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# ENGINE AUXILIARY SYSTEM GUIDE-LINE: FUEL GAS SYSTEMS

Technology and Communication
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Tämä päättötyö tehtiin Wärtsilän Technical Services- organisaatiolle. Tehtävänä oli koota yrityksen sisäisten, olemassa olevien dokumenttien sekä eri osa- alueiden asiatuntijahaastatteluiden pohjalta moottoreiden ulkopuolisten kaasupolttoainejärjestelmien ohje yrityksen sisäiseen vianetsintä- ja koulutuskäyttöön. Työ koski tuotannossa olevien Energy Solutions ja Marine Solutions yksiköiden toimittamien 4-tahtimoottoreiden apujärjestelmiä. Installaatioiden erilaiset kokoonpanot kohteesta tai toteutustavasta riippuen ja näistä vuosien saatossa kerääntynyt suuri informaation määrä ovat olleet motivaatioina laatia ohje, josta oleellisen ja ajantasaisen tiedon löytäminen olisi helpompaa.

Työn rakenne ja vaadittava asiasisältö oli ennalta määrätty työn tilaajan toimesta. Pääasiallinen keino tarvittavan tiedon keräämisen oli tutustuminen satoihin yrityksen sisäisiin aihetta käsitteleviin dokumentteihin ja niistä oleellisen tiedon kerääminen. Merkittävässä osassa oli myös eri alojen asiantuntijahaastatteluiden pohjalta koottu tieto. Saatua tietoa verrattiin joiltain osin aihetta käsittelevään vastaavaan tietoon internetlähteistä. Lopullinen työ koottiin kaiken tämän pohjalta, tarkoituksena luoda helposti omaksuttava kirjoitus.

Työn tuloksena rakentui kattava tietopaketti kaasupolttoainejärjestelmistä käytettäväksi päivittäisissä, sekä sisäisissä, että ulkoisissa asiakaskontakteissa. Työ sisältää tietoa koko kaasupolttoainejärjestelmästä, mutta pääpaino on moottorin ulkopuolisissa kaasujärjestelmissä ja niiden toiminnassa. Kaasupolttoaineiden laatu ja ominaisuudet ovat oleellinen osa moottoreiden häiriötöntä ja tehokasta toimintaa, tämän vuoksi kaasupolttoaineiden kemiallisista ominaisuuksista käsittelevää tietoa on myös sisällytetty työhön. Huolto- ja bulletinraportit ovat merkittävässä osassa, mahdollistaen tiedon saatavuuden aikaisemmista tapauksista uusien tapausten nopeamman selvittämisen vuoksi. Huolto- ja bulletinraportit mahdollistavat myös vikojen toistumisen sekä vioittuvien komponenttien ja järjestelmien välisien suhteiden nopeamman havaitsemisen.

Avainsanat Kaasupolttoainejärjestelmät, maakaasu, 4- tahtimoottori ja voimantuotanto

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## ABSTRACT



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This thesis was done for Wärtsilä Technical Services- organisation. The assignment was to gather and compile company existing internal documentation and product expert interview information into a fuel gas system guideline for internal trouble-shooting and training purposes. The assignment was defined to concern Energy and Marine Solutions delivered 4- stroke portfolio engine auxiliary fuel gas systems. The variety of every installation depending on the purpose and the set- up of the installation and thereby the cumulated great amount of related information have been the initiator for producing this guideline for easier access to relevant and updated information.

The structure and the required factual information of this thesis were predetermined by the subscriber organisation. The main method to gather the necessary information was done by reading and studying hundreds of company internal documents. A significant part of the gathered information was originated in several interviews with company product experts. The gathered information was verified and compared to some extent with corresponding information from internet sources. On the basis of all that, the final document was composed aiming to an easily adopted writing.

An outcome of this thesis is a comprehensive information package about fuel gas systems to be used in everyday, both internal and external, customer service tasks. The writing includes general information about the complete fuel gas system although the main focus is on auxiliary fuel gas systems. As an essential part of fluent and efficient engine performance is fuel gas quality, thus a review on fuel gas characteristics and attributes is included. The service report and bulletin matrices included allow a fast access to earlier service cases for comparison of similarity and relations with faulty components and systems.

Keywords Fuel gas systems, natural gas, 4- stroke engine and power production

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| CAM | Cube Auxiliary Module |
| CGR | Compact Gas Ramp |
| DF | Dual Fuel |
| E & A | Electricity and automation |
| EAM | Engine Auxiliary Module |
| EFIC | Electronic Fuel Injection Control |
| FBOG | Forced Boil-off Gas |
| FOM | Fuel Oil Module |
| GRU | Gas Regulating Unit |
| GVU | Gas Valve Unit |
| HFO | Heavy Fuel Oil |
| HT- circuit | High Temperature Cooling Water Circuit |
| IAS | Integrated Automation System |
| IMO | International Maritime Organisation |
| LFO | Light Fuel Oil |
| LNG | Liquefied Natural Gas |
| LPG | Liquefied Petroleum Gas |
| LT- circuit | Low Temperature Cooling Water Circuit |
| MDF | Marine Diesel Fuel |
| MDO | Marine Diesel Oil |

| | |
|---|---|
| ME | Main Engine |
| NBOG | Natural Boil-off Gas |
| PLC | Programmable Logic Controller |
| SOGAV | Solenoid Operated Gas Admission Valve |
| UNIC | Engine Control System |
| WIAS | Wärtsilä Integrated Automation System |
| WOIS | Wärtsilä Operator Interface System |

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# 1 INTRODUCTION

This guideline is made to cover the fuel gas system and related components used in both Energy- and Marine solutions. The guideline includes information about components used in the entire fuel gas system, but is focusing on engine off-components.

The purpose of this guideline is to gather and structure existing company internal information from Energy and Marine solutions, R&D and Technical Services documents into one guideline that is being used by Technical Services personnel for means of troubleshooting the fuel gas system and as a training material.

## 1.1 Wärtsilä as a Company

Wärtsilä is a global leader in sustainable power for the marine and energy markets. The company operations are executed in Energy and Marine solutions and in Service operations. Wärtsilä produces complete energy producing solutions and is committed to lifecycle care of the installations. To practise reliable operations in co-operation with the customers and to produce efficiency, flexible and versatile systems with advanced technologies and minimised environmental impact are the main drivers. A Wärtsilä net sale in 2015 was 5,029 million euros and it is employing approximately 18,800 people in 70 different countries around the world. Wärtsilä was established in 1834 and the headquarters are located in Helsinki Finland. /1/

### 1.1.1 Wärtsilä Services

Wärtsilä Services supports its customers throughout the lifecycle of their installations by optimising efficiency and performance and provides the most comprehensive portfolio of services and the broadest service network in the industry, for both the energy and marine markets.

Wärtsilä is committed to providing high quality, expert support, and the availability of services in the most environmentally sound way possible, wherever our customers are.

Wärtsilä Services employs approximately 12.000 people and the net sales was 43, 4% of the total sales in 2015. /1/

## 1.2 Limitations

This guideline focuses on the fuel gas systems of those 4-stroke engines that are currently in production in Wärtsilä, but a review of the history of Marine and Power plant deliveries and some special applications are presented.

The main focus is on fuel gas systems with 4-stroke engines based on Spark Ignition Gas (SG) and Dual Fuel (DF) technology. A short overview on high pressure Gas – Diesel (GD) engine is also presented.

Additionally the guideline takes into account the typical power plants installations as well as typical marine installations within Wärtsilä’s scope of delivery.

# 2 FUEL GAS SYSTEM

The primary function of the fuel gas system is to secure a safe and constant fuel gas supply to the engines.

Concerning arrangements in all fuel gas system applications, the implementation by a safe and proper way is highly prioritized. Safety is the first concern to be taken into consideration, not to ignore the local legislation and ergonomics in the installations as well.

In power plant solutions fuel gas delivered to the site is typically in vapour-form and in marine solutions the fuel gas is stored on board in liquated form. The fuel gas fed to the engines must always be in gaseous form despite the storing method.

Maximizing the total effectiveness of installations and maintenance, compact and modular fuel gas handling units are used in both power plant and marine solutions. This method will shorten the delivery time, saves space and makes possible to use standard parts.

The fuel gas system configuration may vary widely depending on the combination and purpose of the overall solution.

The main tasks of the fuel gas system are to:

- Store the fuel gas in liquid form if necessary
- Transport the fuel gas
- Secure the purity of the fuel gas by filtering
- Control the flow, pressure and temperature of fuel gas.

More specific information about components used in fuel gas systems can be found in chapter 3 (components) and about the fuel gas characteristics in chapter 4 (fuel gas).

## 2.1 General Information

Wärtsilä is manufacturing different engine types capable of using fuel gas. The basic engine concept is equipped with the required components determining the character of an engine. The Wärtsilä current gas engine types are the SG, DF and GD engines. SG and DF are low fuel gas pressure engines, whereas the GD engine is a high fuel gas pressure engine. SG and DF engine technologies are presented more specifically in chapters 2.1.1 and 2.1.2. A closer review on GD has been left outside this guideline because of its rareness. GD main principles are presented in chapter 2.1.4

All Wärtsilä fuel gas engines are utilizing the lean – burn technology, on both fuel oil and fuel gas mode. The lean – burn technology considerably reduces emissions and fuel consumption by lower combustion temperature and allowing a higher charge pressure. In a stoichiometric system the amount of the air charged to the cylinder is 1 to 1, meaning that the air supplied into the cylinder is sufficient to burn the whole amount of fuel. In a lean-burn engine the amount of charged air is doubled, air / fuel ratio being 1 to 2, meaning that the amount of air charged into cylinders is twice more as in stoichiometric combustion.

### 2.1.1 SG Engine

#### 2.1.1.1 SG Internal Components

SG engines run on fuel gas only. The essential internal fuel gas system components in a SG engine are presented in the figures 1 and 2. On the engine, the gas is supplied through gas manifolds (1), running along the engine, continuing with individual feed pipes to each main gas admission valve (2). A fine filter is placed inside every gas admission valve, preventing particles from entering the valve.

Since the gas admission valve is timed independently of the gas inlet to pre-chamber valve (4), scavenging of the cylinder is possible without risk that unburned gas is escaping directly from the inlet to the exhaust.

The pre-chamber (3, 6) is one of the key components in a lean burn gas engine and it is the ignition source for the main fuel charge. The pre-chamber is optimised to give the best possible ignition with a rapid and repeatable combustion. The design of the pre-chamber and the choice of material are essential for optimal cooling of the pre-chamber and the spark plug. Optimal cooling is required for a long spark plug lifetime. After reaching the pre-chamber a small but rich amount of fuel gas is ignited with a coil connected spark plug (5) making also the main fuel gas explode. /2/

**Figure 1.** Internal fuel gas components on a SG engine. /2/

**Figure 2. P**re-chamber and spark plug. /2/

The relations between fuel components in a SG engine are explained in Figure 3. Gas admission valves controlled by engine control system (UNIC) are operating independently of mechanically operated pre-chamber valves. Vent valves are placed in both fuel gas lines. /2/

**Figure 3.** Fuel component relations in a SG engine. /2/

#### 2.1.2.1 DF Internal Components

DF engines can be run on even three fuels (Tri fuel): fuel gas, LFO and HFO, due to the redundancy and fuel flexibility DF engines are used in both energy- and marine applications.

Differing from a SG engine a DF engine is missing the spark plug, but is equipped with pilot fuel gas system.

On the fuel gas mode, the actual air–gas mixture is triggered with a small amount of pilot fuel injected into the cylinder. The pilot fuel pump unit elevates the pilot fuel oil pressure to the required level by the engine control system. Pilot fuel gas injected into the cylinder via dual fuel injection valve (3) ignites and makes the actual air–gas mixture explode. Pilot fuel used is LFO.

The DF engine on the fuel oil mode utilizes also the pilot fuel components. The essential internal fuel gas system components on a DF engine are presented in Figure 4.

**Figure 4.** (1) Gas manifold, (2) Gas admission valve, (3) Dual fuel injection valve, (4) Inlet valve, (5) Main fuel oil pump, (6) Pilot fuel oil line. /3/

Having entered the cylinder the actual air–gas mixture explodes by the impact of pilot fuel ignition, shown in Figure 5. /4/

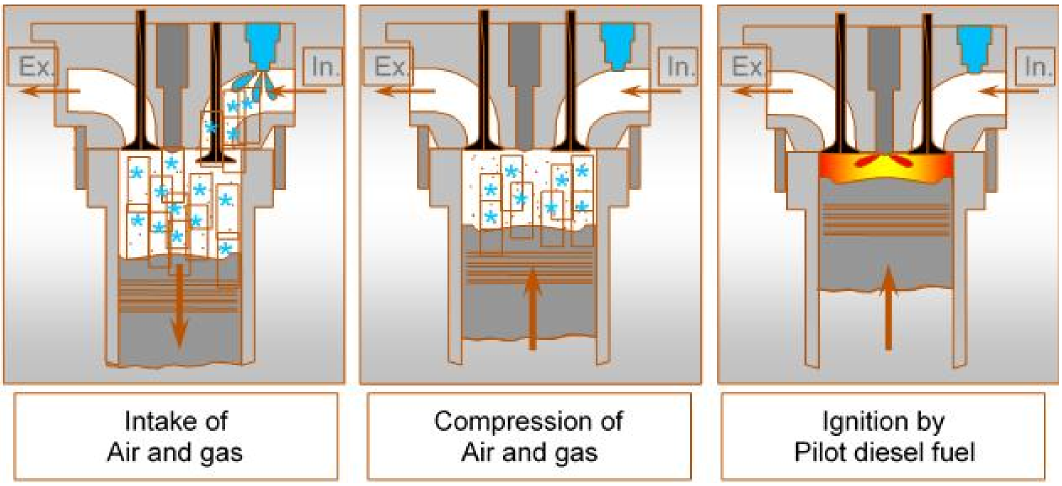



**Figure 5.** DF engine ignition on fuel gas mode. /4/

### 2.1.3 Fuel Gas Pressure

Wärtsilä SG and DF engines are so called low pressure gas engines, The design pressure for all fuel gas systems and components is < 10 bar (g). In some applications there are systems with higher fuel gas pressures, designed and manufactured with more strict requirements.

The required fuel gas pressure in SG and DF engines varies depending on the observation point and can be divided roughly in two main categories, before the gas regulating unit (GRU) and after the GRU. Fuel gas pressure demands depending on the location are presented in chapter 2.6.1.

