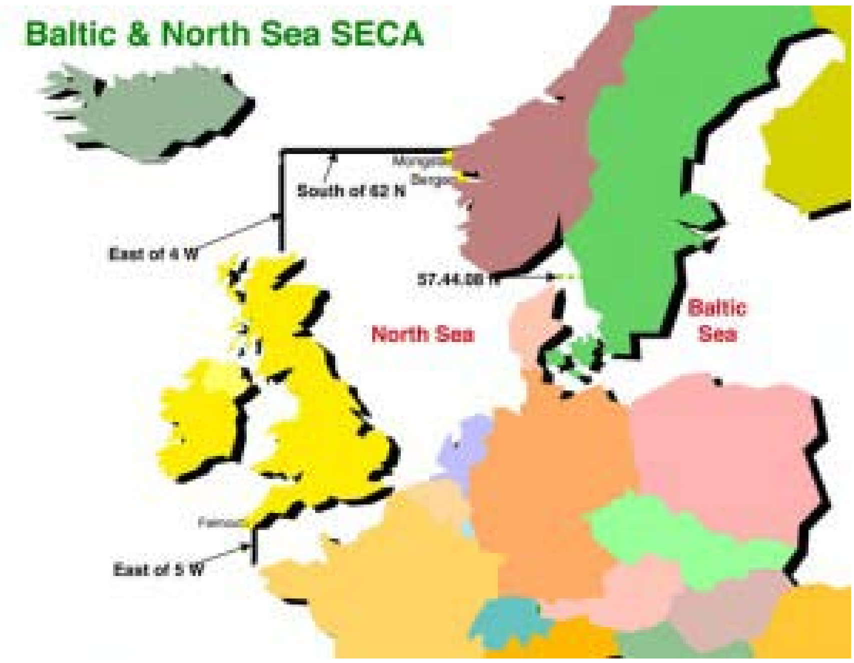

Figure 5.Sulphur emission control area. 2007. Environment Crisis Management.

5 NATURAL GAS

As mentioned above, there are several fossil fuels burned in marine internal combustion engines to achieve propulsion of ship. Liquid fossil fuels have a common main source and it is crude oil. Crude oil is heated and subsequent vapors are condensed and several fractions are achieved. They are called distillate fuels. What is left of crude oil after heating is called residual fuel and they are far heavier fractions. Residual fuels are cheaper to burn but need additional treatment on a ship, and also part of contained energy is used for pre-heating. The fuel oil system is more complex compared to the combustion of distillate oils. Also, residual fossil fuels contain more impurities and particles that are abrasive to engine fuel oil system. Both residual and distillate fuels consist sulphur. Due to environmental issues, ships are demanded to use low-sulphur fuels, and also CO_2 emissions shall be reduced. Therefore, alternative fuel is the objective in maritime world. One option may be natural gas.

5.1 Properties of natural gas

Natural gas is a mix of hydrocarbons, dominantly containing methane and some minor quantities of ethane and propane. It is odorless, colorless, non-toxic and non-corrosive. The boiling temperature of natural gas is -157-(-162) Celsius, at normal atmospheric pressure. The density of LNG is about 430-470 kg/m^3. Its volume is 600 times less when in liquid form compared to gaseous form (Chandra 2006). Its chemical formula is CH_4, that is, four hydrogen atoms are bound to one carbon as seen in Figure 6 (Tabak 2009).

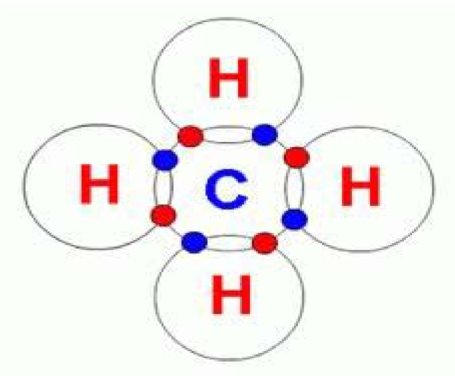

Figure 6. Methane.

5.2 Reserves

Natural gas is a non-renewable energy source. Some experts have stated that it is complicated to estimate how much natural gas is available. Estimations are shown in Table 1.

Russia	**47.57**
Iran	29.59
Qatar	25.45
Asia & Oceania	15.23
Africa	14.02

Table 1. Top 5 proved reserves of natural gas in trillions of cubic meters.

5.3 Transportation

Gas is mostly found in offshore reservoirs, far from where it is used. Figure 7 shows transportation chain of natural gas. Gas is chiefly transported via pipelines or by gas-carrier vessels. Natural gas has a lower energy-to-volume ratio than crude oil. It means that gas needs more space than other liquid fuels. Currently, gas is transported from gas fields to consumers by pipelines or by LNG carriers. Gas transportation has a good safety record. (Tabak 2009, 26.)

Figure 7.Gas supply chain. (Chandra 2006)

5.3.1 LNG carriers

LNG carriers are vessels ranging from 10,000 m^3-140,000m^3 cargo capacity (Figure 8). Vessels have thermally insulated tanks to prevent liquefied gas from gasification. Mostly, these vessels use ”boil-off gas” to propel the vessel. The vessels are built to transport gas over long distances between liquefaction-terminal and re-gasification terminal. The Latter is considered as an import terminal from where gas is distributed further by pipelines. LNG carriers are more flexible for transport because a destination can be chosen by demand.

Figure 8. LNG Carrier. China gets first overseas order for LNG Ships. 2011

5.3.2 Liquefaction

To be able to economically transport and store natural gas, gas has to be liquefied. Before liquefaction, gas is cleaned of impurities such as water, carbon dioxide and heavier hydrocarbons. There are several liquefaction options. The most commonly used is”cascade cycle liquefaction”. (Everett C. Hunt 2002,20-3) .

5.3.2.1 The cascade cycle liquefaction

This system is used in loading port facility. The cascade cycle (Figure 9) has three compressors, three heat-exchangers, three expansion valves and three gases as coolant-agents. In the first loop, propane is compressed, condensed in heat-exchanger by cooling water, expanded, vaporized in the second loop condenser (vaporizer for propane) for ethylene and finally the first loop compressors suck the agent and the cycle starts over again. In the second loop the cooling agent is ethylene. The cycle here is similar to the previous one: the agent is compressed, condensed (in propane vaporizer), expanded, vaporizes methane condenser and finally again the compressor sucks the agent. In the third loop is methane. Similar cycle takes place, the only difference being that condensed gas exits the loop and enters into storage tank. This kind of cooling process is also referred to as cryogenic cooling. There is also a small tank between storage tank and the loop. If some condensed gas changes back to gaseous form, the compressor sucks it back to the loop. (Everett 2002, 20-3.)

