CONCEPT GUIDANCE for X-DF-M

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Winterthur Gas & Diesel

CONCEPT GUIDANCE for X-DF-M

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0 Purpose of this document

The purpose of the Concept Guidance for the X-DF-M engine is to introduce the methanol as a fuel for marine application with the related implication on the system design. This document covers a wide range of information, such as the characteristics of methanol as a fuel, the related risks of fire and explosion, as well as toxicity for humans. The engine design criteria are under WinGD responsibility, while the design requirements for the external supply system are mentioned for reference only and are not binding.

1 Characteristics of Methanol as a Fuel

1.1 Introduction

Methanol, also known as methyl or wood alcohol, is a colourless organic liquid at ambient temperature and pressure. This makes it easy to be stored on board ships like other distillate fuels. It is also hygroscopic and completely miscible with water.

Methanol generates less CO_2 during the combustion process than distillate or residual fuels. Therefore, it is an attractive fuel for marine applications moving towards lower carbon emissions as required by the International Marine Organization's (IMO) CO_2 and Greenhouse Gas (GHG) targets for 2030 and 2050.

Furthermore, methanol can be produced from different sources. “Black” and “grey” methanol are produced from fossil fuels or natural gases. “Green” and “blue” methanol can be produced from biomasses and renewable energy and are considered renewable fuels because they have a lower carbon intensity compared to “black” and “grey” methanol. A gradual decarbonisation is possible by increasing the amount of “blue” or “green” methanol in use.

Allowed limits for sulphur content in bunker fuels for all commercial vessels were further reduced since Regulation 14 of MARPOL Annex VI came into effect. The Emission Control Areas (ECA) sulphur limit was gradually reduced from its initial value of 1.5% m/m sulphur to 1.0% m/m sulphur (2010) and finally to 0.1% m/m sulphur (2015). The global limit was also gradually reduced from its initial value of 3.5% m/m sulphur (2012) to 0.5% m/m sulphur (2020). This makes methanol attractive as a marine fuel since it is practically sulphur free.

The WinGD X-DF-M is a dual-fuel engine which injects methanol into the engine in liquid form. This engine utilises the diesel combustion principle, ensuring stable and efficient combustion.

The WinGD methanol engines meet IMO Tier II NO_x emission levels in both methanol mode and diesel mode. The engines also meet IMO Tier III NO_x levels in both modes through exhaust gas aftertreatment (e.g. Selective Catalytic Reduction (SCR)).

This document is based on the IMO's Maritime Safety Committee Circular MSC.1/Circ.1621, *Interim Guidelines for the Safety of Ships using Methyl/Ethyl Alcohol as Fuel*.

1.2 Methanol properties

Table 1-1 provides the required methanol specifications at the engine inlet.

Table 1-1: Methanol specifications at the engine inlet

Characteristic	Unit	Limit	Methanol	Test method reference
Purity (on a dry basis)	% w/w	Min.	95	IMPCA 001-14
Water	% w/w	Max.	5	ASTM E1064-12*
Ethanol	Mass %	Max.	5	IMPCA 001-14
Acetone	mg/kg	Max.	30	IMPCA 001-14
Chloride	mg/kg	Max.	0.5	IMPCA 002-98
Sulphur	mg/kg	Max.	0.5	ASTM D3961-98 or ASTM D5453-12
Appearance	NA		Homogeneous clear and free of suspended solids	IMPCA 003-98

(*) Method valid up to maximum 2% water

The following values are only for guidance. Project-specific values must be considered.

Table 1-2: Comparison of energy properties for methanol and marine gas oil

Properties	Unit	Methanol	Marine gas oil
Flash point	°C	10–12	60
Density	kg/m³	790 (at 20°C)	890 (at 15°C)
Lower Heating Value (LHV)	MJ/kg	19.9	42.7
Relative volume per energy content	-	2.5	1
Boiling point	°C	64.7	150–380
Explosive limit in air	%(vol)	6–36	1–6
Solubility: methanol in water/water in methanol	%	100/100	NA

2 Safety

2.1 Fire or explosion

A fuel flashpoint is defined as the temperature at which ignition is enabled by sufficient vapour concentration. This is an important temperature used for classification of fuels. Methanol is classified as a low-flashpoint fuel which is highly flammable with a flashpoint of 11 °C and a boiling point of 65 °C. Since ambient temperatures can be well above its flashpoint, methanol vapour can be generated and it burns if exposed to an ignition source and air.

Methanol vapour density is almost the same as air and, therefore, tends to follow air flow. Warm temperatures generate vapour and low temperatures can cause accumulation in low areas. Consequently, methanol is hazardous in confined spaces. The auto-ignition temperature of methanol is approximately 454 °C.

Combustion releases heat, typically producing flames and smoke. In contrast, methanol combustion produces less heat, transfers less heat to the surroundings and is difficult to see. This is due to the efficient combustion of methanol, which produces minimal soot, without which methanol flames are light blue in colour, invisible in daylight, and smokeless.

2.1.1 Fire prevention

Methanol fire and explosion prevention is achieved by ***methanol vapour control, reducing potential ignition sources to a minimum, using certified safe type electrical equipment*** suitable for hazardous zones.

Methanol vapour control

Methanol fire can be prevented by limiting methanol vapour release, which is achieved by keeping the methanol temperature below the flashpoint.