### 2.1.4 GD Engine

GD engines are high-pressure gas-diesel engines running on various gas-diesel mixtures or alternatively on diesel. The main difference to other Wärtsilä fuel gas engines is the fuel gas pressure reaching approximately 350 bars.

## 2.2 Fuel Gas Aux System

In this chapter only a short notice of the sub-systems is presented and in chapter 3 gives detailed information about each of the sub-systems and/or their components.

The external (outside engine) gas supply system and related support systems can be split into these sub-systems:

- Fuel gas supply and storing
- Piping
- Gas regulating system
- Fuel gas venting system
- Inerting the system
- Gas leak detection system /5/

### 2.2.1 Fuel Gas Supply and Storing

In power plant solutions the fuel gas source is typically a connection to the local gas system infrastructure (fuel is in gas mode) and in marine solutions the storage is the LNG tanks (fuel is in liquid mode). /5/

### 2.2.2 Piping

The fuel gas is travelling along the piping between components. The aim is to build a tight, corrosion resistant pipe line with excellent flow features. The piping system includes several manual and automatic shut-off and venting valves, temperature and pressure indicators. /5/

### 2.2.3 Gas Regulating Unit

In general the gas regulating unit is called GRU. The main function of the GRUs is to regulate the pressure and flow of fuel gas fed to the engines. The specific applications, compact gas ramp (CGR), cube auxiliary module (CAM) are used in power plant applications and the gas valve unit (GVU) is used in marine solutions. Detailed information about the GRUs is presented in chapter 3.2.4. /5/

### 2.2.4 Fuel Gas Venting System

A fuel gas venting system is used to depressurize and vent different parts of the fuel gas system, either for operational or safety purpose. The component initiating the venting can be by the automatic vent valves or safety valves, venting can also be initiated manually. The ventilation pipeline outlet shall terminate in a safe place and remote from any potential ignition source. Venting is depressurising the particular piping area at the same time replacing the fuel gas with air making it safe to work in. Venting valves can be also used for inerting the system.

Typical venting components of the fuel gas system are:

- Automatic vents after shut-off valves
- Gas regulating unit vents; safety, manual and automatic vent valves
- Engine vent lines
- Vents from optional Gas pressure reduction station
- Project specific pipe line, component and filter vents. /6/

#### 2.2.4.1 Inerting

Inerting is done to replace the gas/air from the gas supply pipeline for safe maintenance and installations. Typically all related fuel gas pipelines are equipped with inerting connections or the venting connections can be used for inerting. Inerting gas is replacing the actual fuel gas in the system eliminating the possibilities of fire and explosion. Nitrogen gas is typically used for inerting. /5/

### 2.2.5 Gas Leak Detection System

The gas leak detection system is installed to protect the operators and equipment in case of a gas leak. A typical setup of this system is that if a leak in the system is detected, the fuel gas feed is stopped by automatic fast responding shut-off valves and the fuel gas is vented outside by the means of the fuel gas venting system.
Gas detectors are placed in engine halls and engine rooms where the leak can be most likely discovered and in case of leak the fuel gas feeding is closed. More information about fuel gas leak detection can be found in energy solution related document
Venting lines must always be installed in the way of avoiding the possibility of backflow. Especially the venting lines from engines and tank room must be separated. See bulletin  for more information of marine related venting. /5/

## 2.3 Typical Power Plant Solution

For Power Plants the typical setup is that the customer will arrange a gas supply line from a local gas infrastructure. The available pressure and gas quality is reviewed in each installation and the project team includes needed additional components to compensate for possible mismatch between engine requirement and provided gas type. In some cases it is needed to increase the gas pressure (typically arranged by a low pressure gas compressor) to reach the required level for the engine and in some cases the pressure is too high and a gas pressure reduction station is needed. If the cleanness level (particles) of the gas is not within specification, then a filtration system needs to be added which then keeps the dirt load of the other standard system components. /5/
Depending on gas pressure and other relevant factors, the fuel gas system contains the following parts or subsystems (Figure 6):

- Gas piping
- Gas main shut-off valves: one manual and one automatic
- Gas regulating unit one per engine

Optional parts or subsystems:

- Gas filtration unit and plant gas flow metering unit
- Pressure reduction
- Low pressure gas compressor unit

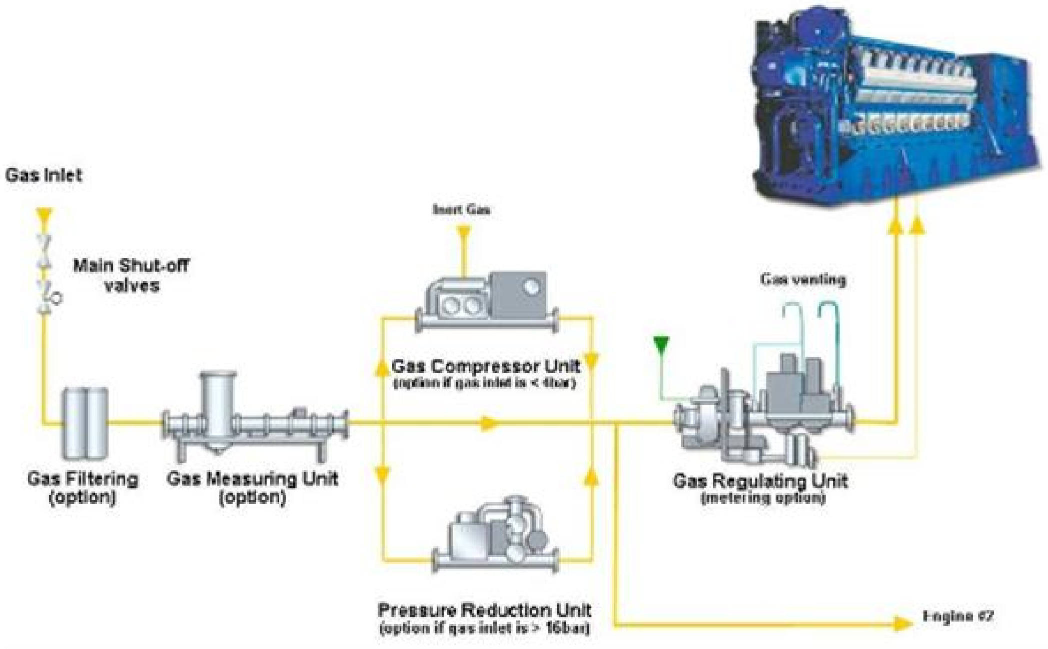



**Figure 6.** Typical power plant set-up. /7/

In most cases the circumstances for fuel gas pressure are not optimal and therefore either the gas compressor or the pressure reduction unit is installed. /7/

Several engines and the CAMs / EAMs are typically placed side by side in power plant solutions (Figure 7).


**Figure 7.** Typical power plant layout. /8/

### 2.3.1 Power Plant, History of Deliveries

First Fuel Gas Engine:

Wärtsilä has delivered fuel gas engines already in the 60s- and 70s with join-venture arrangements, those engine types are no more portfolio engines.

The year 1995 was when the first Wärtsilä brand fuel gas engines were delivered. Engine type was **18V 34SG** and they were sold to Denmark. /9/

First Dual Fuel Engine:

In 1997 the first DF engines were delivered. The engine type was 18V 32DF and were sold to Turkey and to United Kingdom.

## 2.4 Typical Marine Solution

In marine solutions the fuel gas system has the same functional requirements concerning e.g. the pressure and temperature than in power plant solutions, but often in limited space.

Fuel gas carried in the vessels is Liquefied Natural Gas (LNG) to maximize the amount of fuel gas and to decrease the needed space. Despite the storing media in LNG form, fuel gas used in SG and DF engines must be prepared into vapour form before use.

The DF engines are the only concept used in marine solutions at the moment, due to the requirements for double installations in a SG solution for redundancy.

In marine solutions engines utilize the available natural boil-off gas (NBOG) and the rest of the needed fuel gas is produced by “forcing” (letting) the LNG to boil-off (FBOG).

In LNG solutions there are two evaporators in the system, the pressure build-up evaporator and the main gas evaporator. The pressure build-up evaporator takes LNG from the bottom of the tank and returns it in gaseous form to the top of the tank, causing a pressure increase. The pressure increase is required because the gas in LNG form will not otherwise transfer to the main evaporator. The main gas evaporator takes LNG from the storage tank, vaporizes it and heats the gas to the desired temperature before it enters the gas regulation system of the engine. The source for the LNG heating energy is taken from the system low temperature cooling circuit (LT), where the main gas evaporator is connected to. More information about NBOG and FBOG is in chapters 2.4.1 and 2.4.2. /12/

In a typical marine solution the essential off-engine fuel gas components are:

- Fuel gas storage tanks with bunkering station
- Piping for fuel gas
- Piping for venting, venting valves
- Evaporators

- Gas heater unit for vaporized LNG
- GVUs
- Monitoring equipment

Heating unit and evaporators are located in LNG / gas treatment compartment. A typical marine solution layout is shown in Figure 8. /13, 14/

**Figure 8.** Typical marine solution layout. /14/

### 2.4.1 Natural Boil-off Gas

In liquefying process natural gas is cooled down under its boiling point of ~ -162°C in atmospheric pressure reducing the volume by 1/600. As a disadvantage the warmer ambient temperature is constantly warming the stored LNG making it boil forming NBOG and increasing the pressure inside the tank. In order to maintain the suitable pressure, the vaporized LNG must be released from the tank by using it as fuel, it can be re-liquefied or it can be vented to atmosphere.

LNG carriers are maximising the utilization of the NBOG released from the tanks they are carrying. The sufficiency of NBOG for the only fuel depends on the size of the LNG tanks and on the load and speed conditions of the ship, those details determine if FBOG is needed as assistant fuel. In large LNG carriers (≥155 k m3) the forming of NBOG is can be up to 75 tons / 24 h. A LNG carrier with re lique-faction plant installed shown in Figure 9. /14, 15/

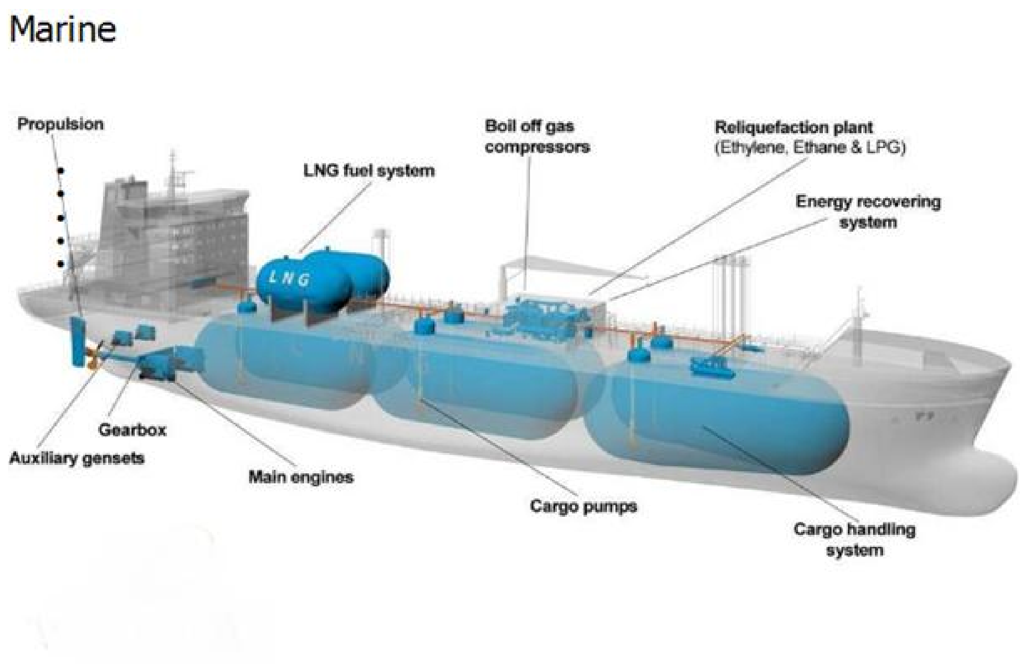



**Figure 9.** LNG carrier with re-liquefaction plant. /15/

### 2.4.2 Forced Boil-off Gas

Another typical fuel gas application in marine solutions is ships using primarily LNG. The fuel gas is stored in LNG tanks on-board, typically for several days of operation. Today Wärtsilä can provide complete LNG handling systems but applications concerning LNG tanks and bunkering may vary depending on shipyard's decisions. Third party LNG tanks can be used in solutions to be delivered. Back-up fuel (HFO/MFO/LHO) is also stored on-board for redundancy.

The engine constructions remains the same but due to the LNG characteristics controlling the temperature and pressure in LNG tanks is one of most important things to take care of. Refuelling the on-board LNG tanks requires also a safe and valid bunkering procedure.

The stored fuel gas in LNG tanks produces some amount of NBOG, but the main fuel gas consumption is provided by forcing the LNG to evaporate. The forced boil-off gas must be heated and pressure reduced to suitable level./16/

### 2.4.3 Marine, History of Deliveries

## 2.5 Safety of Installations

The fuel gas applications in marine solutions and power plants vary considerably, therefore Wärtsilä has a separate safety concepts for power plants and marine solutions in order to ensure the safety validity in all circumstances.

The idea of safety concept is by default to fulfil all relevant classification society rules and EU-directives (conformity to EU directives forms the design bases for a fuel gas power plant delivery). This method, i.e. standardization, in addition to increase safety, is simplifying processes making the delivery time shorter and strengthening overall the chain of value.

In some countries local laws and regulations are over-ruling the concept design and thereby installations differing from the standard safety concept have been delivered. /21/

### 2.5.1 Safety Concept Marine Solutions

In marine solutions safety requirements are defined by a certain classification method. Classification means in practice that a ship and all critical parts and modules have been designed and built according to the appropriate rules of a classification society. The rules define key technical requirements for the critical products, components and materials. They also define procedures, which have to be followed when products, modules, materials are manufactured and delivered. Normally a ship owner or in some cases a ship yard decides which classification society is used in a project. There are several different ship categories in the market and they each have their own rules they must be build according to. Wärtsilä marine classification procedure can be found in document

The basis for classification society rules are international laws and regulations. The most important factor is the International Maritime Organisation (IMO). IMO is the global standard-setting authority for the safety, security and environmental performance of international shipping. Its main role is to create a regulatory framework for the shipping industry that is fair and effective, universally adopted and implemented.

In addition to IMO, there are several other international laws and regulations that the classification society rules are based on. Among them are EU-directives which are complied with by the classification societies. EU-directives are not complied with directly as directives, but classification rules will in minimum meet them. Classification rules are typically strengthened with e.g. higher safety factor or thicker steel material.