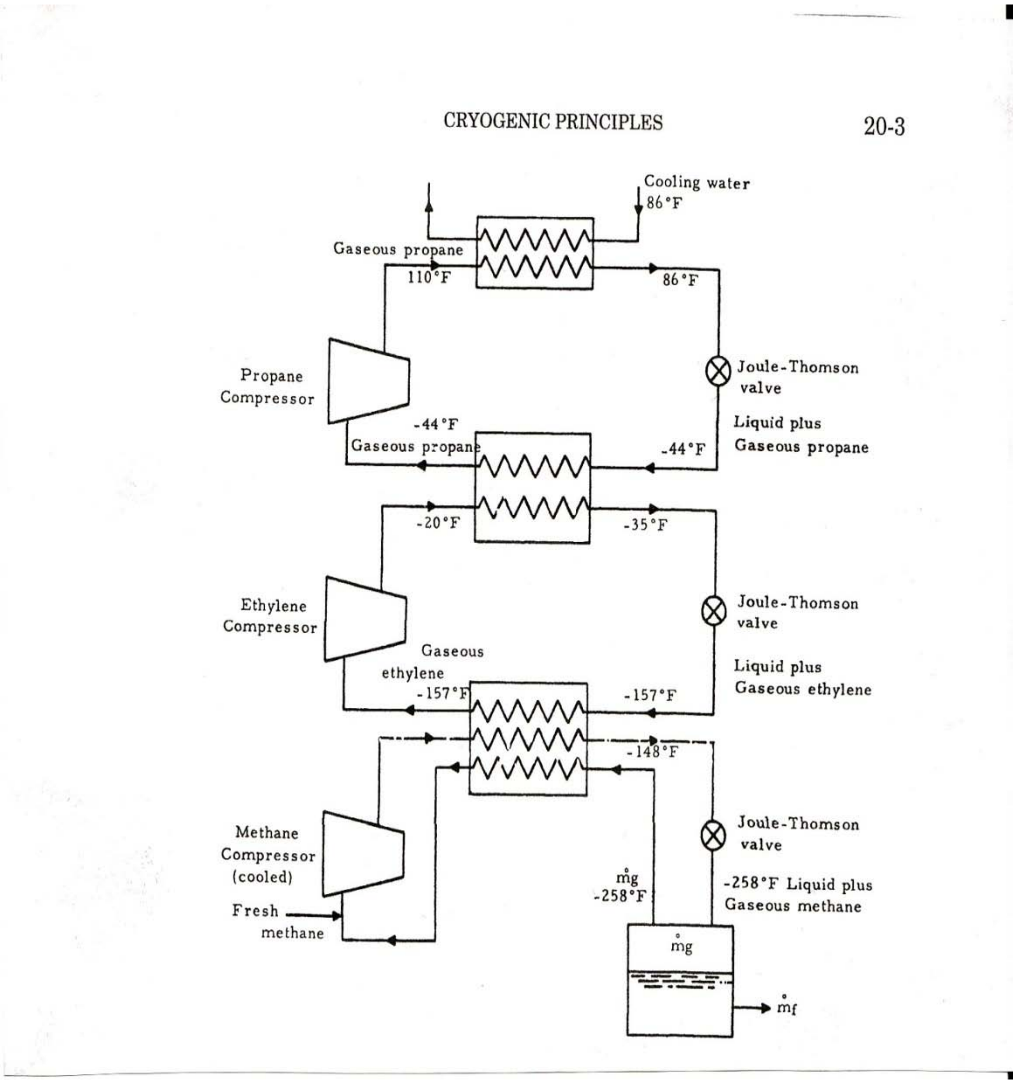

Figure 9. Cascade liquefaction cycle. (Everett et al.2002, 20-3.)

5.3.3 Pipelines

The main method by which gas is transported is to use pipelines. Pipelines have been established and continuously developed since the late 19. century. Pipes offer great opportunity to relocate gas with moderate costs. Billions of cubic meters of gas have been annually transported. For instance, there are about 526 000 km of pipelines in USA, and 150 000 km in Russia. Pipelines have diameter of 41-122 cm. Transporting pressure is about 70 bar. Pipelines have compression stations after every 100-160 km where condensation is removed. The European gas pipelines are shown in Figure 10.

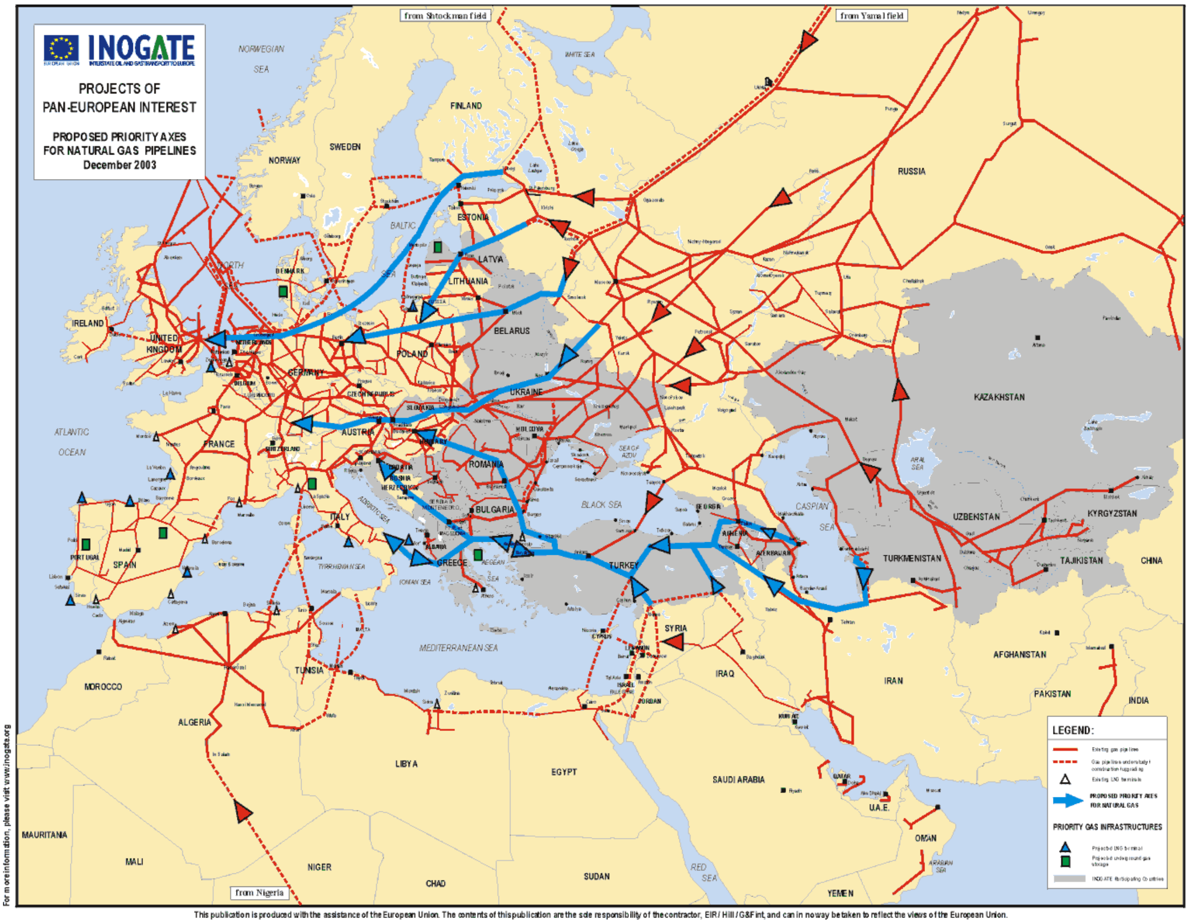

Figure 10. Mappery. The map of Europe Proposed Natural Gas Pipelines.