Another measure to control methanol vapour in the methanol tank is by inert gas blanketing or padding. This provides an additional level of protection against ignition within a tank and limits vapour being emitted from the tank. This measure is particularly pertinent if normal temperatures of methanol leads to the vapour concentration within the freeboard volume of the tank to be above the flashpoint. Nitrogen is normally used as inert gas for methanol because it is free of carbon dioxide. With methanol, carbon dioxide can cause corrosion in the presence of moist or salty air.

Vacuum valves and vents with flame arresters are also recommended for vapour control in methanol tanks. Overflow pipes are not recommended because liquid methanol can collect and drip from them when the ambient temperature is below the storage temperature. Gas detectors are also used. Since the methanol vapour density is only slightly higher than that of air (1.1 relative to air), the vapour tends to follow air flow. However, the density varies with temperature, which affects the positioning of gas detectors. Positions close to potential leak points, in the ceiling, in the ventilation system and at low points must be considered (e.g. in the bottom area of the engine room). Gas detectors provide both toxicity and flammability warnings and must activate alarms well before reaching toxicity or flammability limits.

Reducing potential ignition sources to a minimum

Methanol fires and explosions can be prevented by reduction of the potential ignition sources to a minimum from the area in which methanol vapour can be present.

Based on the distance from a potential vapour source, specific recommendations must be followed:

- Smoking must be prohibited.
- Explosion-proof equipment and tools must be used.

Certified safe type electrical equipment

To facilitate the selection and design of appropriate electrical equipment and installations, hazardous containment areas are classified into zones 0, 1 and 2 based on the associated risk of explosion. All hazardous areas must always be inaccessible to passengers and unauthorised crew.

Hazardous area zone 0 includes the following areas:

- methanol tanks interiors
- pipework for pressure relief or other venting systems for fuel tanks
- pipes and equipment containing methanol.

Hazardous area zone 1 includes the following areas:

- cofferdams surrounding the fuel tanks
- fuel preparation spaces
- areas on open deck within 3 m of any methanol fuel outlet, such as tank outlet, gas or vapour outlet, bunker manifold valve, fuel valve, fuel pipe flange, and fuel preparation space ventilation outlets
- areas on open deck or semi-enclosed spaces on deck in the vicinity of the fuel tank Pressure/Vacuum (P/V) outlets, within a vertical cylinder of unlimited height and 6 m radius centred upon the outlet centre and within a hemisphere of 6 m radius below the outlet
- areas on open deck or semi-enclosed spaces on deck within 1.5 m of fuel preparation space entrances as well as fuel preparation space ventilation inlets
- areas on open deck within spillage coamings surrounding methanol bunker manifold valves and 3 m beyond these, up to a height of 2.4 m above the deck
- enclosed or semi-enclosed spaces in which pipes containing methanol are located
- spaces protected by airlocks.

Hazardous area zone 2 includes the following areas:

- areas 4 m distance from fuel tank P/V outlets
- areas within 1.5 m surrounding cofferdam and airlocks.

2.1.2 Fire detection

Different devices can monitor signatures such as heat, electromagnetic radiation, as well as gases. These indicators are useful for early detection of methanol fires. Based on methanol characteristics and burning behaviour, some devices are more suitable than others for specific applications. The introduction to different devices used for methanol fire detection is given below.

Flame detection

A suitable device for early detection of methanol fires is the flame detector. It detects in the ultraviolet or infrared region. The latter is preferred for methanol flames.

Vapour detection

Another device for early detection of methanol fires is the vapour detector. If a source emits excessive quantities of vapour, it is only a matter of time before ignition and flashback occurs. With a vapour detector, it is possible to detect a leakage and to isolate and mitigate the vapour source before the vapours ignite.

Thermal imaging

Another technology which can be used for early detection of methanol fires is thermal imaging. This technology is used to scan temperature changes in the area and to localise fire.

Smoke detection

Smoke detectors are not recommended as a preventive measure for early detection of methanol fires. It cannot detect fire until the fire spreads enough to involve adjacent materials.

Heat detection

A methanol fire releases significantly less heat than most other fuels. It can lead to delayed detection. Nevertheless, a portable heat detector can still be a good option to consider in small enclosures and spaces with low ceilings.

2.1.3 Fire control

Controlling a methanol fire requires appropriate installations and actions with regards to methanol characteristics. Methanol has a low flashpoint, bound oxygen, lack of radiation, is 100% miscible in water and ignitable up to 75% (vol) water content.

For these characteristics, dry powder or carbon dioxide fire-extinguishing systems can provide quick extinguishment. Otherwise, automated application of foam, water mist (fog) or water spray (traditional sprinkler) must be considered. Foam concentrate can also be used as an additive to water mist or water spray to increase the possibilities for extinguishment. Otherwise, water spray and water mist systems do not extinguish a methanol fire until the fuel is sufficiently diluted. The dilution is achieved faster with a water spray (large drops) compared to a water mist (small droplets).

Fire extinguishment by water

The methanol flashpoint increases when it is diluted by water, which primarily reduces the available methanol vapour for combustion. Therefore, extinguishment is achieved by affecting fuel temperature to flashpoint relation. Combustion stops when the flashpoint exceeds temperature of the fuel surface layer. At ambient temperature, methanol water solutions are flammable to approximately 35% (vol) water content, while methanol is ignitable up to 75% (vol) water content. It corresponds to methanol temperature of approximately 39°C. Fuel on fire has significantly higher temperature, and measurements after tests with water spray systems show water content of up to 87.6% (vol) at extinguishment.