Also local national and regional laws and regulations are complied with by the classification societies. Local authorities like Trafi in Finland are in co-operation with the IMO. More detailed information about related EU-directives can be found in document

When international and local laws and regulations have been taken into consideration by the classification society, the society formulates its rules. The classification society will take advantage of its own experience and know-how regarding previous installations when formulating the rules to create safe and durable systems. The classification society may also interpret laws and regulations independently and therefore differences in rules between societies are existing.

Wärtsilä has also designed a specific safety concept for GVUs, the content can be found in document /22, 23/

### 2.5.2 LNG Pac Classification Reference

### 2.5.3 Safety Concept Power Plant Solutions

In power plant installations safety requirements are defined mainly on EU-directive basis. The power plant safety concept content can be found in document In most cases at least the following EU-directives are complied with:

- Machinery Directives (MD 2006/42/EC)
- Atmospheres explosive (ATEX 94/9/EC)
- Pressure Equipment (PED 97/23/EC) , including CE-marking when needed

In addition also Low Voltage Directives (LVD 2006/95/EC), EMC Directive (EMC 2004/108/EC) and Directives on emissions from non-road mobile machinery (NRMM 97/68/EC, 2002/88/EC, 2004/26/EC and 2006/105/EC) directives in many cases must be complied with. Safety concept content for GD engines can be found in document /25/

### 2.5.4 Machinery Directive

Machinery Directive 2006/42/EU is the main directive. All the other directives, such as PED, EMC, LV and ATEX are made for design areas that need special attention, but the main principles for design are found from the Machinery Directive and standards related to it. In order to meet the requirements of the directives the relevant standards need to be followed. /26, 27/

### 2.5.5 ATEX

ATEX is one of the main directives to be taken into consideration. It contains definitions for safety and health protection and for the equipment and protective systems intended for use in Potentially Explosive Atmospheres. The main ATEX definitions are:

- Assessment of explosion risks
- Explosion protection document
- Area classification into zones 0, 1, 2 & unclassified
- Criteria for the selection of equipment based on area zone classification
- Criteria determining the classification of equipment into categories 1, 2 & 3
- Content of the EC declaration of conformity
- Equipment marking

More detailed information about zones in document The ATEX hazardous zones are shown in Table 1. /28/

**Table 1.** ATEX hazardous zone table. /28/

### 2.5.6 PED Module G

The PED directive is divides pressure equipment components into four conformity assessment categories. Number 1 with the lowest requirements and number 4 with the highest requirements. In Wärtsilä with category 2 or higher procedure G, called also module G is followed. In this procedure final assessment (final inspection and proof test) is performed by a notified body. Technical documents must be available for final assessment whether that assessment is carried out by the manufacturer or by the notified body. The manufacturer must keep the declaration of conformity with the technical documentation for 10 years. In Wärtsilä installations piping is in category 1, filters in category 3 and assemblies in category 3 (module G). More information about the effects of the PED directive on fuel gas piping and assemblies can be found in documents and . /12, 29/

## 2.6 Essential Parameters

The primary function of the fuel gas system is to secure a safe and constant fuel gas supply to the engines. Wärtsilä fuel gas engines are designed and developed for continuous operation on natural gas, without reduction in the rated output. The essential parameters are reviewed in the engine point of view.

The essential parameters for durable and smooth engine performance are fuel gas quality and composition related, added with the factors of correct fuel gas quantity and temperature. Significant for the correct amount of fuel gas injected into cylinders is the suitable fuel gas pressure and flow. The combination of designed pipe sizing and the pressure secure the needed amount of fuel gas, not forgetting that the inlet temperature of fuel gas must be in the range of 0 °C – +60 °C. Fuel gas purity in terms of particles is also important. Variates of hydrogen, water and particles have certain tolerances they must be within.

The natural gas attributes vary depending on the sources, even gas from the same well may vary. When using LNG, wanted attributes can be achieved by liquefying process. The composition of used natural fuel gas must be in prescribed limits especially concerning the lower heating value (LHV) and methane number (MN).

Fuel gas quality:

- Each well can have its own gas quality -even on the same field
- Field quality can be maintained by mixing gases from different wells
- Quality between different wells can vary so much that adjustments has to be made in the equipment using the gas.

Table 2 shows an example of natural gas composition variations in different fields around the world. /30/

**Table 2.** Natural gas compositions in different fields. /30/

More information about fuel gas attributes is presented in chapter 4.

The sufficient quantity of fuel gas is controlled by the engine controlling unit. The UNIC system controls the fuel gas pressure and thereby the actual amount of fuel gas. The fuel gas pressure operates in a narrow pressure range and it is load dependent. The temperature of fuel gas fed into the GVUs must be in correct range and pre-heated when using LNG. Purity is secured with filters in gas inlet pipeline, in GVUs and fine filters before gas admission valves.

### 2.6.1 Fuel Gas Pressure

#### 2.6.1.1 Off Engine

The amount of needed fuel gas is depends on engine load conditions and the quality of used fuel gas. The UNIC system controls the actual amounts of fuel gas. The sufficient fuel gas amount is achieved with high enough of fuel gas pressure in co-operation with the gas admission valves. The increased fuel gas demand in the engine increases the fuel gas pressure as well.

The circumstances on the power plants in most cases are not optimal and therefore either a compressor or a pressure reduction unit is required for making the fuel gas pressure suitable. The fluctuation of the pressure causes fluctuation in engine performance and must therefore be controlled.

In marine solutions when using LNG, the pressure pre-adjusting is done in the tank releasing and heating unit by the gas evaporators. The normal storing pressure in a LNG tank is 6 bar (g). /31/

The piping length is recommended to be the shortest possible due to the pressure drop and response time in long pipe installations e.g. emergency shut-off valve function, typically the piping between GRU and  the engine is recommended not to be more than 10 m. /32/

#### 2.6.1.2 On Engine

The level of the fuel gas pressure injected into the manifold must always be kept above the charged air pressure in order to avoid the reverse fuel gas flow. The general rule is set the fuel gas pressure led into the gas admission valves one above the charged air pressure. /35/

# 3 FUEL GAS SYSTEM COMPONENTS

The fuel gas system components are presented in this chapter. The needed functions and components for the typical SG and DF engine fuel gas systems in power plants and marine solutions are principle the same, only the solution structures varies. Fuel gas components are presented in on engine and off engine categories according to their appearance in the systems.

## 3.1 On Engine Components

### 3.1.1 Piping

The current marine installation design has the gas supply piping in the engine room and on the engine is with double-wall. The double wall structure is designed for safety reasons and allows by the classification society rules to have the GVU next to the engine, thereby allowing for shorter gas piping and faster reaction time for gas pressure/flow regulation. The air space between the inner and outer pipeline is continuously ventilated and in case of leak in the inner pipe the outer pipe prevents the fuel gas entering the engine room and instead leads the leak gas to pass into the ventilation system and exit outside the vessel in a safe area. The double wall ventilation systems are typically equipped with a fuel gas leak detection system that will then shut-off the engine (or trip it into diesel mode) and provide some level of alarm to the control room. /5/

The gas supply piping in the engine room and on the engine is with double-wall. The double wall structure is designed for safety reasons. The air space between the inner and outer pipeline is under pressured and in case of leak the outer pipe is preventing the fuel gas entering the engine room. The possible leaked fuel gas is lead into the venting pipelines.

On the engine the double-wall structure covers all pressurised parts of the gas supply piping. The inlet to the annular intermediate space is arranged on the engine, and is close to the gas vent line from the engine. Installations after approximately the year 2005 are implemented with double wall piping. Material for double wall pipelines is typically seamless pipe of stainless steel of type grade.

Instructions links for welding and bending can be found in document The double wall structure is shown in Figure 10. /40, 41/

**Figure 10.** Double wall fuel gas manifold structure on-engine piping. /41/

The fuel gas piping arrangements between the engine flange and external fuel gas components are typically implemented with flexible hoses. This is done to avoid the connection problems caused by the vibration of the engines. Some flexible hoses are shown in Figure 11. /42/

**Figure 11.** Flexible hoses are used to avoid vibration effects. /42/

#### 3.1.2 Pre-chamber Valve

Gas to the pre-chamber flows through a hydraulically operated valve. The yoke for the inlet valve presses down a piston, on top of the pre chamber, at the same time as the inlet valve is opened. The generated oil pressure will then open the pre chamber valve and allow gas to flow in to the pre chamber. This solution is reliable and gives an excellent mixture in the pre chamber. The amount of injected gas is controlled by gas pressure. The pre chamber valve is shown in Figure 12. /2, 43/

**Figure 12.** Pre-chamber valve. /43/

### 3.1.3 Pilot Fuel Oil Pump

In DF engines the pilot fuel oil pressure is set to the required level by the engine control system. A common rail pipe delivers pilot fuel to each injection valve and acts as a pressure regulator against pressure pulses. /44/

The engine driven pump (Figure 13) unit consists:

-Radial piston pump

-Fuel Filters

-Necessary valves

-Control system

**Figure 13.** Engine driven pilot fuel oil pump. /44/

### 3.1.4 Dual Fuel Injection Valve

When running in the gas mode, the main components are the gas admission valves and the dual fuel injection valve. Pressurised pilot fuel is delivered from the pilot fuel pump into a common rail pipe. The common rail pipe circulates around the engine delivering pilot fuel to each injection valve. The pilot fuel is the ignition source for the air-gas mixture. In the fuel oil mode the main injection needle is providing the main fuel supply.

### 3.1.5 Solenoid Operated Gas Admission Valve

The main gas admission valve is the component which actually lets the fuel gas into the manifold, gas admission valves are solenoid operated (SOGAV) and one SOGAV is installed before each cylinder. SOGAV is controlled by the engine UNIC system. The earlier bottom-load gas admission valve was replaced by the top-load main gas admission valve 2010. SOGAV is shown in Figure 14. /41/

**Figure 14.** SOGAV, gas venting valves and gas manifold. /41/

## 3.2 Off Engine Components

### 3.2.1 Storage

There are two main principles in supplying or storing fuel gas to the installation locations. Natural gas in vapour form can be led via a gas pipeline to the power plant or the natural gas can be stored in specially designed and manufactured LNG tanks. The main principle in LNG tanks is the double shell structure forming an annular space between shells. The annular space is kept vacuumed by a vacuum device. The vacuumed space makes excellent insulations to minimize the effect from ambient temperature. After all in any case, the fuel gas must be in gaseous form for the engines.

#### 3.2.1.1 LNG (Wärtsilä System)

In marine solutions there are different types of LNG tanks. The main types are Membrane, IMO Type A – B and IMO Type C. IMO Type C is cylindrical and therefore accepts higher pressure but is not space optimal like prismatic shaped Membrane and IMO Type A – B. /45/

Wärtsilä has developed the LNGPac™ solution (Figure 15) which is a complete fuel gas handling system for LNG fuelled ships and includes the bunkering station, LNG tank and related process equipment as well as the control and monitoring system. The main process equipment inside the tank connection space ensures correct gas temperature for the engines and maintains sufficient pressure inside the LNG tank. The tank connection space is also called “cold box”, this is the area where the evaporators are located. In the new LNGPac concepts GVUs and heating unit are also integrated in the tank connection space making space and cost savings in installing phase and maintenance. Since the GVUs are integrated in the tank connection space the distance between engines and the LNG pack cannot exceed 10 m. In solutions with not integrated connection space, the GVUs are located near to the engines. /46/

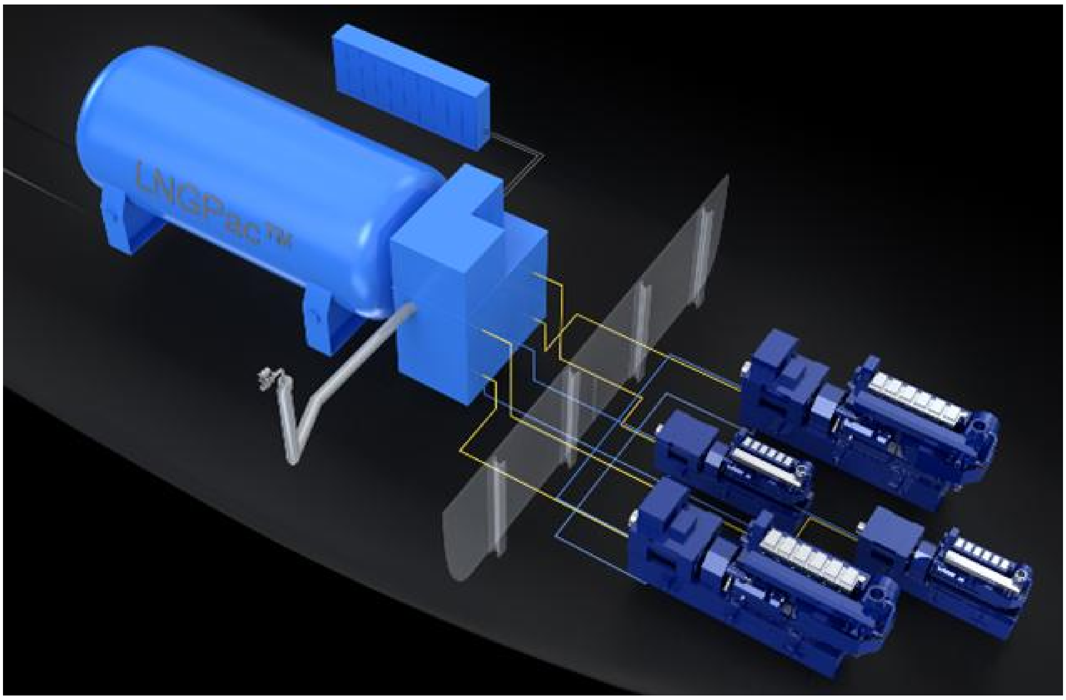



**Figure 15.** Wärtsilä LNG Pack. /46/

#### 3.2.1.2 Main Gas Evaporator

In LNG solutions the main gas evaporator provides the engines with gaseous fuel. LNG from the storage tank is vaporized in a heat exchanger connected to the glycol/water circuit. The heat exchanger also heats the gas to a suitable temperature. The evaporator is in operation whenever an engine is running on fuel gas. Automatic valves on the inlet and outlet sides of the evaporator control the fuel feed to the engines. The evaporator normally receives LNG from the bottom of the storage tank. An additional inlet line allows gas from the top of the tank to be released to the engine fuel system through the evaporator if the tank pressure rises too high. The evaporator system includes connections for venting and inert gas filling, a pressure relief valve and sensors for temperature and pressure monitoring.