6 LNG AS MARINE FUEL

For more than 150 years, there has been demand for energy to propel ships. At first, coal was the prime energy source to produce steam for propulsion.Later, diesel engines were developed to use liquid fuels. During the last decade, environmental issues have pushed people to create engines that can use eco-friendly natural gas. There are already several vessels in short-sea traffic using LNG as main fuel. Mostly, these vessels are ferries calling the same ports daily. This, in turn, allows to build vessels with smaller fuel tank capacities because bunkering can be carried out daily. In ports, are insulated gas vessels from where ships are supplied LNG. These gas storing vessels are refilled by LNG carriers or by LNG trucks.

6.1 Engine builders.

As mentioned before, environmental aspects have impel to find alternative ways to propel ships in a more environment-friendly way. One of the options is to use natural gas to achieve clean operation of ships. Currently, there are four manufacturers: Wärtsila, Rolls-Royce, MAN and Mitsubishi, who have developed engines using solely gas or combined with diesel oil or heavy fuel oil. These manufacturers have developed DF engines and lean-burn gas engines. In DF engines, gas with pilot fuel is used, and in lean-burn engines a mixture of gas and air is ignited by a spark plug. Air-gas ratio is 1.8 to 2.2.

6.1.1 Wärtsila Dual fuel engines

Wärtsila has two engines for maritime application. They are 32DF and 50 DF with cylinder bores 320mm and 500 mm. Respectively, output power ranges from 2010 – 17100 kW.

Wärtsila DF engines can run on diesel and natural gas. Additionally, Wärtsila 50 DF engine can also burn HFO. On”Gas mode”, the engine also consumes diesel oil and its proportion is 1%. This small amount of diesel oil is called pilot fuel and used for ignition. Wärtsila DF engines have the switch which allows a change of fuel without interruption. When running on gas mode (Figure 11), the engine switches to diesel operation if gas feed is interrupted. This switch takes less than one second and does not affect the load or speed of the engine. Again, when reverse switchover takes place, it happens gradually. Diesel supply is gradually decreased while gas supply is increased.

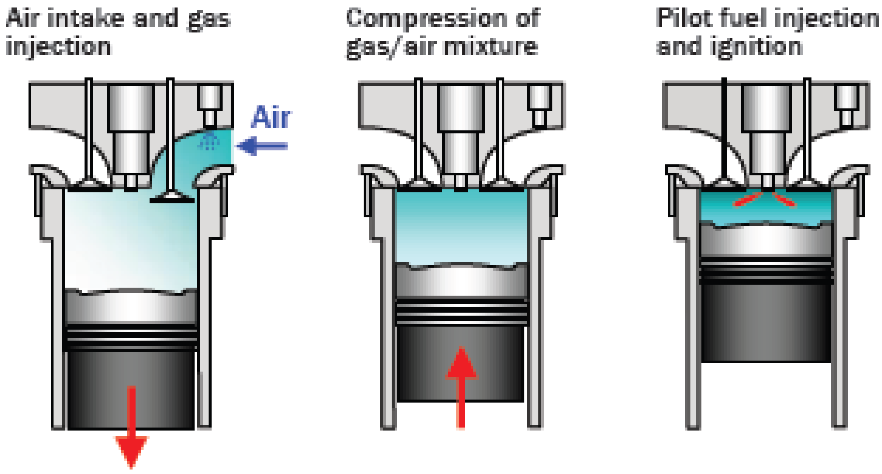

Figure 11. Wärtsila 50 DF operating principle in gas mode.NKN.

Normally, DF engines are started only on pilot fuel (diesel) and when the engines have reached 60 % of nominal speed, gas admission is activated and the engine speed is increased to nominal. This safety precaution guarantees that unburnt natural gas does not flow directly to atmosphere. When running on gas mode with a load below 15% more than three minutes or if the gas supply is suddenly cut off, automated system switches back to diesel mode. Load related options are shown in Figure 12.

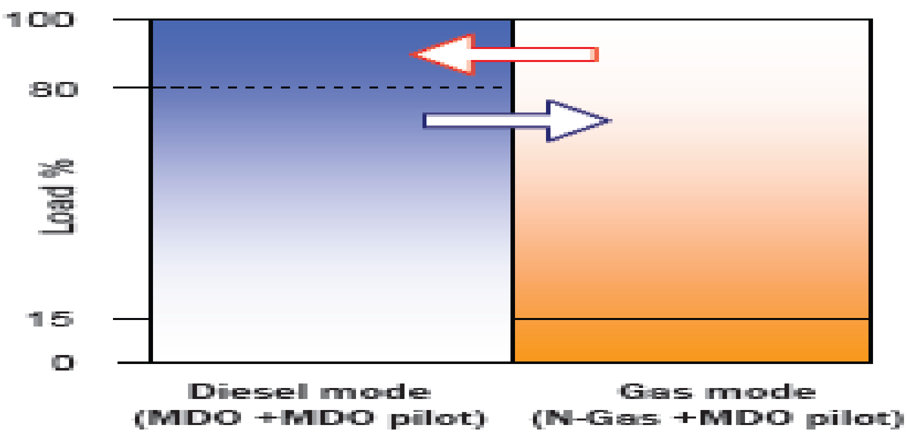

Figure 12.Operating mode depending on load. NKN

6.1.1.1 Gas admission valve on Wärtsila 50 DF

A gas admission valve (Figure 13) is installed before the air inlet valve in the cylinder of the 50DF engine. Gas is supplied to each cylinder by opening or closing this valve. The gas admission valve and fuel injection control valve are electronically operated. It enables sufficient monitoring and adjusting of the engines operating parameters while the engine is on.

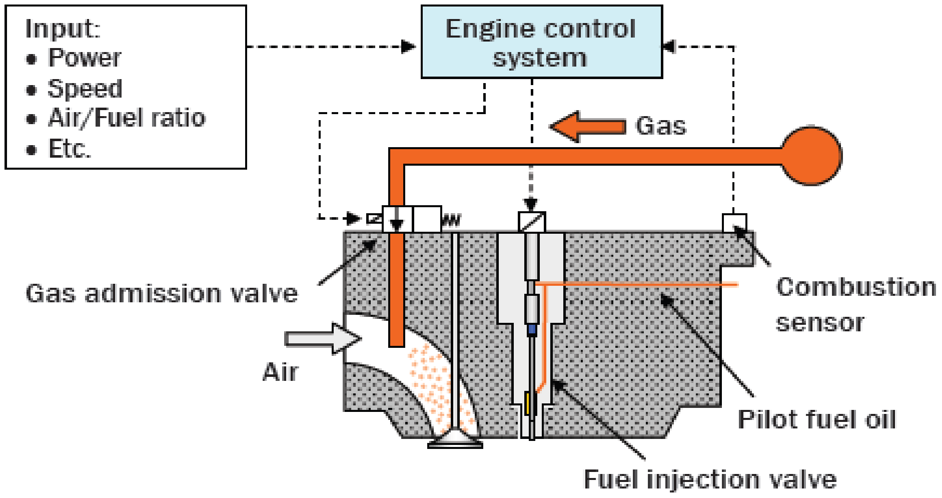

Figure 13. Control of gas fuel.