Fire extinguishment by foam

Application of fire-extinguishing foam creates a film which hinders release of fuel vapour from the surface, consequently suppressing combustion. However, conventional fire-extinguishing foam decomposes if it's used for methanol fire. Therefore, it is necessary to use alcohol-resistant foam for fixed fire-extinguishing systems that include methanol installations. Furthermore, mixing small concentration of alcohol-resistant foam as an additive in water spraying or water mist systems can significantly improve their effectiveness against methanol fires.

2.2 Health impact

The information in this section is mainly based on the Methanol Safe Handling Manual published by the Methanol Institute and the U.S. Occupational Safety and Health Administration (OSHA). For further information on safe handling of methanol, please refer to the aforementioned manual.

Humans are routinely exposed to methanol through air, water and food, as well as by using certain consumer products, such as paints, windshield washer fluids, antifreeze, de-icers and adhesives containing methanol as a solvent. Studies led by the OSHA show that the Permissible Exposure Limit (PEL) for humans to methanol is 200 ppm for an 8-hour day and 40-hour week. The Immediately Dangerous to Life or Health (IDLH) concentration is 6,000 ppm. If possibilities of exposure above these limits exist, breathing apparatuses must be considered.

Toxic exposure can occur by inhalation (breathing in vapour), ingestion (swallowing liquid), dermal or eye contact with methanol vapour or liquid. The signs can be delayed between 8 and 36 hours after initial exposure. In case of exposure, prompt first aid actions are required.

2.2.1 Inhalation

In case of inhalation of methanol vapours, the individual must be moved to an area with fresh air. Supplemental oxygen with assisted ventilation can be also required.

2.2.2 Ingestion

Methanol ingestion of a small amount (between 10 to 30 millilitres) can cause death. Smaller amounts are known to cause irreversible blindness. In case of ingestions, the individual must receive immediate medical attention.

2.2.3 Skin contact

In case of contact with skin, it is recommended to immediately use an emergency shower and flush the exposed area with ample amounts of lukewarm water for at least 15 minutes. Contaminated clothing and shoes must be removed and washed before reuse. Medical attention is required in case any symptoms persist.

2.2.4 Eye contact

In case of contact with eyes, it is recommended to immediately flush the eyes with ample amounts of lukewarm water for at least 20 minutes.

2.3 Spill prevention and handling

Spill prevention and methods of handling them are different depending on the source and cause of the spill. A prevention strategy to minimise the risk of spillage must be applied during the design of the methanol storage and supply system.

This prevention strategy includes:

- engineering controls
- definition of operating procedures
- definition of standard maintenance procedures
- definition of a spill response plan
- periodic training for the crew handling methanol
- availability of spill kits in hazardous areas.

Engineering controls include but are not limited to different preventive measures which minimise the risk of spillage. These include fuel tank overfill alarms, secondary containment barriers, such as double-wall pipes with inert liquid or gas, vapour detectors and alarms, as well as drip trays in strategic locations.

Operation and maintenance procedures for detection and prevention of leaks and spills must include periodic visual inspections (minimum once per shift). In addition, non-destructive test on tanks, valves, pipes and hoses must be conducted on a regular basis, as well as preventative maintenance. Written procedures for loading and transferring methanol, as well as steps for a prompt response in the case of spillage are recommended to be developed and reinforced through periodic training of operating personnel. Workers must be trained to manage methanol in a safe manner and spill kits must be available in all areas where methanol is handled, stored or used.

The spill kit must contain the following items:

- absorbent materials (e.g. vermiculite, activated carbon, as well as absorbent pads)
- a non-spark plastic shovel to disperse the absorbent materials
- mechanical or chemical barriers to isolate the area
- a drum or container to hold the collected waste material
- emergency communication devices.

Personal Protective Equipment (PPE) must include the following:

- chemical splash goggles and face shields
- suitable gloves
- anti-static rubber boots
- chemical-resistant coveralls
- provision for supplied fresh breathing air
- multiple fire extinguishers.

In the event of a spill, the following steps must be taken into consideration:

- Activate the emergency stop of methanol supply and initiate the purging procedure, if applicable.
- If there are vapours, evacuate the area and notify the emergency coordinator.
- Evacuate all persons not wearing PPE from the area of the spill or leak until clean-up is complete.
- Do not walk over spilled product.
- Avoid skin contact and inhalation.

Spills on floors must be contained by surrounding the liquid with mechanical or chemical barriers, such as sand, vermiculite or absorbent pads. The spill surface must be covered with the absorbent materials or activated carbon to capture the pooled methanol. After use, the saturated absorbent materials must be removed and packed for disposal. Contaminated absorbent material must be treated as hazardous waste. Treatment and disposal options depend on the applicable regulations. To prevent fires or explosions, vapor release inside confined spaces must be ventilated to achieve less than 10% of PEL for methanol (equivalent to 0.6% or 6000 ppm). However, at this level methanol vapours are still considered dangerous to life and health. Outdoor release of methanol vapours disperses relatively quickly and can be considered wherever permissible by the regulations.

3 Methanol fuel system

3.1 System arrangement

The methanol fuel system includes the following:

- methanol bunkering station
- methanol storage and service tanks
- methanol Fuel Supply System (FSS)
- Fuel Valve Unit (FVU)
- methanol piping system
- venting system
- ventilation system
- purging water supply system
- inert gas supply system.