The primary heat source for main gas evaporator for heating the LNG is the LT-water cooling circuit. The central component of the heating system, apart from the evaporators, is the glycol-water skid, which circulates the heating medium through the evaporators and controls the temperature. The LT glycol-water circulates in engine lubrication oil and compressed air coolers transferring the heat to the main gas evaporator. The main gas evaporator is shown in Figure 16. /47/

**Figure 16.** Main gas evaporator. /48/

#### 3.2.1.3 Pressure Build up Evaporator

The pressure build-up evaporator raises the pressure in the storage tank to the set level after the fuel bunkering. It also operates intermittently after the initial pressure build-up, to compensate for pressure losses as fuel is fed to the engines. The evaporator is put in operation whenever the pressure in the tank drops too low. The normal tank pressure level is [illegible] The pressure build-up evaporator is heated by the glycol/water circuit, and the heat transfer causes vaporization of LNG. The gaseous fuel is returned to the storage tank, causing the pressure in the tank to increase. /47/

#### 3.2.1.4 Cold Recovery

Wärtsilä's patented Cold Recovery System utilises the latent heat of LNG in air conditioning systems, reducing the amount of electricity consumed in cooling compressors.

An LNG tank cold recovery system uses the new local heat transfer units, of which one is connected to the vessel's cold recovery system. This connection reduces the number of separate pumps and heat exchangers that have been needed in a conventional cold recovery system. The recovered cold can be used e.g. in ship air conditioning system. /17, 49/

### 3.2.2 Glycol-water Skid

The glycol-water skid circulates the heating medium through the evaporators and controls the temperature. The evaporators (PBE&MGE) are heated by available on-board heat source(s) using an anti-freezing heating medium circuit for the heat transfer. The installation specific heat source may be thermal oil system, steam, HVAC system or engine LT-water system. The main components of the unit are the circulation pumps, the heat exchangers and the expansion tank. In the heat exchangers, heat is transferred from the heat source (for example thermal oil) to the heating medium (glycol/water) circuit. The system contains three parallel heat exchangers, all of which are in use at the same time. A motor-operated valve regulates the thermal oil flow through the heat exchangers based on the water temperature. The automatic flow regulation keeps the water at the correct temperature regardless of changes in the heat transfer rate in the evaporators.

The unit includes two circulation pumps, connected in parallel. The pumps are driven by electric motors running at fixed speed. A closed expansion tank compensates for volume changes due to temperature variations in the system, and keeps the system pressurized by means of a nitrogen cushion in the top of the tank. The tank is equipped with a pressure relief valve, a level indicator and level switches for high and low level alarms. It also has a filling line for adding heating medium to the system, and a connection to a nitrogen bottle for pressure adjustment. Manual shut-off valves are installed throughout the glycol-water skid. Non-return valves by the pumps prevent the backflow of water. The unit contains sensors and indicators for monitoring the pressure and temperature of the water and the thermal oil. An example of the flow diagram of the fuel gas heating system is shown in Figure 17. /47/

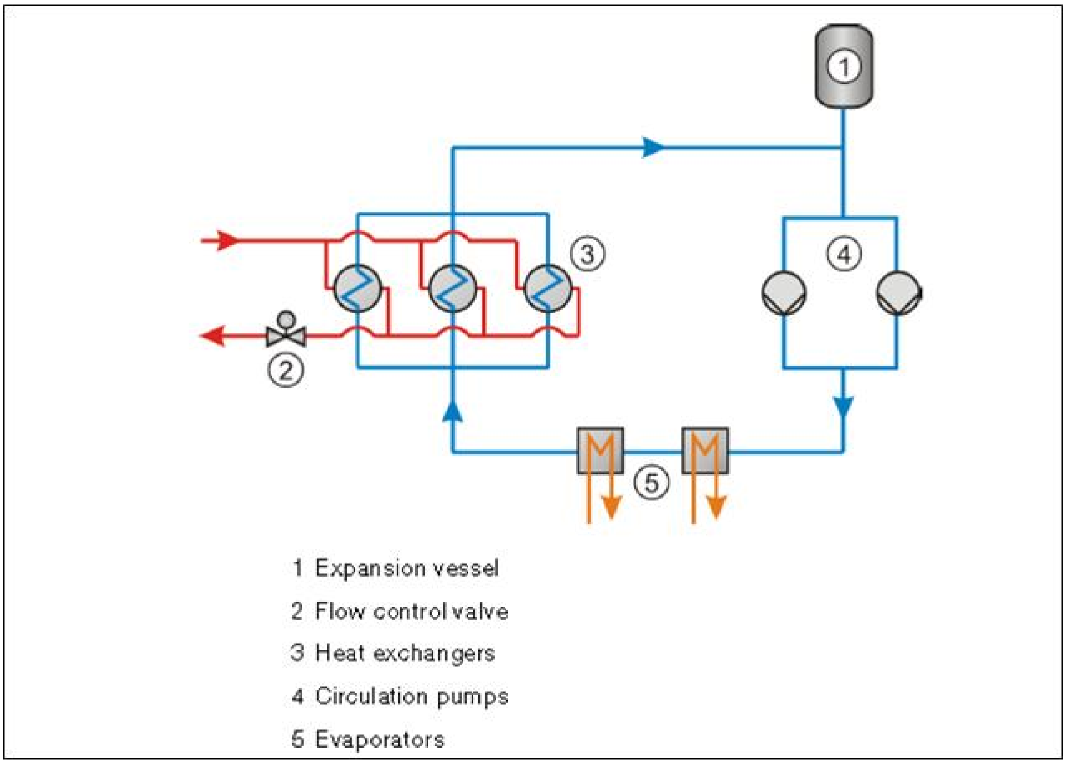



**Figure 17.** Flow diagram of the heating system. /47/

### 3.2.3 Piping

The gas piping is connecting the units into one gas supply system. Typically in power plant solutions the pipes are made of carbon steel and in marine solutions of stainless steel. The piping between the gas regulating unit (GRU) and the engine shall be made of stainless steel in all applications. Stainless steel gas piping is also selected on the engine to reduce pipe scaling and particles ending up to cylinder specific main gas valves. Local regulations regarding the construction of gas piping systems, main shut-off valves and venting must always be considered. This is also a reason why there are installations delivered with solutions that are not in accordance with concept designs, so in troubleshooting cases it is recommended to always look at the installation specific design. /5, 50/

To minimize pressure and flow losses the piping is designed as short and straight as possible. Table 3 shows data for determining the pipe size in relation to gas flow and pressure. The gas flow depends on the number of engines, engine output and efficiency and gas lower heating value (LHV). The size can also be calculated according to Equation 1. In marine solutions installations are considered as an assembly thus piping is arranged according the module G. /50/

**Table 3.** Power plant pipe size determination (Verify up to date document number

d diameter [m]

p absolute pressure (not gauge) [bar(a)]

T temperature [K]

v velocity of gas [m/s]

V volumetric flow of gas [m3/s]

π constant: π (3.14159)

act actual conditions

b base conditions (normal temp and pressure) (e.g., 0oC & 1.0133 bar a).

### 3.2.4 Gas Regulating Units

#### 3.2.4.1 Common

The essential parts in GRUs are filter, auto shut-off valves, venting valves and control valve. The appearance of these components may vary, but all of them are included in all versions of GRUs.

When entering the GRU the fuel gas is filtered by a larger filter (Figure 18, 1). The filter is a cartridge type and equipped with pressure sensors to detect the filter clogging.

Before entering to the control valve, fuel gas passes two auto shut of valves (3) in. The automatic shut-off valves and venting valves (4) are operated during the start and stop sequences, and they are controlled by the engine-specific PLC. The shut-off valves are opened pneumatically and closed by a spring (FAIL CLOSE). The valves are ball type valves and meet the EN161 (A) standard for automatic shut- off valves. Together with the first automatic venting valve the shut-off valves form a double block and bleed connection.

The automatic venting valves are operated pneumatically. The venting valve between the shut-off valves is always open when the engine is stopped. The shut-off valves are closed pneumatically and opened by a spring (FAIL OPEN).

The pneumatic gas regulating valve (5) (control valve) regulates the outlet pressure of the fuel gas. The gas pressure is controlled by the engine control system based on the charge air pressure, through a position reference to the control valve. For each engine, the gas supply pressure has to be adjusted within a narrow, load dependent, pressure range. The adjustment is made by means of a pressure control valve located within 10 m of the engine. A smaller gas volume between the pressure control valve and the engine improves the response time of the system during transient conditions, such as engine load fluctuations. /51/

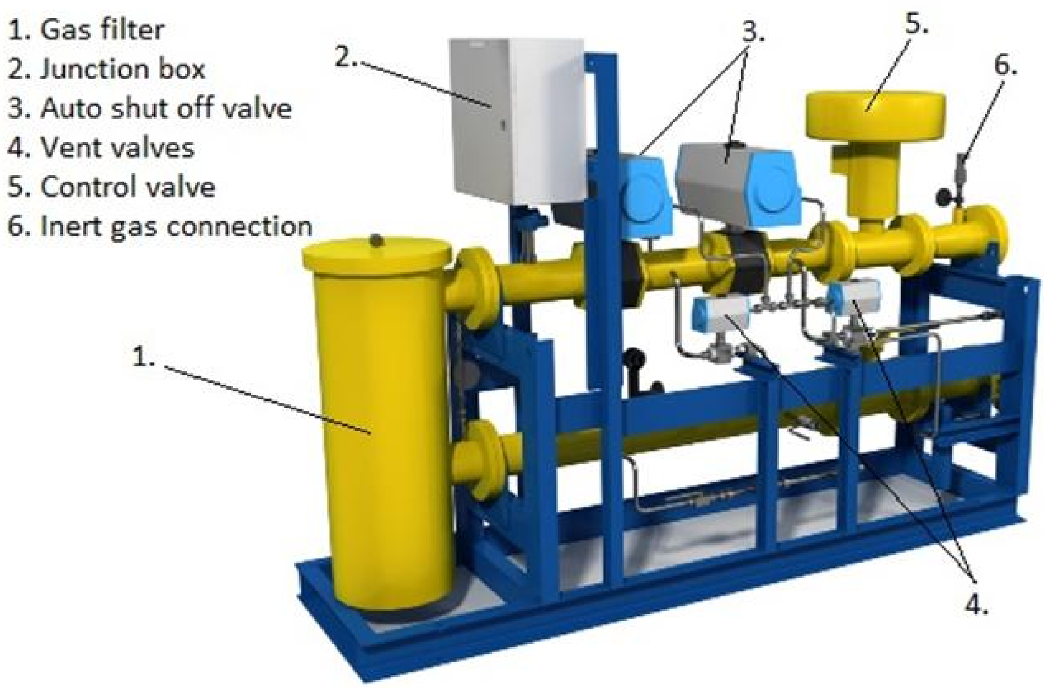



**Figure 18.** Compact gas ramp for a DF engine. /51/

Gas regulating units with SG engines must be equipped with two separate fuel gas lines, one for the main combustion chamber (MCC) and one for the pre-combustion chamber (PCC). Otherwise CGR for SG engines is similar to the CGR for DF engines. CGR for a SG engine is shown in Figure 19.

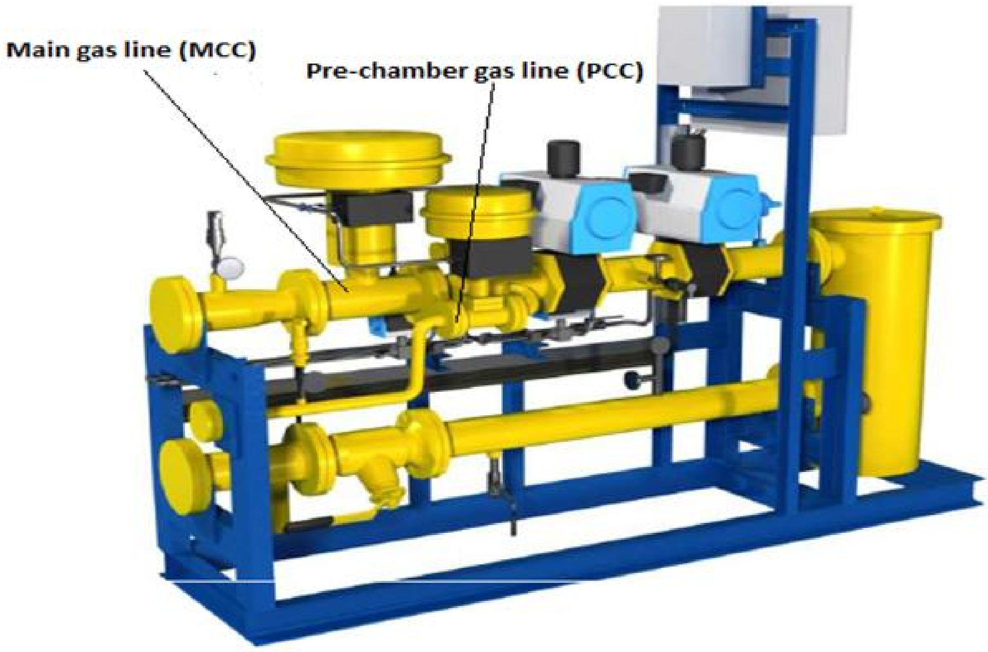



**Figure 19.** Compact gas ramp for a SG engine. /52/

In some solutions third party manufactured systems are used to control the fuel gas. units have been installed as a part of Wärtsilä solutions. Notice different regulating valve control philosophy in third party applications. /53/

#### 3.2.4.2 CAM

Cube Auxiliary Modules are available for W34SG engines. The module features depend on engine design phase and Modular or Gas Cube configuration. Modules used with DF engines have the same principle than CAM, but added with fuel oil module (FOM).