In gas mode, rapid pressure rise in a cylinder can occur and this causes exsessive vibration. Vibration is also called knocking. This kind of pressure rise is a result of abnormal air-fuel ratio. On the top of cylinder is the combustion sensor (knocking sensor), and its output signal is transmitted to control system and from there relevant “orders” are sent to gas admission valve or to fuel injection valve.

6.1.1.2 Gas fuel supply pipe

In the engine room gas, is supplied to the engine by double wall pipe (Figure 14). A gas fuel moving in the inner pipe and space between the outer and inner pipe is ventilated. Protective covers are also fitted to valves, flanges and bellows. This safety construction prevents flammable gas to enter into the engine room.

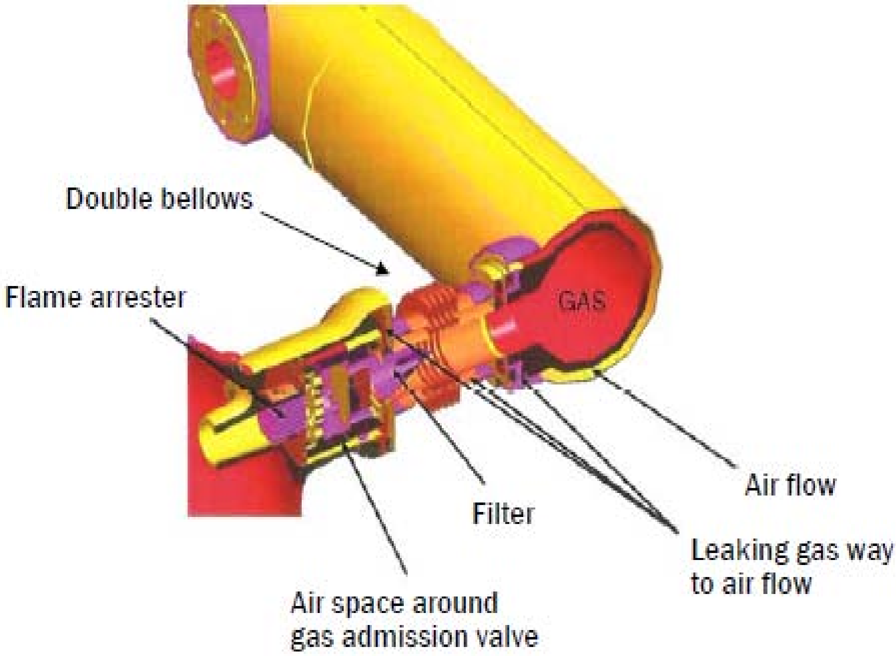

Figure 14. Construction of gas fuel pipe. NKN.

There are not common compulsory rules regarding to usage of gas as fuel yet, but several shipping class societies have issued their own safety guidelines. All pipelines that are inside of ship construction shall be a double wall type. All piping must be a flexible as possible. This is secured by number of bellows added to lines, and this safety measure is against deformations that can occur in case of collision. Gas fuel piping can not lead trough accommodation spaces, service spaces or control stations. (Det Norske Veritas 2011).

6.1.1.3 Supply and control of fuel oil

(Quotatation from Nippon Kaiji Kyokai publication)

The fuel oil supply system to the DFD engine consists of a system for pilot fuel oil and a system for back-up fuel oil. The fuel injection valve has two needle valves; the large needle valve is used in the diesel mode, whereas the small needle valve is used for injecting pilot fuel oil in the gas mode. The pilot fuel oil is adjusted to a specific pressure by a radial piston type engine-mounted pump and is led to the fuel injection valve of each cylinder through a common rail pipe. The common rail pipe serves the role of accumulating oil pressure and inhibiting fluctuations in pressure. The injection of the pilot fuel oil is electronically controlled by a solenoid valve mounted in the fuel injection valve. The pilot fuel oil is injected into the cylinder at a pressure of approximately 900 bars. On the other hand, the back-up fuel oil is pressurized by a camshaft-driven fuel injection pump and led to the fuel injection valve. The fuel injection mechanism is the same as that of the fuel injection valve of diesel engines generally used. The system layout is seen in Figure 15.