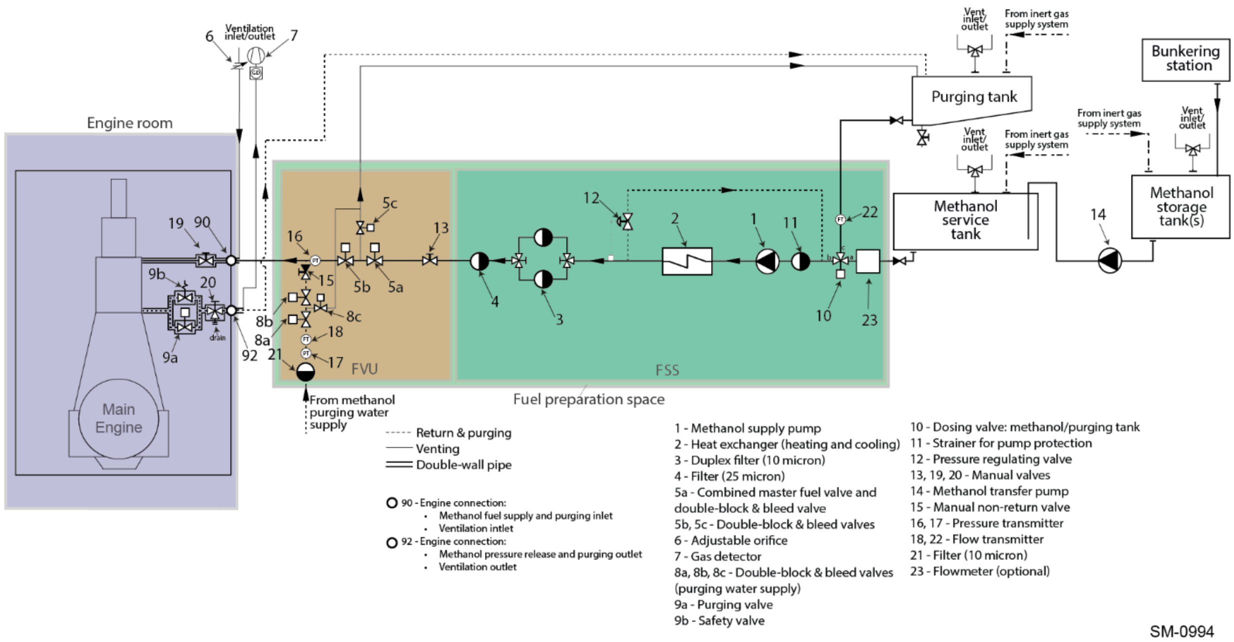

Figure 3-1: Methanol fuel system proposal

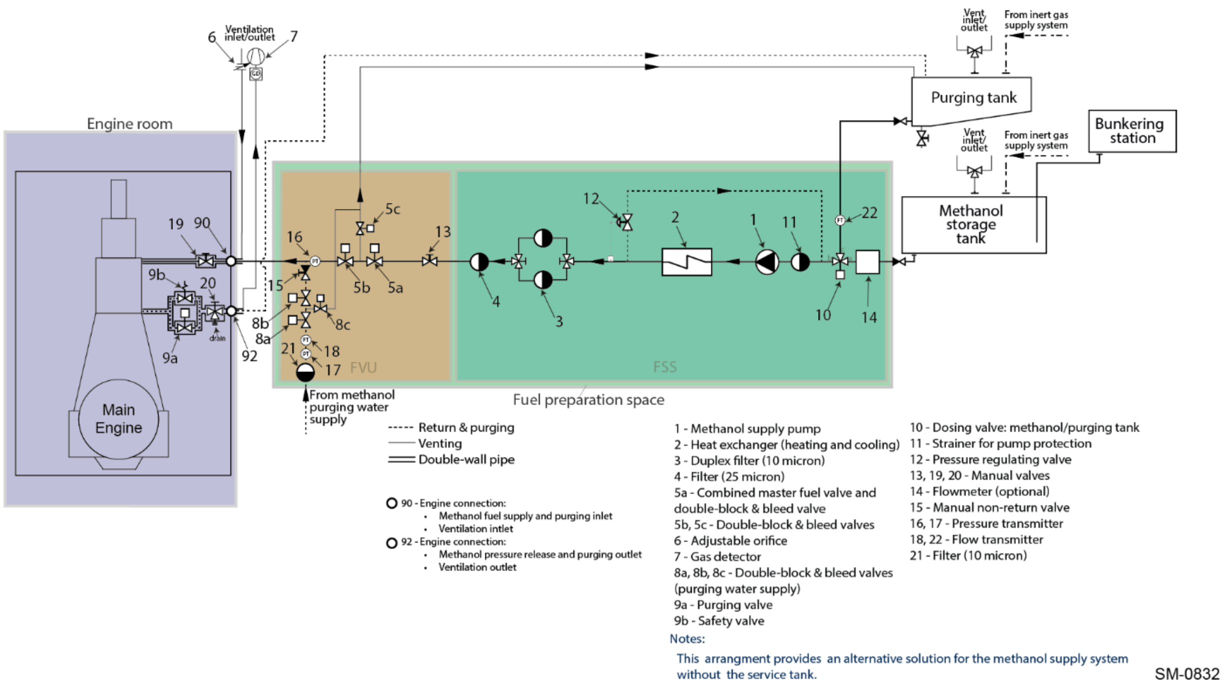

Figure 3-2 Alternative methanol fuel system proposal without service tank

Methanol is transferred on board through a bunkering station and is stored in storage tank(s). From the storage tank(s), it is then transferred to the service tank(s) through methanol transfer pump(s).

The service tank can be omitted as an alternative execution (see Figure 3-2), especially if only one storage tank is installed.