The fuel gas supply is controlled by an integrated gas regulating unit. The module includes the necessary piping, pumps, filters, valves and instrumentation. The main components in a CAM with 34 SG engine are shown in Figure 20. /54, 55/

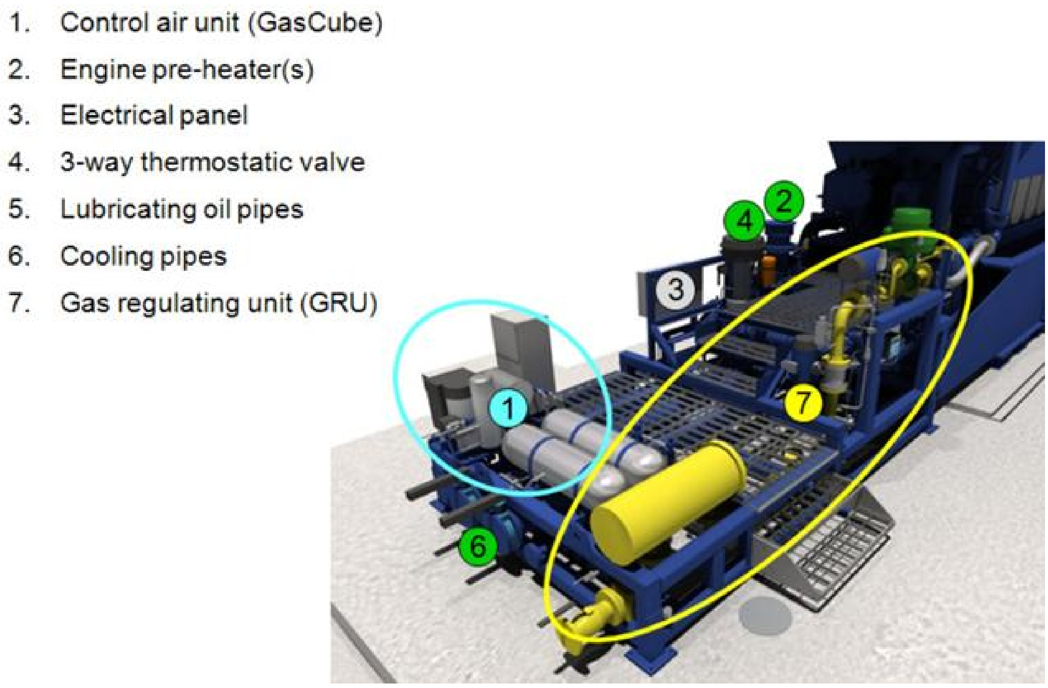



**Figure 20.** 34SG engine CAM main components. /55/

### 3.2.4.3 GVU

The Gas Valve Unit (GVU) is a marine solution for regulating fuel gas and it is connected to the DF engine gas supply piping. Each engine has its own GVU and the unit controls the gas pressure to the engine depending on the engine load. The Gas Valve Unit can be implemented either as an open design (GVU-OD) or enclosed design (GVU-ED). /56/

The Gas Valve Unit has three main functions:

- Prior to gas operation of DF-engine the GVU performs a gas leakage test of the main shut-off valves in order to ensure that the valves are working properly before it enables gas supply to the engine.
- During DF-engine operation in gas operating mode the GVU controls gas feed pressure to the engine.
- At specific events GVU prevents gas feed to the engine and performs a purging of gas feed line to the engine with inert gas.

### 3.2.4.4 GVU-EDTM

The Wärtsilä GVU-EDTM is a solution where all the equipment is mounted inside a gas tight enclosure. This arranging allows the GVU to be placed inside the engine room next to the engine to give the best engine response and to minimise the installation costs.

The Wärtsilä GVU-EDTM (Figure 21) comes as a complete module with the automation system mounted on the unit. The automation system performs valve a leak test, start & stop sequences, inerting and venting sequences. The gas pressure regulation is controlled by the engine control system. /56/

The enclosure contains:

- Manual shut-off valve
- Gas filter
- Block and bleed valve block with nitrogen connection
- Flow meter
- Pressure control valve

Ventilation valve

- and Nitrogen valves

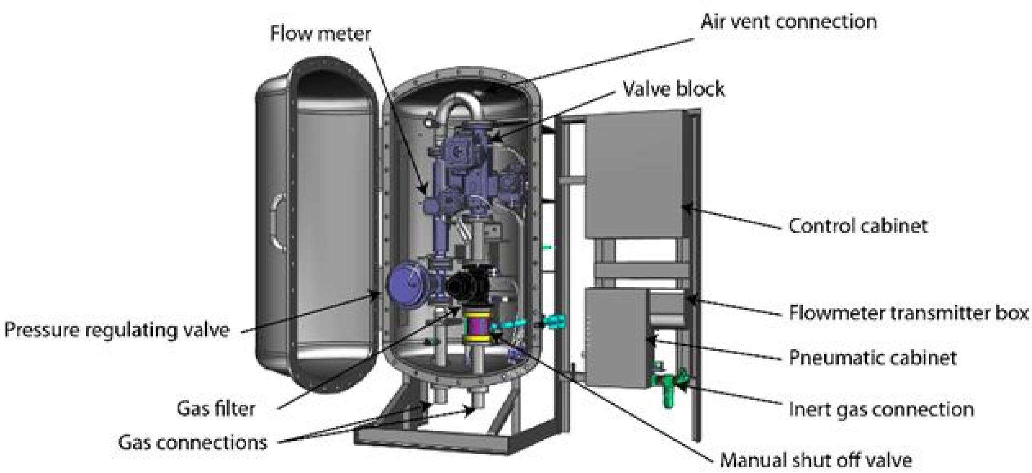



**Figure 21**. Gas valve unit GVU-ED. /56/

### 3.2.4.5 Control Valve

In every version of GRUs the main component is the fuel gas control valve. The control valve regulates the fuel gas pressure fed to the engines according to the UNIC system orders. A drawing of control valve is shown in Figure 22.

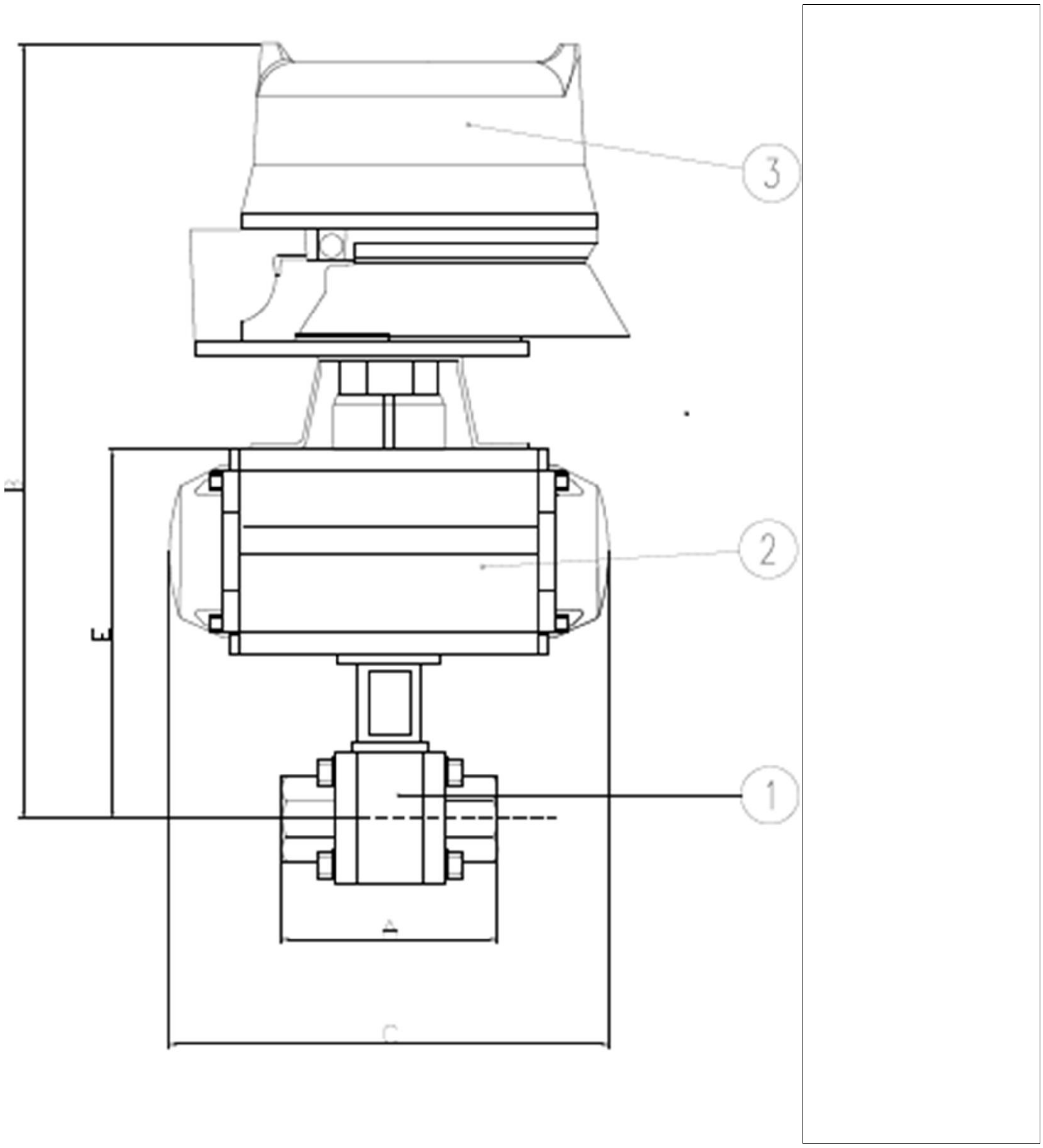



**Figure 22.** Gas regulating control valve drawing. /57/

### 3.2.5 Off Engine Gas Valves

#### 3.2.5.1 Main Shut-off Valves, Power Plants

The main shut-off valves isolate the gas feed line to the plant. One of them is manually operated valve and the other is automatically operated shut-off valve, which is of fail-safe type and is closed either in loss of power or control air. The main shut-off valves are located outside the building and marked clearly according to the local regulations. In the event of a gas leak, fire or gas explosion the valve should always be closed. In the case of a plant emergency, the automatically operated main shut-off valve is closed by a hardwired signal.

The automatic main shut-off valve is assembled of a ball valve, pneumatic actuator (single acting, spring return), fail close (spring closes in loss of electricity or control air), integrated solenoid valve and limit switch. The main shut-off valve is located outside the plant (Figure 23). /58/

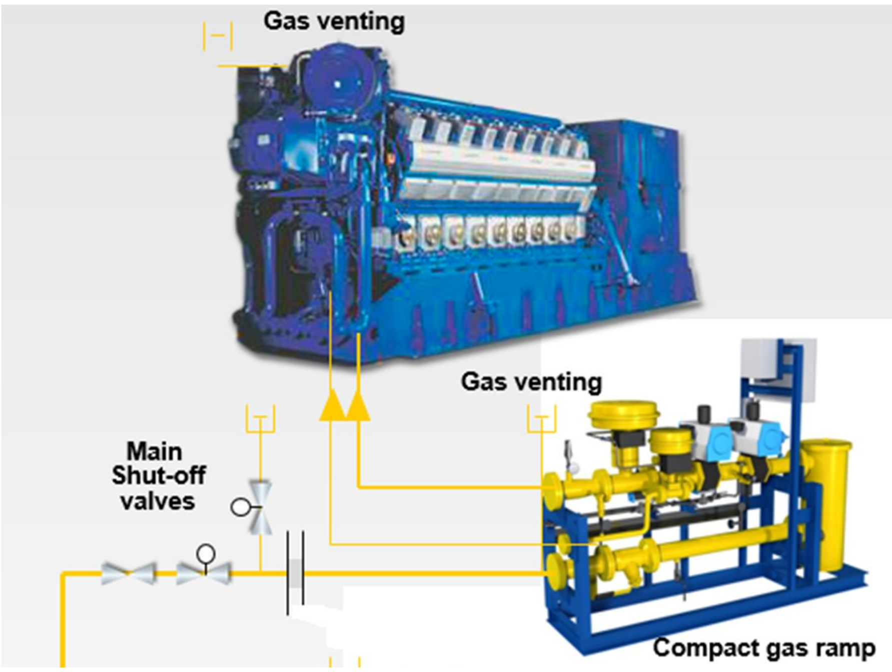



**Figure 23.** Main shut-off valve outside the plant. /59/

The automatic main shut-off valve is connected with hardwired signals and controlled by the power plant shut down relay. The relay is switch by the following events:

- Plant emergency shut down
- Gas alarm level 2 (20% of LEL)
- Fire alarm

#### 3.2.5.2 Auto Shut-off Valves

The safety valves for the CGR are controlled by the PLC. The valves form together with the first automatic venting valve a double block and bleed connection. They are opened pneumatically and closed by a spring. The valve is a ball type valve with the EN161A approval (automatic shut-off valve). The auto shut-off valve is shown in Figure 24. /52/

**Figure 24.** Auto shut-off valve with actuator. /52/

#### 3.2.5.3 Venting Valves

A venting valve can be installed as an option after the main shut-off valve The valve is assembled of a ball valve, a pneumatic actuator (single acting, spring return), fail open (spring opens the valve in loss of electricity or control air), integrated solenoid valve and limit switch.

The venting valve is significantly faster than the main closing valve, further the valves cannot be allowed to operate independently. Therefore an interlock between the valves is required, so that the vent valve cannot in any case open when the main valve is open, e.g. if there is problems with the solenoid to vent valve or the air supply is removed to one of the valves.

A venting valve with actuator is shown in Figure 25. /52/

**Figure 25.** Venting valve with actuator. /52/

#### 3.2.5.4 Main Shut-off Valves, Marine Solutions

At least one remotely operated fail-safe valve, master fuel gas valve, is required in the cargo area upstream the engine specific GVU(s).

It is recommended to install one master fuel gas valve for each engine room. With this arrangement, a gas trip in one of the engine room will not interrupt the total fuel gas supply for the remaining engine rooms and dual fuel engines.

The master fuel gas valve is open in normal operation, and is utilised to shut-off the gas supply to the engine room. This valve is controlled by the gas safety system of the ship. The master fuel gas valve shall be possible to close from each DF-engine rooms, engine control room and wheelhouse. The valve shall also close automatically in leak test and LEL-alarm situations.

Typically in addition one stop valve is installed beside to the master fuel gas valve in tank connection space. /56/

#### 3.2.5.5 Venting Valves

The vent valves are used for depressurizing and purging of the pipes. The gas released through the vent valves is led to the vent mast. A typical layout with shut-off and venting valves is shown in Figure 26. /60, 61/

**Figure 26.** Typical GRU layout with shut-off and venting valves. /53/

### 3.2.6 Plant Filtration Unit

The supply of clean fuel gas is an essential part of reliable engine operation and that is why efficient filtration is needed. Gas from a gas well may contain quite a lot of particles and liquid impurities. The impurities encountered are typically rust, sand, moisture or hydrocarbon condensate. Gas compressors may leave traces of lubrication oil in the gas stream (E.g. oil carry over). /5/

A plant filtration unit should be supplied when:

- The gas quality is uncertain in the plant inlet.
- There is a risk that water or condensed hydrocarbons are present in the gas stream.
- The plant is a critical power supplier and any stops should be avoided.