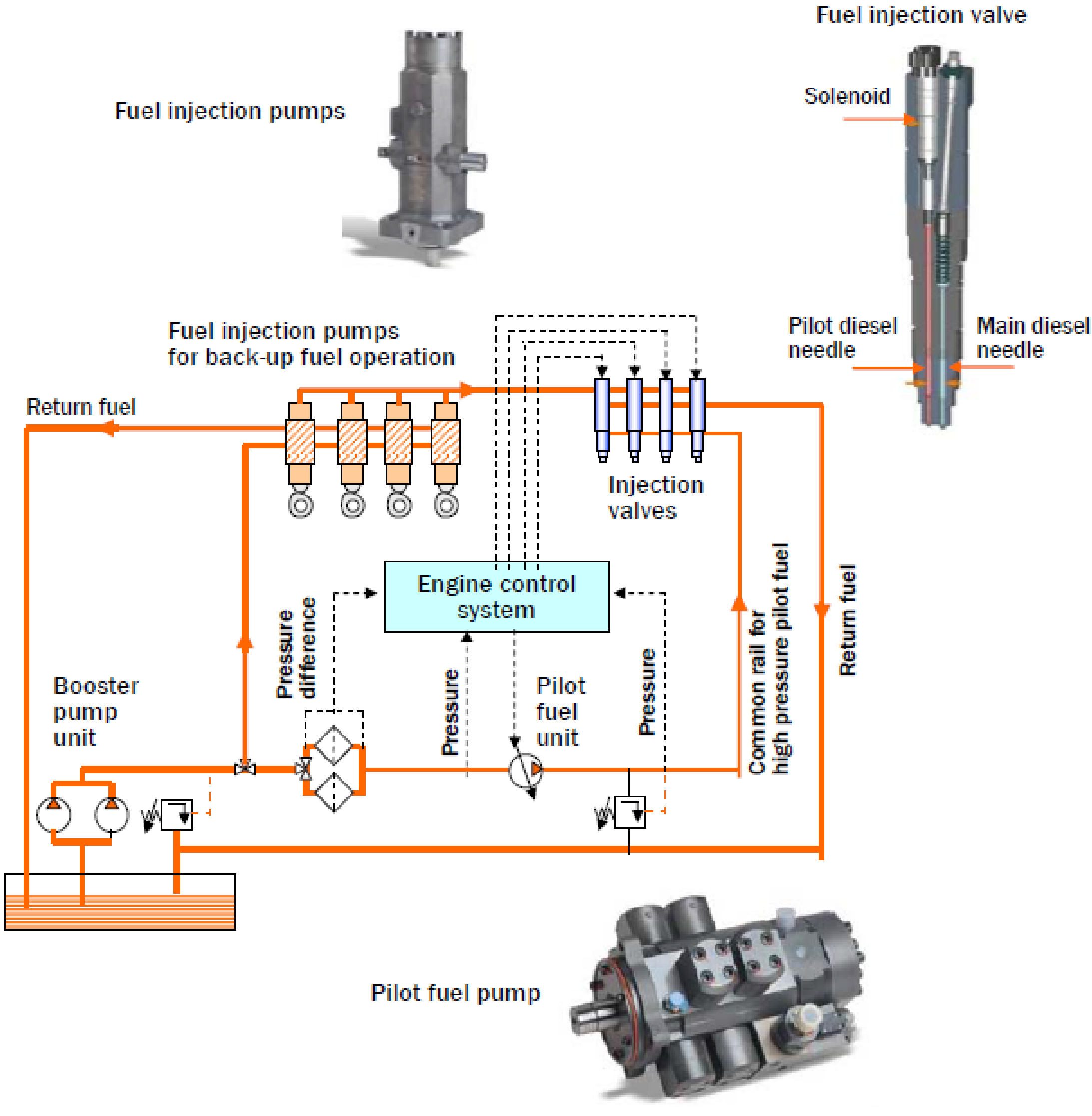

Figure 15. Control of pilot fuel oil and back-up fuel oil.

6.2 Combustion of natural gas

There are fewer emissions when natural gas is combusted. Carbon dioxide emission is cut about 20 % compared to HFO/MDO. Sulphur emission is non-existent. Nitrogen oxide emissions are cut about 85% compared to HFO/MDO. Additionally, there is no visible smoke, no sludge deposits and no lead emissions. However, there is one negative nuance, natural gas is powerful GHG. This means in case of inadequate combustion, unburnt natural gas has a negative effect on a reduction of GHG emissions. Methane is 20 times more powerful GHG than CO_2. (DNV 2010). In Figure 16 is shown the comparison of emissions of conventional fuels and LNG.

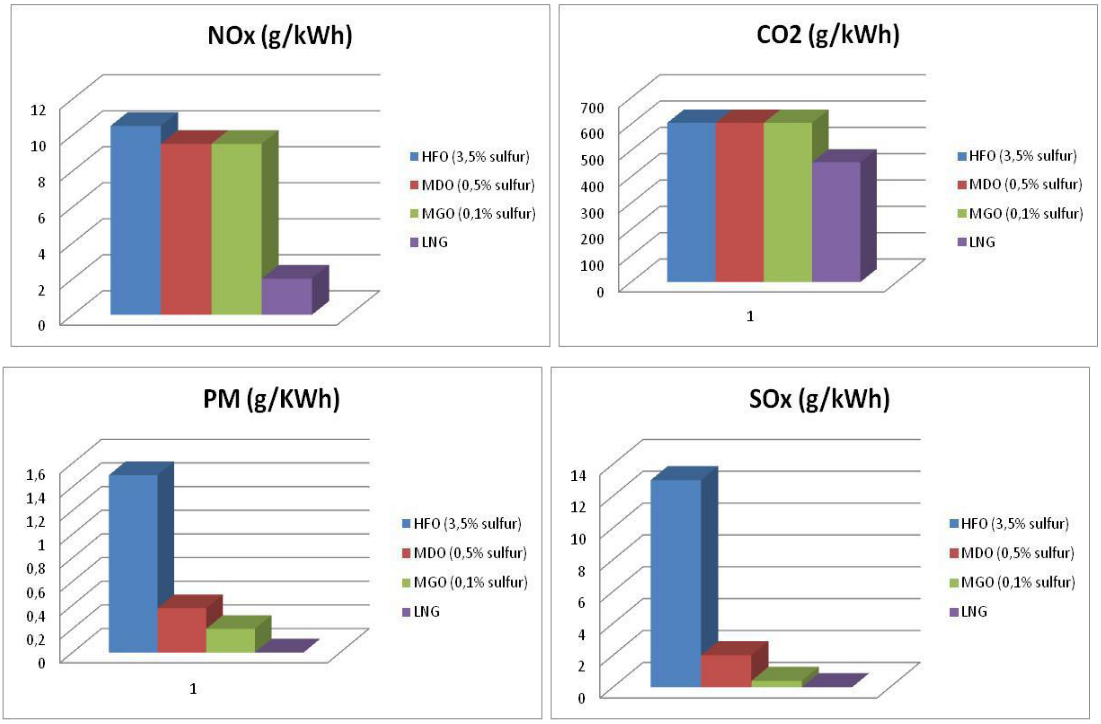

Figure 16.Emissions of LNG and conventional liquid fuels.(Rolls Royce 2009).

7 BUNKERING AND STORAGE

The handling of gas in a safe way is a great importance. It requires accurately working systems to gas from bunkering stations to tanks and from tanks to engines where gas is finally burned. There are several bunkering and storage systems developed for ships using LNG as fuel. One of them is LNGPac developed by Finnish Wärtsila.

7.1 Wärtsila LNGPac system

LNGPac system focuses mainly on safety and simplicity. The system is designed according to IMO *Interim Gas-Fuelled Engine Installations in Ships* .The system consists the bunkering stations, piping, LNG tank, pressure build-up unit, gas valve unit and product evaporator. The system layout is seen in Figure 17.