Methanol supply pump, heat exchanger and filters ensure that methanol is supplied to the engine with the defined pressure, temperature and purity. Purging and inerting systems must be provided for safety purposes.

A detailed description follows about the requirements for the main components included in the methanol fuel system.

3.1.1 Bunkering station

Methanol is transferred on board the vessel through a bunkering station. The recommended location for this station is on the open deck because there is sufficient natural ventilation. In addition, it must be located at a certain distance from air intakes, accommodation openings and machinery spaces. The bunkering lines must not be led through accommodations. In case of passage in enclosed spaces, a second barrier for the bunkering line must be considered (e.g. double-wall type or located in gas-tight ducts). To prevent methanol contamination, filters must be considered on the bunkering lines. All the bunker hoses on board must be suitable for methanol. The bunkering manifold must be designed to withstand the external loads during bunkering. The connections at the bunkering station must be of dry-disconnect type equipped with additional safety dry break-away coupling or self-sealing quick release type. A manually operated stop valve and a remotely operated shutdown valve must be arranged in series and as close as possible to the connection point. Otherwise, a combined manually operated and remote shutdown valve can be used. Remote control must be possible from the bunkering control station. The bunkering lines must be arranged for inerting and gas freeing.

For safety purposes, drip trays must be provided below the bunkering connections to collect and direct any spillage to a dedicated drain tank. In addition, a water hose must be available for washing the deck, if required.

3.1.2 Storage and service tanks

From the bunkering station, methanol is transferred to the methanol storage tank(s). Given that the Lower Heating Value (LHV) of methanol is lower compared to MGO, larger quantities of methanol are required compared to MGO for the same energy content. Methanol requires about 2.5 times more storage tank volume than MGO.

Table 3-1: Design parameters for the methanol storage tank

Parameter	Methanol storage tank
Max. design temperature [°C]	60
Density [kg/m^3] at 15°C	790
LHV [MJ/kg]	19.9

From the storage tank(s), methanol is transferred to the service tank(s). This is achieved by means of methanol transfer pumps. The main purpose of the service tank(s) is to collect methanol required for the main engine combustion.

The following requirements must be considered for the service and storage tanks:

- Tanks must be provided with corrosion-resistant material lining.
- Access to the tanks must be provided, preferably on the open deck (for further information, please refer to MSC.1/Circ.1621, 5.11.3 and 5.11.4).
- Methanol tank inlet and outlet valves must be provided for methanol storage and service tanks. It is recommended to place these valves as close as possible to the tanks (for further information, please refer to MSC.1/Circ.1621, 9.6.2).
- Methanol tanks must always be inerted.
- Methanol tanks must be equipped with a controlled venting system (for further information, please see section 3.5).

NOTE	All methanol tanks must always be inerted to prevent methanol vapours from mixing with air.

Different types of tanks can be used for methanol, such as independent, portable and integral tank(s).

3.1.2.1 Independent tank(s)

Independent tanks are self-supporting and not integrated into the ship structure.

The following requirements must be considered for independent tanks:

- Tanks can be located either on open decks or in fuel hold spaces.
- Tanks must be secured to the ship structure.
- Tanks located on open decks must be protected against mechanical damage, surrounded by coamings. Drip trays must be provided for spill collection.
- A water spray system for emergency cooling must be provided if located on open decks.

3.1.2.2 Portable tank(s)

Portable tanks are independent tanks which can be easily loaded and unloaded from the vessel and connected and disconnected from ship systems.

The following requirements must be considered for portable tanks:

- Portable tanks must meet the same requirements as independent tanks (see section 3.5).
- The effect on the ship stability must be considered.
- Connections to the ship fuel piping systems must be made using approved flexible hoses suitable for methanol.
- The pressure relief system must be connected to fixed venting system.
- Control and monitoring systems must be integrated into the ship control and monitoring system.
- Access to all tank connections must be ensured for inspection purposes.

In addition, the portable tanks connected to the ship methanol Fuel Supply System (FSS) must be designed in such a way that they can be isolated at any time without affecting any other tanks.

3.1.2.3 Integral tank(s)

Integral tanks are part of the ship structure and stressed by the same loads which affect the adjacent hull structure.

The following requirement must be considered for integral tanks:

- Integral tanks must be surrounded by protective cofferdams (see section 3.7), except on surfaces bound by shell plating below the lowest possible waterline.

3.1.3 Methanol piping

The pipes of the methanol fuel system must be designed to minimise the risk of fire or explosion in case of leakage.

The following design requirements must be considered for methanol piping:

- In machinery and enclosed spaces, all methanol piping must be double-wall piping. The annular space must be gas and liquid tight. This double-wall piping is not required in cofferdams, fuel preparation spaces or spaces containing any independent tank(s), because these spaces already provide a second barrier.
- Piping on open decks and ro-ro spaces must be protected against mechanical damages.
- Piping must be located at least 800 mm from the ship side.
- Piping cannot be directed through accommodation or service spaces, as well as electrical equipment rooms.
- Piping must be self-draining to a suitable drain tank under static trim and list of the ship. Alternative solutions for drainage can be accepted by the classification society.