Particles are removed to avoid damage to the mechanical components in the fuel gas system. The plant filter unit (if delivered) is designed to filter particles 5 µm and larger with 100 % efficiency. If a plant filter unit is not installed and the particle count is higher than recommended then the filters in the GRU's will often require cartridge replacements. /5, 62/

### 3.2.7 Fuel Gas Compressor

The gas compressing unit is used when the pressure in the natural gas grid may be lower than the minimum pressure required by the gas regulating unit. Typically the lower limit of fuel gas pressure is 4 bars. The gas compressing unit may serve one or more engines depending on the power-plant layout. There are two different types of compressors that have been used in the Wärtsilä Power Plants SG and DF engine installations; rotary vane compressors and screw compressors. The compressor units are usually designed for variable inlet pressure, but the pressure range needs to be considered carefully. The compressor internal pressure ratio has to be considered, to determine if an additional by-pass or pressure reduction valve is needed.

Figure 27 shows a rotary vane type gas compressor. The rotary vane compressor is a positive displacement type compressor, which has a one-piece eccentrically mounted rotor that traps the gas between the vanes. The compressor is lubricated by oil injection between the compressor vanes. The lubrication oil needs to be separated after the gas cooler. If the lubrication oil reaches the engine it will clog the gas valves on the engine. The rotary vane is one of the four types of compressors used in Wärtsilä solutions. /63/

**Figure 27.** Rotary vane type compressor. /63/

To be specified when ordering a fuel gas compressor:

- Inlet fuel gas pressure (min & max operating / design)
- Required outlet fuel gas pressure (min & max operating / design)
- Inlet fuel gas temperature (min & max operating/design)
- Fuel gas flow (min & max operating / design)
- Gas composition
- Wet or dry gas
- Required filtration degree at compressor outlet
- Size and rating of connecting flanges
- Indoor or outdoor assembly
- Ambient temperature (min & max)
- Control philosophy and power for the compressor
- Classification of hazardous area surrounding the unit, zone 2
- Manual isolation / outlet non-return valves /5, 35/

In LNGPac solutions the pressure build-up evaporator (PBE) increases the inlet pressure to the required level.

### 3.2.8 Pressure Reduction Unit

The purpose of the pressure reduction station is to reduce the gas pressure to a constant level, suitable for the gas regulating units. The gas reduction unit is required when inlet gas pressure to power plant exceeds The outlet pressure from the gas pressure reduction station is set to /34/

The pressure reduction station is a non-standard unit and is typically in the customer's scope of supply. The scope of the unit can vary due to:

- Design pressure (e.g. PN25, PN40, PN100)
- Single line or double line (one in operation, one in stand-by. Both dimensioned to 100 % capacity)
- Different filter types
- Heating requirements
- Different safety arrangements

In Figure 28 is shown a gas pressure reduction unit operating in with bar (g) pressure. /63/

**Figure 28.** Gas pressure reduction unit. /63/

#### 3.2.8.1 Fuel Gas Temperature Control

Pressure reduction cools the gas. A rule of thumb is -0.5°C per 1 bar pressure drop. Accurate temperature reduction can be calculated with a simulation program.

The cooling may result in condensation of hydrocarbons and water, formation of methane hydrate in the pipes and frost on the piping. The recommendation is to keep the gas temperature curves for hydrocarbons and water, whichever is the highest. /36/

The required heating power depends on the inlet and outlet pressures, the inlet temperature and the gas composition. The gas heaters may be either electrically or hot water heated. The hot water can be heated in an auxiliary gas boiler or the engine cooling water can be utilised.

### 3.2.9 Gas Detectors

Gas detectors are part of the control system giving vital information for possible gas leaks, thus fuel gas feed can be stopped in case of thread of danger.

#### 3.2.9.1 Gas Types to Detect

The presence of gases and vapours other than air can cause property damage and a threat to human life. The nature of the threat depends on the gas present, but in general gas hazards is divided into three main categories:

- Combustible gas
- Toxic gas
- Asphyxiate gas

In Wärtsilä solutions the primary fuel gas used is natural gas (methane), natural gas is non-toxic but combustible and in high concentrations methane displaces oxygen and will become a asphyxiate gas. The same characteristics go to propane as well. /64, 65/

#### 3.2.9.2 Lower Explosive Limit (LEL)

For a combustible gas to ignite, three conditions are needed:

- The presence of gas in sufficient quantities
- The presence of air, (oxygen) in sufficient quantities
- The presence of a source of ignition

The gas must be present in a high enough concentration to ignite. The minimum concentration needed is called the Lower Explosive Limit or LEL. If the gas concentration goes high enough, then the gas starts to displace the oxygen, and eventually there is insufficient oxygen for combustion to occur. The gas concentration at this point is called the Upper Explosive Limit or UEL. The Flammable Risk (LEL-levels) are based on the IEC60079-20-2000 and EN61779-1:2000 standards. For methane it is 4.4% volume at 100% LEL. /65/

#### 3.2.9.3 Detector Types

The point IR detector unit uses a dual wave length infrared sensor type.

The detector is powered by 24VDC from the gas detection panel and provides a 4-20mA signal proportional to the gas concentration. The detector is suitable for use in zone 1, zone 2, zone 21 and zone 22 hazardous areas. A test gas is needed for calibration. Alarms are connected to the automation system. The typical detector is supplied with methane calibration feature other gases need to be considered in design/purchase.

The open path detector unit is a xenon IR open path type. It is immune to influences from solar radiation, arc-welding, stack flares, lightning and vibrations from machinery. The optical lenses are thermostatically heated to eliminate build-up of condensation. The detector is powered by 24VDC from the gas detection panel and provides a 4-20 mA signal proportional to the gas concentration. The detector is suitable for use in zone 1, zone 2, zone 21 and zone 22 hazardous areas. A handheld tool and commissioning kit is needed for installation and calibration.

The handheld detector is a model of three or four sensing gases, depending on the project the following two models are used:

- Package Kit 1: Methane $CH_4$, Carbon Monoxide CO and Oxygen $O_2$
- Package Kit 2: Methane $CH_4$, Ammonia $NH_3$, Carbon Monoxide CO and Oxygen $O_2$.

The handheld detector needs a charger and test unit. The packages include a multi charger and a quick gas tester unit with suitable calibration gas (s). /65/

### 3.2.9.4 Detector Location

The vapour density has obvious implications as regards the best positioning of a sensor in order to detect any gas leaks. If no other factors are present, the sensors for lighter than air gases should be positioned high, and those for heavier than air, low. However, other factors often do intrude. Important to consider is:

- Where are the likely sites of any leaks?
- Where are the likely sites where gas could accumulate?
- Is there any plant or machinery which may be hot enough to cause convection?
- Ground topology – trenches, manholes etc.

- Ventilation and wind directions etc.

### 3.2.10 Flow Measuring

As an option the Wärtsilä installations can be supplied with flow meters to verify the fuel gas flow and keep record on the gas consumption. /56/

## 3.3 Automation

This chapter presents the fuel gas supply and storing main automation functions and corresponding actuator relations in a simplified form.

In Wärtsilä Technical Services there are several internal organisations related to electrical and automation (E&A). More information about electrical and automation organisations and responsibility areas can be found in documents and

Due to simplification the descriptions of the automation systems are not all inclusive.

The fuel gas supply system monitoring includes several sensors and detectors. Pressure and temperature sensors and gauges, flow meters and gas detectors are providing essential information about the fuel gas system status to the automation system.

The monitoring and automation main tasks in the fuel gas supply system are:

- Valve leakage test
- Start & stop sequences
- Fuel trips
- Pressure control
- Inerting and venting sequences

The control of the fuel gas supply system is implemented by PLCs (programmable logic controller) and the UNIC.

The rule of thumb is that valves on – off type are controlled by PLCs and adjustable valves are controlled by the UNIC. In some marine installations GVU is controlled by a separate MCM (UNIC HW).

- The leak test – is performed by PLC
- Control valve pressure regulation – is controlled by the UNIC

Figure 29 shows the main principle of controlling the different types of valves. /66/

**Figure 29.** Main principle of adjustable and on/off valves control. /52/

The overall control system in power plant installations is Wärtsilä Operator Interface System (WOIS). In marine solutions the control systems can be implemented with similar or corresponding to the WOIS system, or in some cases all the control systems are gathered into the Wärtsilä Integrated Automation system (WIAS).

All PLCs and UNICs are connected to installation automation systems WOIS or WIAS depending on the solution for accurate control and for producing vital information about the state of the systems.

#### 3.3.1.1 Leak Test and Pressure Control

The fuel gas leakage test is performed to check the tightness and performance of the shut-off valves in the gas regulating unit. The test is based on requirements set by IGE/UP/3 procedures (issued 2006) that meet the international standards for gas engines in gas industry. The fuel gas leakage test is carried out after an engine stop and checks that there is no leakage through the shut-off valves. During longer stops the leakage check of the first shut-off valve is performed every [redacted] If the main leakage test is passed and no leakage is detected by the leakage test the engine can be started directly after a start request is given. In addition to these two tests a special sequence is used for DF transferring from liquid to gas.

The gas pressure to the engine is controlled by the control valve(s) [redacted] A 4...20 mA control signal is given by the engine control system (UNIC) to set the position of the control valve. The CGR is equipped with three venting valves to enable venting of the unit, one manual [redacted]) and two automatic [redacted] and [redacted]. /67/

### 3.3.2 Power Plants

#### 3.3.2.1 WOIS

The WOIS workstation is used for monitoring the status and the essential data of a power plant. It gives the possibility to visualize the information, therefore simplifying the operator's work. WOIS is used for monitoring the engine and the auxiliary systems, while the operations mainly are performed at the control panels and related controllers. The WOIS workstation includes several displays for supervision of the plant. Process displays are graphic pictures with measuring values and status information of the systems in the power plant. The process displays includes a plant view, common views, as well as individual genset related views. A trend display is available for each analogue value. Alarms occurring in the power plant are displayed in the alarm list and, as an option, printed to an alarm printer. The WOIS user manual is in document [redacted] A typical power plant automation lay-out is shown in Figure 20. /68/

**Figure 30.** Typical power plant automation lay-out. /68/

### 3.3.3 Marine Solutions, Wessel Integrated Automation System

WIAS comprise all the functionality one will expect from a modern Vessel Automation system. WIAS acts as a main alarm system for the vessel, and it monitors and controls other Wärtsilä products/systems as well as ship utility systems, such as ballast, bilge, cargo, fuel and cooling. It also interfaces fire centrals and maintenance systems.

WIAS is delivered as part of Engine Automation solutions, and is a scalable, distributed and highly redundant system that is developed in tight cooperation with end users to ensure user friendly and unambiguous operation philosophy. A typical topology of WIAS is shown in Figure 31. A marine installation without the all-inclusive WIAS-system, automation is typically controlled by the WOIS or WOIS similar system. /69/

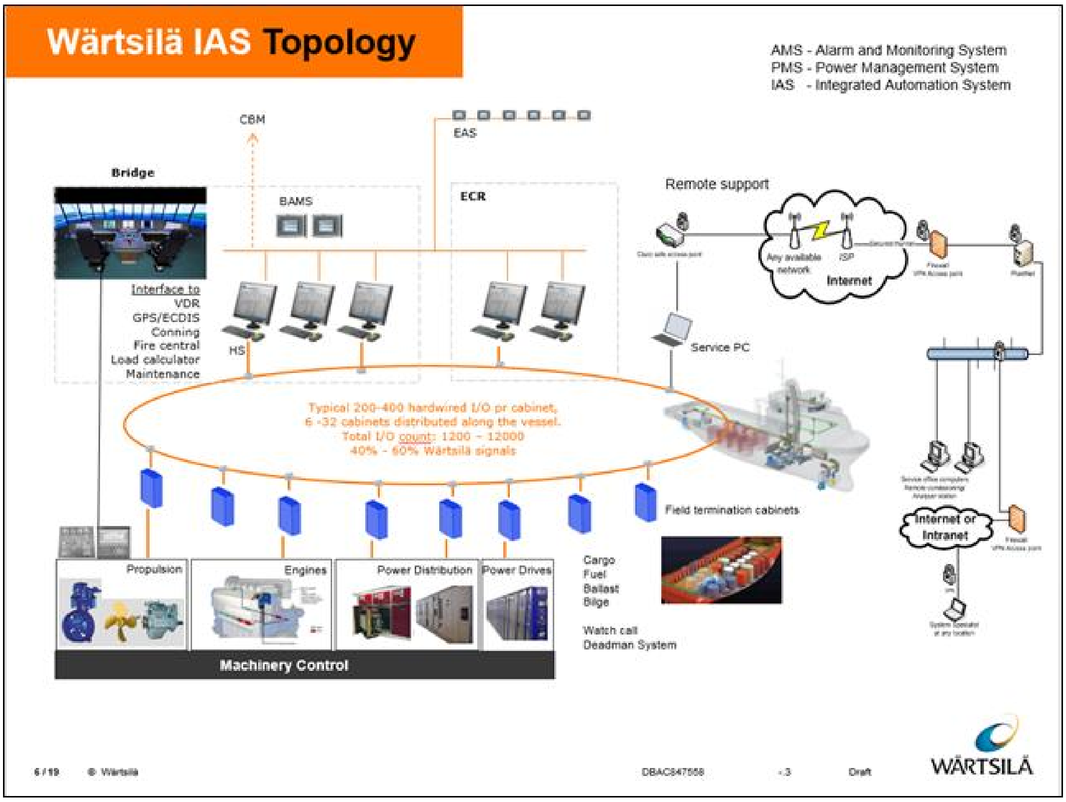



**Figure 31.** Typical WIAS topology. /69/

In LNG solutions in addition to the leak – test and pressure regulating the control of LNG Packs is a high priority procedure.

The operation of the LNGPac is largely automated and it is controlled by a PLC-based control system. The central unit of the control system is the PLC cabinet together with a cabinet for controlling the pneumatic valves. The bunkering system has a separate control panel.

An operator terminal is used for monitoring the operation of the LNGPac, giving control commands and adjusting set points. Monitors on the bridge and in the engine control room enable remote monitoring of the LNGPac. The PLC cabinet is connected to WOIS or WIAS.