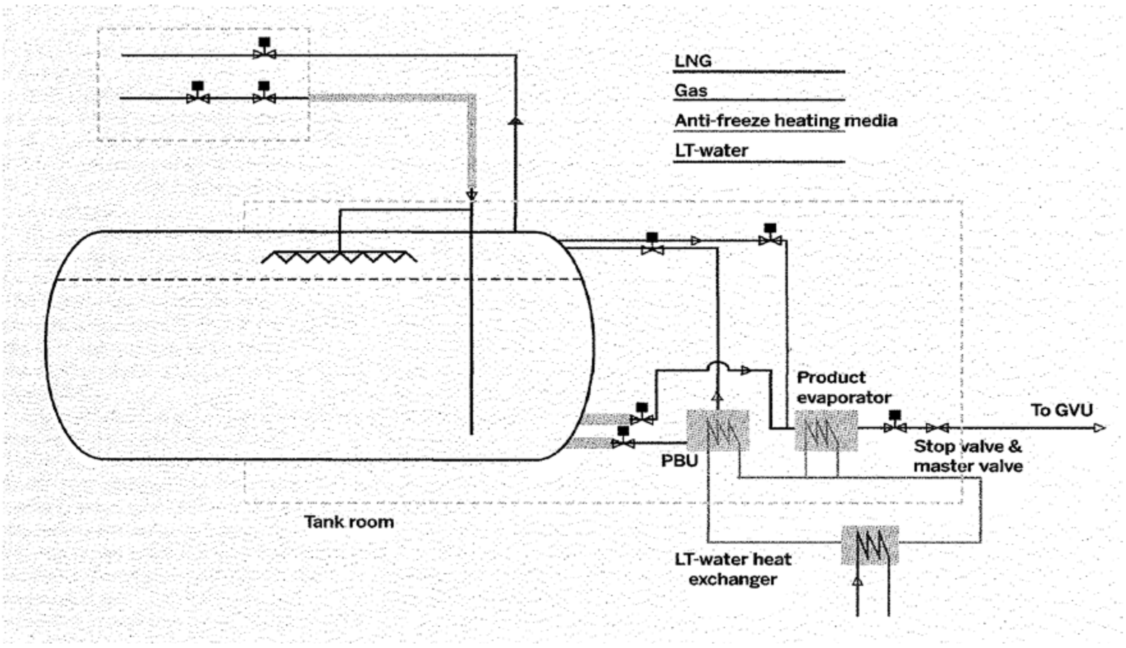

Figure 17.LNGPac system overview. Wärtsila Corporation.

7.1.1 Bunkering station

This is the ships's connection with LNG terminal on shore or with the LNG bunkering barge. A ship has to have at least two bunkering stations. Each station consists of common LNG line, one return line and one nitrogen purging line. Also, the system has control valves and safety valves.

7.1.2 LNG vacuum insulated pipes

From the bunkering station LNG is transferred to LNG storage tanks by pipes. These pipes are vacuum insulated to avoid LNG evaporating.

7.1.3 LNG tank

The pressurized storage tank is cylindrical and has dished ends. LNGPac tanks are insulated with perlite or vacuum. A tank also has the inner tank which is made of stainless steel and is designed for internal pressure .The outer vessel is made of stainless steel or carbon steel and it acts as a secondary barrier in case of leaking. The barrier provides safety also in case of collision, external load and protects against heat in case of fire. The tanks must locate as close to the ship's middleline possible for safety. Each tank must have separate remotely operatable valve.(Det Norske Veritas 2011). In Table 2 are listed tank types stipulated by IMO IGC Code.

Tank Type	Description	Pressure	Pros	Cons
A	Prismatic tank adjustable to hull shapes. Full secondary barrier	< 0.7 bar(g)	Space efficient	■ Boil-off gas handling ■ More complex fuel system (compressor required)
B	Prismatic tank adjustable to hull shapes. Partial secondary barrier	< 0.7 bar(g)	Space efficient	■ Boil-off gas handling ■ More complex fuel system (compressor required)
	Spherical (Moss type). Full secondary barrier	< 0.7 bar(g)	Reliable/proven system	■ Boil-off gas handling ■ More complex fuel system (compressor required)
C	Pressure vessel (cylindrical shape with dished ends)	> 2 bar	■ Allows pressure increase (easy boil-off gas handling) ■ Very simple fuel system ■ Little maintenance ■ Easy installation	■ Space demand on board the ship

Table 2. IMO IGC code = International code for the construction and equipment of ships carrying liquefied gases in bulk.

According to current IMO Guidelines, the LNG fuel tank must be chosen from among independent tanks, type A, B or C. LNGPac have selected type C. Type C is a cylindrical shape with dished ends, and maximum pressure is 2 bars. Advantages are that it allows pressure increase, a very simple fuel system, little maintenance and easy installation. Disadvantage is larger space demand on the ship.

7.1.4 Pressure Build-up unit

Purpose for PBU is to build up pressure in the LNG storage tank after bunkering and maintain pressure during operation. PBU consists an insulated pipe, an evaporator, valves, single wall pipe and sensors. The required pressure in the tank must be 5 bar. This ensures that during gas-engine operation at full load the feeding to the engine with gas works properly.

7.1.4.1 The principle of pressure build-up

LNG is bunkered to ship at -162 C° and atmospheric pressure, which is about 1 bar. For reliable operation, gas engines require 5 bar pressure in LNG tank to transfer the gas from the tank to the engine gas valve unit because the system does not have any compressor or pump for transferring. Some of the gas in LNG storage tank is evaporated in the pressure build-up unit and led back to the tank thus the pressure in the tank increases. The circulation of LNG from the tank to PBU evaporator is achieved by hydrostatic pressure difference between the top and the bottom of the tank. This natural circulation lasts until desired pressure is achieved. Relevant heat for evaporator is provided from LT cooling system.

7.1.5 Product evaporator

The product evaporator consists an insulated pipe, an evaporator, valves, single wall pipe and sensors. The task of product evaporator is to evaporate LNG into gas and heat it to a minimum of 0C° as per engine specifications. Relevant heat for evaporator is provided from LT cooling system.