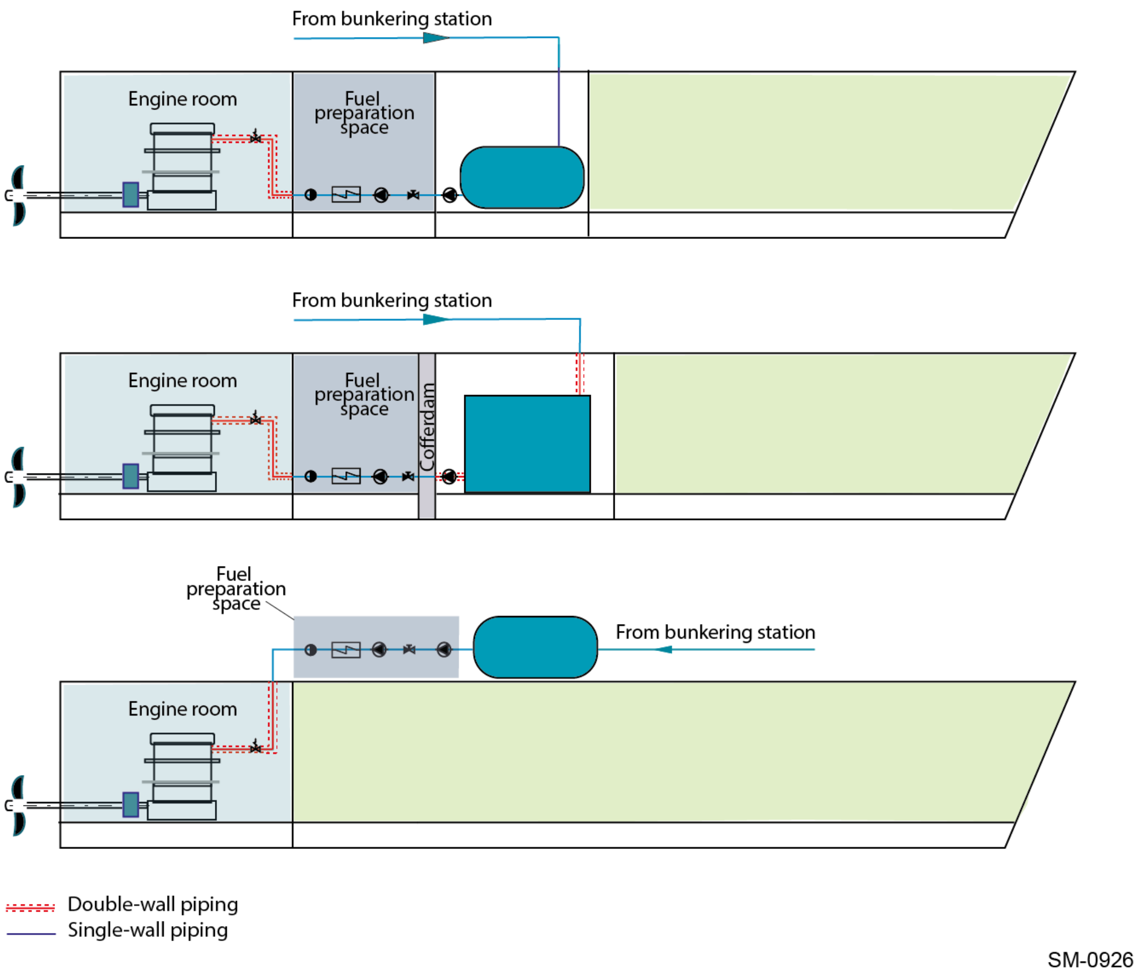

Figure 3-3: Design requirements of methanol piping for the methanol fuel system

The maximum gauge pressure, to which the system can be subjected in service, must be taken into consideration for the piping system design.

Table 3-2: Preliminary design parameters for the methanol supply system

Parameter	Methanol supply system
Supply pressure [bar(g)]	13
Design pressure/setting for pressure relief valve [bar(g)]	16

As stated in MSC.1/Circ.1621, 7.3.2 and 7.3.3, the minimum wall thickness for steel pipes can be calculated using the following formula:

$$t = \frac{(t_0 + b + c)}{(1 - \frac{a}{100})}$$

Equation 3-1: Wall thickness calculation for steel pipes

where:

- $t[mm]$ represents the minimum wall thickness for steel pipes at the design pressure
- $t_0[mm]$ represents the theoretical thickness for steel pipes at the design pressure
- $b[mm]$ represents the bending allowance
- $c[mm]$ represents the corrosion allowance
- $a[\%]$ represents the negative manufacturing tolerance for thickness.

The theoretical thickness t_0 can be calculated using the following formula:

$$t_0 = \frac{(PD)}{(2Ke + P)}$$

Equation 3-2: Theoretical wall thickness calculation for steel pipes

where:

- $\mathrm{P}[MPa]$ represents the maximum system design pressure defined in Table 3-2
- $D[mm]$ represents the outside pipe diameter
- $K[\frac{N}{mm^2}]$ represents the allowable stress, which is defined as the lower value between $\frac{R_m}{2.7}$ and $\frac{R_e}{1.8}$
- $R_m[\frac{N}{mm^2}]$ represents the specified minimum tensile strength at ambient temperature
- $R_e[\frac{N}{mm^2}]$ represents the specified minimum yield stress at ambient temperature
- e represents a non-dimensional efficiency factor. For this value and further details, please refer to MSC.1/Circ.1621, 7.3.2.

The bending allowance b can be calculated using the following formula:

$$b = \frac{(Dt_0)}{(2.5r)}$$

Equation 3-3: Bending allowance

where:

- $\mathrm{r}[mm]$ represents the radius of the bend.

3.1.4 Fuel valve unit

The Fuel Valve Unit (FVU) comprises a series of fuel control valves before the consumers and represents the interface between the engine and the ancillary systems. The purposes of this unit are to isolate the engine from the methanol supply system, as well as to connect the methanol purging water supply. The FVU must be placed outside the engine room.