The LNG Pack PLC cabinet and GVUs are connected with hardwires in order to perform an emergency stop in both directions. More information about LNG Pac automation can be found in document

Figure 32 shows the fuel gas supply and storing system main responsible control units. /66, 70, 71/

**Figure 32.** LNG Pac automation connections. /71/

# 4 FUEL GAS

## 4.1 Natural gas

Fuel gas used in Wärtsilä solutions is typically natural gas in gaseous form. Natural gas consists primarily of methane (CH4). Some amount of nitrogen, carbon dioxide, ethane, propane, butane and other parts are also present in natural gas composition. Notice the requirement of water and hydrocarbon condensate not allowed in composition of natural gas before the engine. /38, 39/

Natural gas is:

- Non-toxic
- Colourless
- Odourless
- Lighter than air

Natural gas fields are wider spread than oil fields in the world. At today's consumption resources are estimated to last at least for next 70 years. /39/

Natural gas emissions are one of the lowest of fossil fuels. Natural gas is also lighter than air and it rises in upper part of the facilities and escapes to the atmosphere in leak situations e.g. in ship engine rooms.

Gas operation gives a great environmental advantage compared to diesel mode seen from the exhaust gas emission point of view. When operating the engine in gas mode the exhaust emissions are extremely low. In Wärtsilä gas engines the air-fuel ratio is very high, and uniform throughout the cylinders.

Maximum temperatures and subsequent NOx formation are therefore low since the heat quantity released by combustion is used to heat up a large mass of air. The reduction of NOx can be even 85 % compared to the diesel mode.

When using natural gas, the $CO_2$ emissions decreases considerably, even up to 25 % less $CO_2$ emissions compared to the diesel mode.

Another significant emission reduction is sulphur ($SO_2$). Compared to the diesel mode, reduction of $SO_2$ sulphur and particles in fuel gas mode can be 99 %. This is the unique feature of the lean-burn principle. /72/

In marine installations the IMO Tier III regulations has been is in force starting 1 January 2016, it regulates how much nitrogen oxides (NOx : NO and $NO_2$) engines are allowed to emit. More information about marine emissions is available in Wärtsilä environmental product guide document. An emission comparison between fuel gas mode and diesel mode in a Wärtsilä engine is shown in Figure 33. /72, 73/

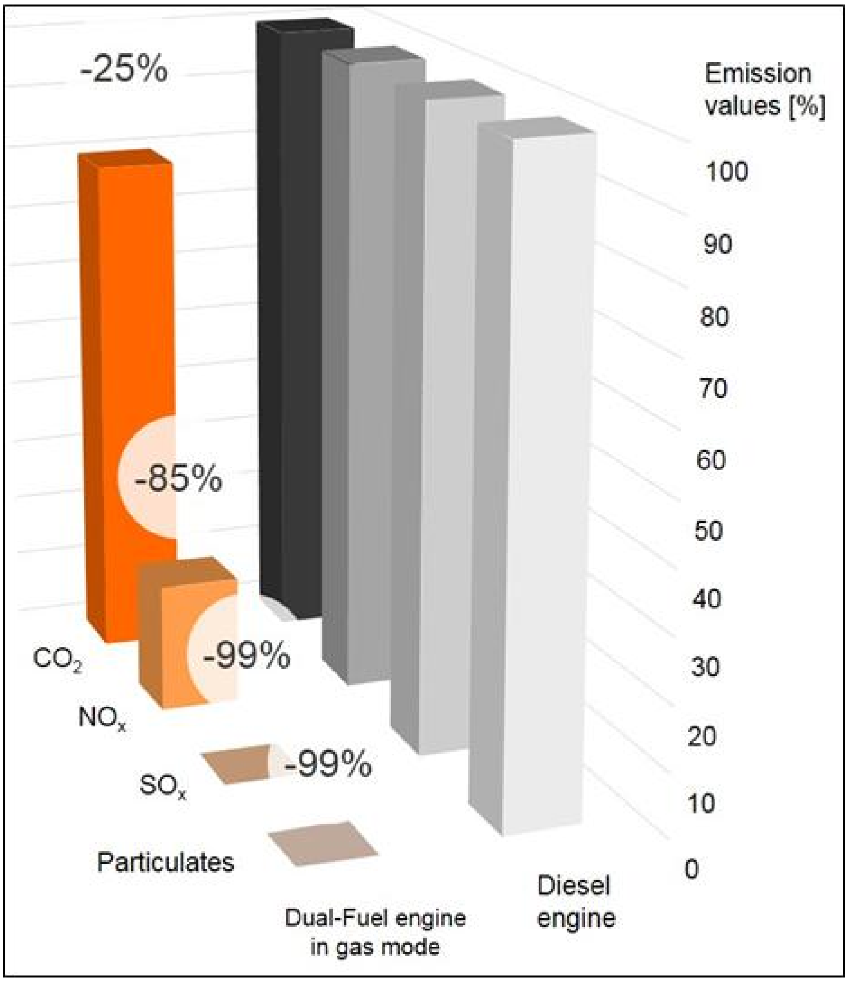



**Figure 33.** Emission comparison. /73/

## 4.2 Engine Specific Fuel Gas Requirements

Engine specific fuel gas quality requirements define the required characteristics for the fuel gas.

The normal fuel gas quality specifications may vary depending on the delivered applications. The delivery contract should always be checked in case of fuel gas quality causing problems. The fuel gas requirement definition documents can be found in Table 4.

**Table 4.** Engine based fuel gas definitions.

| | |
|---|---|
| W20DF | |
| W32DF | |
| W34SG | |
| W34DF | |
| W46DF (FDF) | |
| W50SG | |
| W50DF | |

## 4.3 Lower Heating Value

Lower Heating Value corresponds to the energy content of the gas. If the LHV is lower than specified, the engine output has to be adjusted or a higher gas pressure to the engine is needed. The lower heating value of a fuel is defined as the amount of heat released by combusting a specified quantity of fuel. The higher the moisture contents of the fuel, the lower the LHV. There is an upper limit of moisture content in which a fuel is able to combust. Too high a moisture content increases the amount of heat needed for evaporation, which can become larger than the heat produced from the combustion reactions. As a result, the self-sustaining combustion process cannot occur. LHV is also known as a net calorific value. The recommended minimum value for LHV with Wärtsilä engines is normally 28 MJ / N $m^3$. The LHV unit of measure is mega joules / nominal cubic metre. /74, 75/

## 4.4 Methane Number and Methane Content Share

The methane number (MN) is an indication of the knock sensitivity of the natural gas. The definition of the methane number is similar to the definition of the octane number as used with gasoline fuel. MN is defined as follows:

The percentage by volume of methane blended with hydrogen that exactly matches the knock intensity of the unknown gas mixture under specified operating conditions in a knock testing engine. In other words if a gas mixture has a methane number of 80, the knocking resistance is the same than a gas mixture consisting of 80 % methane and 20 % hydrogen has.

The methane number is calculated on the basis of a gas analysis. An example of gas analysis values from and the methane number calculation is shown in Tables 5 and 6.

**Table 5.** Example of gas analysis values.

*GAS EVALUATION TOOL v.1.2*

WÄRTSILÄ

**Select ENGINE TYPE:** 18V50SG

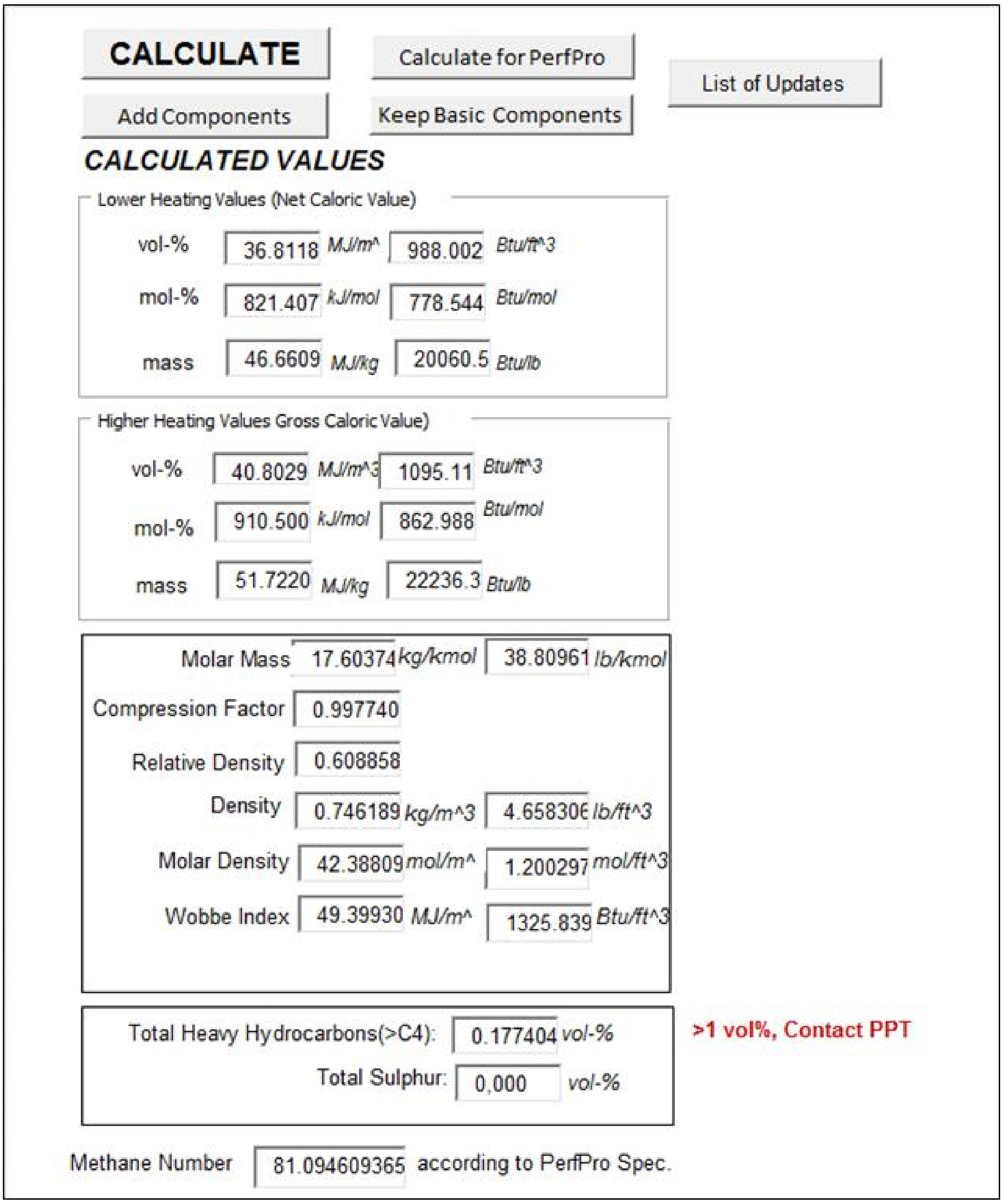
Pressure: 101,325 kPa

Temperature: 15 [°C]

Mol-%

| **Components** | **Formula** | 2,000 | Vol-% | Mol-% | Mass-% |
|---|---|---|---|---|---|
| **Methane** | $CH_4$ | 91,435 | 91,50 | 91,43 | 83,33 |
| **Ethane** | $C_2H_6$ | 3,389 | 3,37 | 3,39 | 5,79 |
| **Propane** | $C_3H_8$ | 0,989 | 0,97 | 0,99 | 2,48 |
| **n-Butane** | $n\text{-}C_4H_{10}$ | 0,262 | 0,25 | 0,26 | 0,87 |
| **i-Butane** | $i\text{-}C_4H_{10}$ | 0,202 | 0,20 | 0,20 | 0,67 |
| **n-Pentane** | $n\text{-}C_5H_{12}$ | 0,060 | 0,06 | 0,06 | 0,24 |
| **i-Pentane (2-Methylbutane)** | $i\text{-}C_5H_{12}$ | 0,078 | 0,07 | 0,08 | 0,32 |
| **n-Hexane** | $n\text{-}C_6H_{14}$ | 0,052 | 0,05 | 0,05 | 0,25 |
| **n-Heptane** | $n\text{-}C_7H_{16}$ | | 0,00 | 0,00 | 0,00 |
| **n-Octane** | $n\text{-}C_8H_{18}$ | | 0,00 | 0,00 | 0,00 |
| **n-Nonane** | $n\text{-}C_9H_{20}$ | | 0,00 | 0,00 | 0,00 |
| **n-Decane** | $n\text{-}C_{10}H_{22}$ | | 0,00 | 0,00 | 0,00 |
| **Hydrogen** | $H_2$ | | 0,00 | 0,00 | 0,00 |
| **Hydrogen Sulfide** | $H_2S$ | | 0,00 | 0,00 | 0,00 |
| **Carbon Monoxide** | $CO$ | | 0,00 | 0,00 | 0,00 |
| **Oxygen** | $O_2$ | | 0,00 | 0,00 | 0,00 |
| **Nitrogen** | $N_2$ | 3,058 | 3,07 | 3,06 | 4,87 |
| **Carbon Dioxide** | $CO_2$ | 0,476 | 0,47 | 0,48 | 1,19 |
| **Water** | $H_2O$ | | 0,00 | 0,00 | 0,00 |
| **Helium** | $He$ | | 0,00 | 0,00 | 0,00 |
| **Argon** | $Ar$ | | 0,00 | 0,00 | 0,00 |
| | ***TOTAL*** | **100,000** | **100,00** | **100,00** | **100,00** |

**Table 6.** Methane number calculating tool.




Minimum MN values depend on the engine type, typically with Wärtsilä engines the minimum recommended MN number is 80. The practical consequences of low MN is possible damages to the engine by knocking, knocking is prevented by automated engine de-rating output. The content share of methane is recommended to be in minimum of 70 % by volume. /38, 76/

### 4.5 Filtration

The supply of clean fuel gas is an essential part of reliable engine operation and that is why efficient filtration is needed. Gas from a gas well may contain quite a lot of particles and liquid impurities. Also during work done at the site and in the transmission lines, impurities will be introduced into the gas stream. The impurities can be e.g. rust, debris, sand, moisture or hydrocarbon condensate. /77/

The fuel gas filtering unit may be an optional part of installation, but almost in many case filtering is assembled. Typically there is a filter located outside the engine room or engine hall, also in addition one larger filter is located in GRU and one fine filter is located before each gas admission valve on the engine. A gas filter used e.g. in CGR is shown in Figure 34.