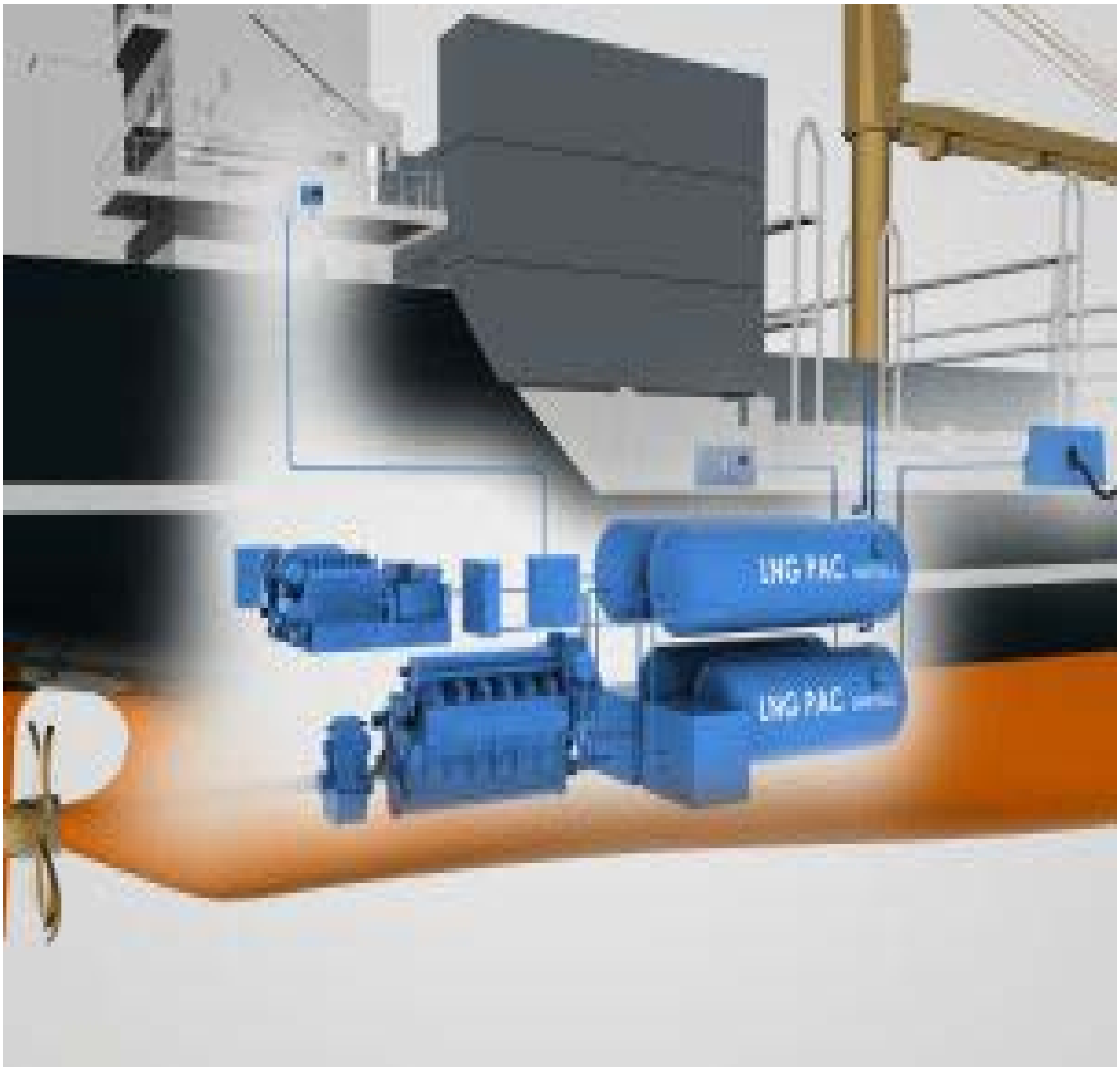

Figure 18. The LNGPac system layout Wärtsila Corporation.

8 MATERIALS OF CONSTRUCTION

As the temperature in LNG system can be at some point very low, even -162 C°, the materials in contact with LNG shall be resistant to brittling. (EN 1160:1996)

8.1 Materials in direct contact

The main materials which are used in direct contact with LNG are listed in Table 3. (EN 1160:1996)

Materials	General use
Stainless steel	Tanks, unloading arms, nuts and bolts, pipes and fittings, pumps, heat exchangers
Nickel alloys, ferronickel alloys	Tanks, nuts and bolts
Aluminium alloys	Tanks, heat exchangers
Copper and copper alloys	Seals, wearing surfaces
Asbestos [1], elastomer	Seals, gaskets
Concrete (prestressed)	Tanks
Epoxyd (resin)	Pump casings
Epoxy (silerite)	Electrical insulation
Fibreglass	Pump casings
Graphite	Seals, stuffing boxes
Fluoroethylene propylene (FEP)	Electrical insulation
Polytetrafluoroethylene (PTFE)	Seals, stuffing boxes, bearing surfaces
Polytrifluoromonochloroethylene (Kel F)	Bearing surfaces
Stellite [2]	Bearing surfaces
1) Asbestos may not be used in new installations.	
2) Stellite : Co 55 %, Cr 33 %, W 10 %, C 2 %.	

Table 3. Materials in direct contact with LNG. (EN1160:1996)

8.2 Materials not in direct contact with LNG

The following materials are used in construction where the temperature is relatively low but they are not in direct contact with LNG. These materials are seen in Table 4.

Materials	General use
Low alloyed stainless steel	Ball bearings
Concrete (Prestressed reinforced)	Tanks
Colloid concrete	Retention dykes
Wood (balsa, plywood, cork)	Thermal insulation
Elastomer	Mastic, glue
Glass wool	Thermal insulation
Rock wool	Thermal insulation
Exfoliated mica	Thermal insulation
Vinyl polychloride	Thermal insulation
Polystyrene	Thermal insulation
Polyurethane	Thermal insulation
Polyisocyanurate	Thermal insulation
Sand	Retention dykes
Calcium Silicate	Thermal insulation
Silica (glass)	
Foamed glass	Thermal insulation, Retention dykes
Perlite	Thermal insulation

Table 4. Materials not in direct contact with LNG.(EN1160:1996)

9 HEALTH AND SAFETY

If at a very low temperature LNG comes a contact with uncovered or unshielded parts of the body or gas is inhaled, the consequences can be severe. Contact with LNG can produce effects on body similar as does burning. Extremely cold gas can cause severe damages to tissues. Unprotected parts of body are not allowed to touch any uninsulated pipes or vessels containing LNG. Prolonged exposure to cold gas and vapour can generate frostbite. Freezing can occur so fast that the body does not give local pain warning. If extremely cold gas is inhaled, lungs can be damaged. Danger of hypothermia exists at temperatures up to 10°C. Persons suffering hypothermia should be relocated from cold area and instantly rewarmed.

9.1 Fire precautions and protection

Fire extinguishers of the dry powder type must be used in case of fire. The most effective way to fight fire is to cover the area with high expansion foam. Water must be used only for cooling purpose. While using an extinguisher, attention must be paid so as not pointed directly to flames. (EN1160:1996)

9.2 Protective clothing

When handling LNG, the eyes should be protected by clogs or a face shield. Leather gloves should be used when handling anything that is contact with LNG. Tight overalls should be worn, preferably without pockets, and trousers should be worn outside shoes. Operating personnel should bear in mind that proper clothing provides some protection against LNG. Any kinds of spills or splashes should be avoided. (EN1160:1996)

10 SHIPS USING LNG

In Table 5 are listed vessels which run with gas engines.

Year	Type of vessel	Vessel name	Owner	Builder	Class	Engine
2000	car/passenger ferry	Glutra	Fjord1		DNV build	MHI
2003	offshore vessel	Viking Energy	Eidesvik	Kleven	DNV	Wârtsilla DF
2003	offshore vessel	Stril Pioner	Simon Møkster	Kleven	DNV	Wârtsilla
2006	car/passenger ferry	Bergensfjord	Fjord1	Aker Yards	DNV	Rolls Royce
2007	car/passenger ferry	Stavangerfjord	Fjord1	Aker Yards	DNV	Rolls Royce
2007	car/passenger ferry	Raunefjord	Fjord1	Aker Yards	DNV	Rolls Royce
2007	car/passenger ferry	Mastrafjord	Fjord1	Aker Yards	DNV	Rolls Royce
2007	car/passenger ferry	Fanafjord	Fjord1	Aker Yards	DNV	Rolls Royce
2008	offshore vessel	Viking Queen	Eidesvik	West Contractor	DNV	Wârtsilla DF
2009	car/passenger ferry	Moldefjord	Fjord1	Gdanska Stoczina	DNV	MHI
2009	car/passenger ferry	Tideprinsen	Tide Sjø	STX France	DNV	MHI gass/Scania
2009	car/passenger ferry	Tidekongen	Tide Sjø	STX France	DNV	MHI
2009	car/passenger ferry	Tidedronningen	Tide Sjø	STX France	DNV	MHI
2009	patrol vessel	Barentshav	REM	Myklebust verft	DNV	MHI
2009	offshore vessel	Viking Lady	Eidesvik	West Contractor	DNV	Wârtsilla DF
2010	car/passenger ferry	Fannefjord	Fjord1	Gdanska Stoczina	DNV	MHI
2010	patrol vessel	Bergen	REM	Myklebust verft	DNV	MHI
2010	car/passenger ferry	Romsdalsfjord	Fjord1	Gdanska Stoczina	DNV	MHI
2010	car/passenger ferry	Korsfjord	Fjord1	Gdanska Stoczina	DNV	
2010	patrol vessel	Sortland	REM	Myklebust verft	DNV	