The main components of the FVU include the following:

- A master fuel engine valve consists of a manually operated stop valve and an automatically operated valve coupled in series. Alternatively, a combined manually and automatically operated valve can be installed on the main methanol supply line to the engine.
- Two shut-off valves, in series with a venting valve in between with a double-block-and-bleed function, are installed on the main methanol supply line to the engine.
- A manual shut-down valve is installed on the main methanol supply line to the engine for maintenance purposes. This must be installed upstream the double block and bleed valve.
- Two shut-off valves, in series with a venting valve in between with a double-block-and-bleed function, are installed on the purging water supply connection.

To enable independent operation of different fuel methanol consumers, it is recommended that each methanol fuel consumer’s supply line is equipped with an independent fuel methanol shut-off valve.

Pressure transmitter, flow transmitter, as well as a 10 µm (absolute sphere passing mesh size) filter are also required in the FVU for the purging water supply system.

Final layout of the FVU can vary depending on the methanol FSS design and engine requirements. The number of valves can be reduced by combining several functions in a single valve depending on different class requirements.

NOTE	These valves must be of fail-safe type. If they are not easily accessible, all valves in the methanol supply system must be remotely controlled.

3.1.5 Fuel preparation space

The fuel preparation space is a dedicated area containing equipment for methanol preparation purposes, which includes the following:

- fuel pumps
- FVU
- heat exchanger and filters.

NOTE	This space must be located outside the machinery space. It must be gas and liquid tight, and be ventilated to open decks.

3.1.6 Methanol transfer and supply pump(s)

The methanol fuel system consists of the following pumps:

- methanol transfer pump(s)
- methanol supply pump(s).

The methanol transfer pump(s) is located adjacent to methanol storage tank(s). The pump(s) is provided with automatic start and stop operation to maintain the methanol level in the service tank(s). This is controlled based on the signals from the level transmitter in the service tank(s). Methanol transfer pump(s) is omitted in case of the alternative methanol fuel system proposal without the storage tank (see Figure 3-2).

Methanol supply pump is located adjacent to methanol service tank(s). This pump must be designed to ensure methanol is delivered to the engine inlet at a proper pressure (e.g. a supply pressure of 13 bar(g)). Methanol supply pump is controlled based on the signals from the engine control system.

All pumps in the methanol storage and supply system must be protected against running dry. For this reason, a flow meter is recommended at each pump outlet. In addition, in case the pumps can develop pressure exceeding the system design pressure, the pumps must be provided with a pressure relief valve. This valve must relieve the pressure to the suction side of the pump.

3.1.7 Heat exchanger and filters

To ensure methanol is supplied to the engine inlet at a proper temperature, a low-temperature heat exchanger must be connected to the main cooling system. A flow control valve must be provided at the heat exchanger outlet to control the desired temperature range.

Table 3-3: Preliminary design parameters for the heat exchanger

Parameter	Heat exchanger
Temperature range at the engine inlet [°C]	25 to 50
Low-temperature shutdown [°C]	15

When the system temperature is below the low-temperature shutdown value, the methanol supply to the engine must be stopped.

A filter of duplex type must be provided at the methanol supply system outlet. The filter must be provided with a differential pressure display and alarm signal. The filter design must consider the possibility of draining the filter during the system purging.

Table 3-4: Preliminary design parameters for the methanol filter

Parameter	Methanol filter
Design pressure [bar(g)]	16
Absolute fineness [μm]	10
Mesh material	Stainless steel/metal mesh

3.2 Inert gas supply system

To control methanol vapour in methanol tanks, inert gas blanketing or padding is required at all times. This inert gas is supplied by the inert gas supply system. Inert gas can also be used for purging the methanol FSS. The detailed design of purging and inerting of the fuel supply system is in the scope of the fuel supply system supplier.

The inerting procedure is used to eliminate the possibility of a flammable mixture being present in the methanol fuel system. This is achieved by utilising inert gas which must be permanently available on board.

NOTE	In cofferdams, purging or filling with water through a non-permanent connection must be considered.

3.3 Purging water supply system

Purging and flushing of the methanol fuel system is performed in case of maintenance work, in case of failure of methanol injection system components as well as in case of depressurisation of methanol injection system during diesel mode. In these cases, the methanol fuel system must be depressurised, and the remaining methanol must be removed by water and collected in the purging water tank. For this purpose, the FVU is equipped with a connection to the purging water supply system.

The purging concept of the FSS corresponds to the concept of the FSS supplier.

For purging, WinGD requires water with the following properties:

Table 3-5: Properties for purging water

Property	Value
Conductivity (µS/cm at 20°C)	<10
Clarity	Clean & Bright
Colour	None
Odour	None
Sediment	None

Purging water pressure (pi) of 5 bar is sufficient to purge methanol to the purging tank.

Figure 3-4 shows an arrangement of the methanol purging water supply system. The purging water can be produced by the freshwater generator in low-salinity mode and can be stored in a purging water storage tank. From this tank, the water is supplied to the engine via the purging pump. Direct connection from the untreated boiler feed water storage tank is also possible.