**Gas filter**

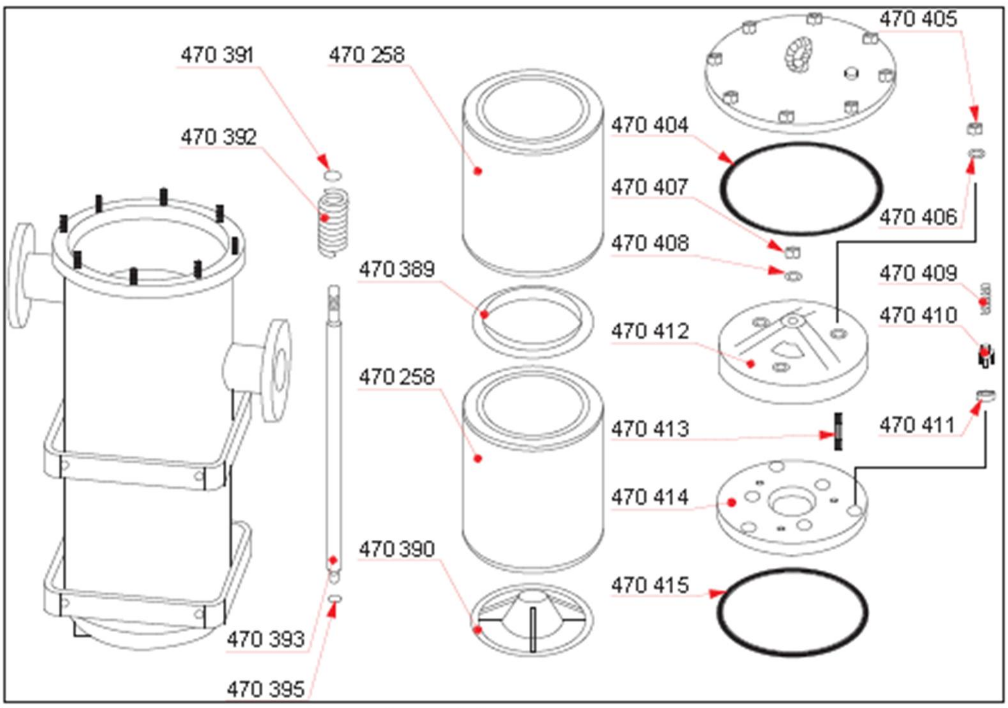



**Figure 34.** Cartridge type gas filter construction. /78/

### 4.6 Fuel Gas Sampling

Fuel gas quality sampling is to make sure the requirements of fuel gas are present. In power plant applications the fuel gas analysis is done before commissioning. In marine solutions on board carried LNG is quality controlled in liquefying process. Typically in natural gas sampling inspected ingredients are shown in Table 7. /79/

**Table 7.** Natural gas sampling example. /79/

### 4.7 Gas Reformer

This solution makes it possible to utilise gaseous fuels that either contain large amounts of heavier hydrocarbons or vary in their composition. Gases that were previously considered as waste can now be converted into a valuable resource of energy. Together with Wärtsilä dual-fuel (DF) engines, this is the most efficient and flexible solution for utilising associated gas, stranded gas, natural gas liquids, liquefied petrol gases or volatile organic compounds (VOCs) recovered from oil and gas industry. The main application area is in offshore oil and gas production. Wärtsilä Gas Reformer has been developed and designed to meet the standards of the oil & gas industry and is the first of its kind in the world. The technology is based on steam reforming (SR), a catalytic process known from the petrochemical industry and refineries, where traditionally hydrogen is produced from various hydrocarbon feeds. The Wärtsilä Gas Reformer exploits the same catalytic process but operates under different conditions. In the Wärtsilä Gas Reformer the methane number (MN) of any fuel gas is improved to 100 ± 5 by converting the heavier hydrocarbons to synthesis gas ($H_2$ + CO) and finally to methane ($CH_4$).

The gas reformer (Figure 35) has not widely taken into use, but the technology should be further developed because of the increasing use in the future. E.g. flare gas, poor quality gas could be taken into use. More advanced and more effective gas reformation system would pay off development investments in the future when poor-quality gases are taken widely in use. /17, 80/

**Figure 35.** Gas reformer. /80/

### 4.8 Propane

Propane is a three-carbon alkane with the molecular formula $C_3H_8$, in gaseous form at standard temperature and pressure, but compressible to a transportable liquid. A by-product of natural gas processing and petroleum refining, it is commonly used as a fuel for engines, oxy-gas torches, portable stoves, and residential central heating. Propane is one of a group of liquefied petroleum gases (LPG). The others include butane, propylene, butadiene, butylene, isobutylene and mixtures thereof. /81/

Propane gas is:

- Non-toxic in low concentrations
- Colourless
- Odourless
- Heavier than air

Natural gas provides approximately 37 MJ / Nm$^3$ (1,000 BTUs per cubic foot / 0.0283 cubic meters).The same volume of propane in gaseous form provides about 92 MJ / Nm$^3$. This means that propane contains about 2.5 times more usable energy content. So, less propane is needed to produce the same amount of energy as natural gas. /82/

Propane chemical characteristics allow propane to be in liquid form at moderate pressure. The pressure inside a LPG tank is approximately [illegible] at the temperature of 25 °C. Propane tanks are typically uninsulated and thus sensitive to ambient temperature, but even if the LPG pressure inside the tank increases, it is less complexed to handle the LPG storing system compared to the LNG storing systems. /83/

Propane is heavier than air, which is heavier than natural gas. Both propane and natural gas will dissipate into the air if they are released in an open environment, and both can pose an explosive risk if they concentrate enough and are ignited. Because propane is heavier, however, it tends to fall to the ground, collect, and pose a greater explosive risk than natural gas, which tends to rise and dissipate into the air. The flame temperatures of both natural gas and propane are similar, approximately 1960 °C. /82/

Natural gas tends to be less expensive, at up to 1/6 the cost of propane, depending on the region. Cost considerations depend on the prices of local utility companies and propane companies. In some areas the availability of propane and the existing infrastructure is making propane notable cost competitive. In those kinds of areas growing interest of new propane driven power plants and conversions of existing ones are expected. /82/

### 4.8.1 Propane Engines

Wärtsilä has recently expanding its Smart Power Generation portfolio by introducing the capability of using propane as fuel for power generation. Wärtsilä first propane-fired project [illegible] using two 20V34SG gas engines has recently been under construction in [illegible] and was taken into operation at the end of 2015.

Now the Wärtsilä 34SG engine can be used not only with natural gas, but also as a dual-fuel engine that can run on natural gas or propane with some physical modifications to the engine. Additional information about the first propane project can be found in Wärtsilä press release dated 6.11.2015. The engines running on propane are rated at 75 % of the NG engine output, e.g. 375 kW vs 500 kW / cylinder. At this moment propene engines are used only in power plant solutions. /84, 85/

#### 4.8.1.1 Physical modifications on engines

Propane energy content and other chemical characteristics differ from natural gas characteristics and in order to be able to maintain the effective and steady engine performance the engine calibration must be adjusted completely differently. This is done by re configuring the performance mapping at least in parameters, such as fuel limiters, ignition timing, gas pressures and the charge air pressure.

#### 4.8.1.3 Fuel Limiters

Propane energy content is approximately 2.5 times greater than in natural gas, therefore fuel limiters must be re-adjusted to feed the correct needed amount of fuel gas into the pre-chambers and cylinders. The performance mapping versus natural gas engines is differing e.g. from mixture parameters, fuel gas pressure and alarm limits.

#### 4.8.1.4 Ignition Timing

The auto ignition temperature, which is the minimum temperature required igniting propane without a spark or flame being present is ~ 470 - 550 °C, whereas the auto ignition temperature for natural gas is ~ 540 - 600 °C. The ignition timing is relevant factor like in all gas engines. The initiation window is wider in propane than in natural gas. The ignition timing is one of the most critical combustion engine factors and when using propene. /84, 85, 86/

#### 4.8.1.5 Gas Pressure

The fuel gas pressure is lower with propane compared to natural gas engine. In natural gas engines the typical overpressure on charge air pressure is lowered to the level of overpressure on the charge air pressure.

#### 4.8.1.6 Charge Air Pressure

The charge air pressure is higher in propane engines compared to natural gas engines, the demand

#### 4.8.1.7 Emissions

The propane engine emissions are at least as good as in natural gas emissions. E.g. the demand emissions is achieved without any extra adjustments. /84/

#### 4.8.1.8 Physical Modifications on Auxiliary Systems

**Figure 36.** LPG system description. /87/

# 5 TROUBLESHOOTING

In this chapter typical issues on fuel gas system are presented. Safe and secure supply of fuel gas can be achieved only by properly maintained and serviced systems. The lack of maintenance and service can result in human injury or in extreme cases threaten human lives as well as cause severe damage to the engines and auxiliary systems.

The main fuel gas system concerns are:

- Ensuring that no leaks occur in the system
- Storing and bunkering
- Reliability of shut off valves, safety valves, regulating valves and venting valves
- Fuel gas purity
- Fluctuations in fuel gas pressure and temperature

In order to maintain and service Wärtsilä installations properly the specific technical instruction are delivered in the project phase and should be available in the plant or vessel control room. In case of missing or deficient information the necessary information can be requested from technical services.

Instructional updates related to equipment or systems designed by Wärtsilä are distributed via the Technical Service Bulletin system. Instructions related to equipment that is delivered by Wärtsilä but designed by a third party is delivered to the end customer either directly from the 3rd part manufacturer or then the third party manufacturer delivers the updated instruction to Wärtsilä and we generate it into a Wärtsilä bulletin and distribute it to the customers that have received the equipment in question from us. Fuel gas related service bulletins examples are presented in Table 7. More specific information about effects caused by lack of proper maintenance and service to the components and possible dysfunctions of subsystems is presented in Chapter 5.1. /88/

## 5.1 Effects of Lack of Proper Maintenance

The precept for maintaining and service is the Wärtsilä instructions and guidance given for every installation, typically named operation and maintenance manual. The instructions must be carefully studied and obeyed. Maintenance and service intervals are typically based on engine running hours but fuel gas related intervals may also be based on calendar time periods. E.g. gas control valves in GRUs must be maintained after two years of using regardless the engine running hours. Anyhow, typically filters are replaced on the basis of running hours. Also operating conditions must be taken into consideration, possibly shortening the service interval.

The maintenance intervals are not in all solutions unambiguous, the specific schedules are presented either in engine, Aux equipment or system maintenance manuals.

The daily monitoring performed by service personnel may give valuable indications for needed pre scheduled maintenance and service. When noticing unexpected wear and reducing in component lifetime, the related components must be checked and replaced when needed.

The main components related to maintenance and service procedures in fuel gas system and typical problems related to lack of maintenance are:

- Piping and connections
- LNG Pac, cold box
- Main shut-off valve
- Auto shut-off valves
- Venting valves
- Gas regulating unit
- Gas compressor unit
- Gas reduction unit
- Fuel gas filters
- Gas admission valves

### 5.1.1 System Tightness

The main concern is the tightness of fuel gas systems avoiding leaking in any part of the fuel gas system. Leaking can cause a risk of explosion and fire. The base for controlling the system tightness is the automated leak tests during engine start and stop procedures and fuel trips. Gas indicators in several locations on the engine and in the engine room are also important ways to detect possible fuel gas leaks. Even if fuel gases are invisible, the visual inspection on system components and in some cases fuel gas odorizing can help personnel to detect fuel gas leaks.

### 5.1.2 Gas Detectors

Gas detectors are critical components when thinking of safety on the engine locations. If a gas detector is not functioning properly and detecting dangerous amount of gas in location, the danger of fire or explosion will be present. Typical sensors used in Wärtsilä installations must be calibrated and they are containing optical surfaces. Dust and other dirt may prevent the sensor to work properly.

The disturbed or stopped circulation and too low a concentration of glycol water have caused dysfunction and damages to the systems. The concentration of the gly-

**Table 8.** Service bulletins examples.

# 6 RELEVANT REPORT SUMMARIES

Relevant fuel gas system service and audit reports are summarized in Table 9.

The report summaries are listed in Table 10 and summaries can be found from the appendices.

**Table 9.** Relevant report summaries.

**Table 10.** List of appendixes and references to IDM documents.

# 7 CONCLUSIONS

## 7.1 Fuel Gas System

The fuel gas system has many demanding functions for securing safe and constant supply of the fuel gas. It has to manage the storing, transporting and controlling the flow, pressure and temperature of the fuel gas. The purity of the fuel gas must also be secured as a critical issue for fluent and durable operation of the related systems and the engines. Venting and inerting in maintenance, starting and stopping situations secure the safe operating environment for persons involved. Gas detectors are giving warning signals in possible gas leaks situations also securing the overall system safety.

The quality of the typical fuel oils used in Wärtsilä engines is in normal situations quite uniform and the engine performance is stable. While the composition and quality of fuel gas may vary in especially power plant installations depending on the source of the fuel gas, in marine solutions the fuel gas quality is more constant due to the liquefying process of natural gas. Controlling and maintaining the engine performance despite the fuel gas quality variations give extra demands for the entire system. One of the most important factors is fuel gas pressure. In order to achieve the flow and thereby the actual amount of fuel gas needed in each situation, the fuel gas pressure and fluctuation must be kept in required limits. Fuel gas pressure is also strongly fuel gas quality and engine load related.

Controlling the temperature of the fuel gas is one of the major tasks for fuel gas system. The inlet temperature of the fuel gas has a relatively wide range and is manageable, but the real difficulty is when handling the liquefied natural gas related components. The approximately -162°C temperature gives extraordinary demands for materials and components related to that temperature.

Due to the fuel gas flammable characterises in certain circumstances, venting and inerting the fuel gas system in e.g. service or malfunction situations are critical acts to do. To be able to vent and / or inert the fuel gas system, allows safe working for the persons involved.

One of the finest points with the fuel gas use is the lower emissions compared to the fuel oils. $NO_X$, SOx and particles emissions are significantly lower and are decreasing the environmental impact. Reduction of $CO_2$ supports also the use of the fuel gases. Investments on research and developing of new engine and subsystem technologies give opportunities for using fuel gases more and more effectively and widely. Today's ineffective use of e.g. flare gas can be turned around to reasonable utilization in the future.

### 7.2 Summary of the Thesis

Wärtsilä has a history of designing and manufacturing engines and related components and subsystems for several decades. The delivered installations are often tailored according to the customer's needs and there are energy and marine solutions focusing on their own customers. So it can be said that there are limited numbers of deliveries with identical content. The cumulative amount of installation related documents is enormous and locating the information can be difficult.

The purpose of this thesis was to gather and structure existing information and knowledge to a comprehensive basic information source for internal customers who face all possible variations of installations in customer contacts. Report summaries will be updated in the future on a regular basis. Updated data about report summaries allows faster identification of the fuel gas system issues and relations and customers can be better served.

The thesis was written mostly on the basis of existing Wärtsilä documents about fuel gas systems, analysing and aiming to produce relevant information to the internal customers. In addition, several interviews with area experts were done for recovering tacit knowledge and more detailed information.

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