Table 5. Ships using natural gas. (DNV 2010)

11 CONCLUSIONS

Natural gas is a prevalent fuel. Some experts have determined that natural gas reserves accommodate enough gas to satisfy energy demand for the next 5-6 decades. Stricter rules to protect environment have enforced companies to reduce emissions. Natural gas is a favoured fuel because it is clean and burns cleanly. This means there are less harmful emissions.

This thesis helped to achieve better knowledge of the engines that can run on gas. Different working concepts were studied. General overview gives better understanding of that technical changes are ahead. It seems to be obvious that shipping world is on the way to adopt new fuel, what will be widely used.

This thesis concentrated on technical issues and solutions. Additionally, economical and political aspects could be examined.

APPENDICES

ANNEX 1

Table 1 — Requirements for marine distillate fuels

Characteristic	Unit	Limit	Category ISO-F-				Test method reference
			DMX	DMA	DMB	DMC [a]	
Density at 15 °C	kg/m^3	max.	—	890,0	900,0	920,0	ISO 3675 or ISO 12185 (see also 7.1)
Viscosity at 40 °C	mm^2/s b	min. max.	1,40 5,50	1,50 6,00	— 11,0	— 14,0	ISO 3104 ISO 3104
Flash point	°C	min. min.	— 43	60 —	60 —	60 —	ISO 2719 (see also 7.2)
Pour point (upper) [c] — winter quality — summer quality	°C	max. max.	— —	- 6 0	0 6	0 6	ISO 3016 ISO 3016
Cloud point	°C	max.	-16 [d]	—	—	—	ISO 3015
Sulfur	% *(m/m)*	max.	1,00	1,50	2,00 [e]	2,00 [e]	ISO 8754 or ISO 14596 (see also 7.3)
Cetane index	—	min.	45	40	35	—	ISO 4264
Carbon residue on 10 % *(V/V)* distillation bottoms	% *(m/m)*	max.	0,30	0,30	—	—	ISO 10370
Carbon residue	% *(m/m)*	max.	—	—	0,30	2,50	ISO 10370
Ash	% *(m/m)*	max.	0,01	0,01	0,01	0,05	ISO 6245
Appearance [f]	—	—	Clear and bright		f	—	See 7.4 and 7.5
Total sediment, existent	% *(m/m)*	max.	—	—	0,10 [f]	0,10	ISO 10307-1 (see 7.5)
Water	% *(V/V)*	max.	—	—	0,3 [f]	0,3	ISO 3733
Vanadium	mg/kg	max.	—	—	—	100	ISO 14597 or IP 501 or IP 470 (see 7.8)
Aluminium plus silicon	mg/kg	max.	—	—	—	25	ISO 10478 or IP 501 or IP 470 (see 7.9)
Used lubricating oil (ULO) - Zinc - Phosphorus - Calcium	 mg/kg mg/kg mg/kg	 max. max. max.	 — — —	 — — —	 — — —	The fuel shall be free of ULO [g] 15 15 30	 IP 501 or IP 470 IP 501 or IP 500 IP 501 or IP 470 (see 7.7)

[a] Note that although predominantly consisting of distillate fuel, the residual oil proportion can be significant.

[b] 1 mm^2/s = 1 cSt

[c] Purchasers should ensure that this pour point is suitable for the equipment on board, especially if the vessel operates in both the northern and southern hemispheres.

[d] This fuel is suitable for use without heating at ambient temperatures down to – 16 °C.

[e] A sulfur limit of 1,5 % *(m/m)* will apply in SO_x emission control areas designated by the International Maritime Organization, when its relevant protocol enters into force. There may be local variations, for example the EU requires that sulphur content of certain distillate grades be limited to 0,2 % *(m/m)* in certain applications. See 0.3 and reference [7].

[f] If the sample is clear and with no visible sediment or water, the total sediment existent and water tests shall not be required. See 7.4 and 7.5.

[g] A fuel shall be considered to be free of used lubricating oils (ULOs) if one or more of the elements zinc, phosphorus and calcium are below or at the specified limits. All three elements shall exceed the same limits before a fuel shall be deemed to contain ULOs.

ANNEX 2

MARINE RESIDUAL FUELS

Parameter	Unit	Limit	RMA [a]	RMB	RMD	RME	RMG				RMK		
			10	30	80	180	180	380	500	700	380	500	700
Viscosity at 50°C	mm²/s	Max	10.00	30.00	80.00	180.0	180.0	380.0	500.0	700.0	380.0	500.0	700.0
Density at 15°C	kg/m³	Max	920.0	960.0	975.0	991.0	991.0				1010.0		
Micro Carbon Residue	% m/m	Max	2.50	10.00	14.00	15.00	18.00				20.00		
Aluminium + Silicon	mg/kg	Max	25	40		50	60						
Sodium	mg/kg	Max	50	100		50	100						
Ash	% m/m	Max	0.040	0.070			0.100				0.150		
Vanadium	mg/kg	Max	50	150			350				450		
CCAI	-	Max	850	860			870						
Water	% V/V	Max	0.30	0.50									
Pour point (upper) [b], Summer	°C	Max	6		30								
Pour point (upper) [b], Winter	°C	Max	0		30								
Flash point	°C	Min	60.0										
Sulphur [c]	% m/m	Max	Statutory requirements										
Total Sediment, aged	% m/m	Max	0.10										
Acid Number [e]	mgKOH/g	Max	2.5										
Used lubricating oils (ULO): Calcium and Zinc; or Calcium and Phosphorus	mg/kg	-	The fuel shall be free from ULO, and shall be considered to contain ULO when either one of the following conditions is met: Calcium > 30 and zinc >15; or Calcium > 30 and phosphorus > 15.										
Hydrogen sulphide [d]	mg/kg	Max	2.00										

a	This residual marine fuel grade is formerly DMC distillate under ISO 8217:2005.
b	Purchasers shall ensure that this pour point is suitable for the equipment on board, especially in cold climates.
c	The purchaser shall define the maximum sulphur content according to the relevant statutory requirements.
d	Effective only from 1 July 2012.
e	Strong acids are not acceptable, even at levels not detectable by the standard test methods for SAN. As acid numbers below the values stated in the table do not guarantee that the fuels are free from problems associated with the presence of acidic compounds, it is the responsibility of the supplier and the purchaser to agree upon an acceptable acid number.

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