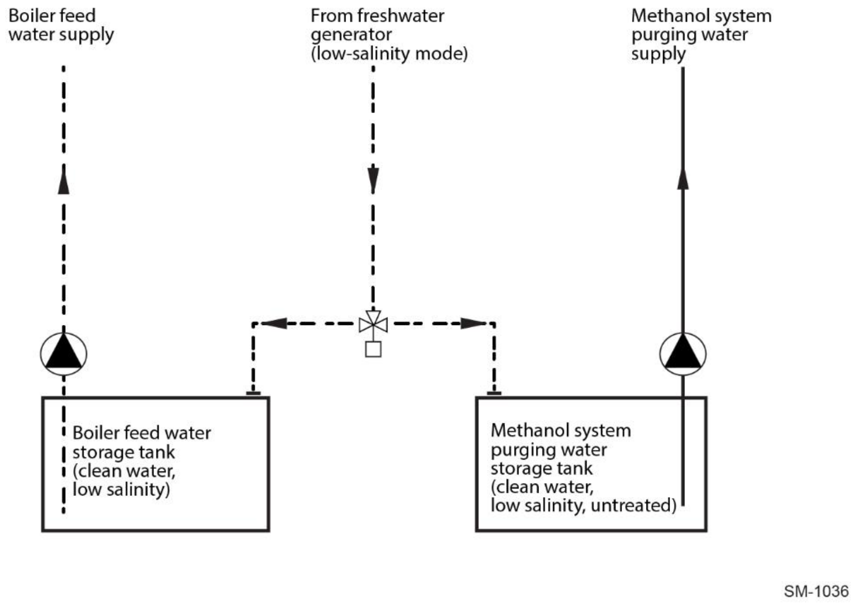

Figure 3-4 Methanol purging water supply system

The purging water consumption for one purging cycle must be at minimum three times the total volume of the space to be purged. This volume is the sum of the main engine internal methanol piping and the external methanol piping (supply and return) including the relevant fittings.

$$V_i = 3 \cdot V_a = 3 \cdot (V_{engine} + V_{system})$$

Equation 3-4: Purging water consumption volume

where:

- $V_i [m^3]$ represents the minimum required water purging volume
- $V_a [m^3]$ represents the total volume of the space to be purged
- $V_{engine} [m^3]$ represents the volume of the main engine internal methanol piping to be purged
- $V_{system} [m^3]$ represents the volume of the external methanol piping (supply and return) including the relevant fittings to be purged.

Further information on the main engine internal piping volume which must be purged can be found in the ‘Methanol Fuel System’ of the MIDS. The volume of the methanol fuel piping on the ship side must be calculated by the shipyard and must be based on the piping layout.

The purging tank must be designed for at least five purging sequences and can be calculated with the following equation:

$$V_p = u \cdot n \cdot V_i$$

Equation 3-5: Purging tank dimensioning

where:

- $V_p[m^3]$ represents the minimum required purging tank volume
- u represents the margin for the ullage and minimum filling level (e.g. 1.2)
- n represents the number of purging sequences to be stored (e.g. 5)
- $V_i[m^3]$ represents the minimum required water purging volume.

3.4 Sealing oil system

Sealing oil is used to create a barrier between methanol and actuation oil within the methanol booster unit. Sealing oil is kept and monitored at pressure higher than the methanol feed pressure to prevent methanol entering the system oil circuit. Therefore, a limited quantity of sealing oil is mixed with methanol and combusted in the engine during operation (no return from the engine to the plant is foreseen in methanol mode). A small quantity of sealing oil can get mixed with water during purging procedure and reach the purging tank. For this reason, the purging tank design is expected to have an oil drain at the lowest point (see MIDS 'Methanol Fuel System' drawing).

Oil leakage is expected to be collected from the methanol booster unit. Such leakage does not directly return to the system oil circuit. It is first monitored for potential contamination and only if it is methanol-free, it is returned to the system oil.

3.5 Venting system

A fixed venting system must be arranged for all methanol storage and service tanks. This system is used to safely fill the tanks with methanol under a gas-free condition.

The main components of the venting system include the following:

- vents
- pressure relief valve(s) installed at the end of the vent pipe or fitted directly inside the vent line
- vacuum relief valve(s) installed on each methanol tank.

NOTE	The opening pressure of the vacuum relief valve(s) must not be lower than 0.07 bar below atmospheric pressure.

Methanol tank vent outlets must be located on open decks and at least 3 m above the deck. The outlets must also be at least 10 m from the nearest air intake or opening to accommodation, service spaces and ignition sources. The venting system must be connected to the highest point of each tank, and the vent lines must be self-draining under all normal operating conditions.

NOTE	The venting system must be designed exclusively for venting and gas freeing purposes. The methanol tank venting system and the fuel preparation space ventilation system must be kept separate.

3.6 Ventilation system

A separate ventilation system for hazardous spaces is required to prevent any accumulation of methanol vapour. This system consists of a mechanical ventilation of extraction type with independent fans. The system must be kept separate from the ventilation system for non-hazardous spaces.

The ventilation system for the fuel preparation space must consist of mechanical ventilation of extraction type. During normal operation, the ventilation must be at least 30 air changes per hour. This ventilation system must be in operation when pumps or other fuel treatment equipment are working. Mechanical ventilation must also be considered for the bunkering station in case of insufficient natural ventilation. Ducts and double-wall pipes containing methanol piping fitted with a mechanical ventilation system of extraction type must have ventilation capacity of at least 30 air changes per hour.

In general, double bottoms, cofferdams, duct keels, pipe tunnels, hold spaces and other spaces where methanol can accumulate must also be capable of being ventilated. This ensures safe environment when entry into any of these spaces is required.

3.7 Fire system provisions

As stated in MSC.1/Circ.1621, 11.4, the following design requirements must be considered for the methanol fire system:

- Fuel preparation space must be classified as a machinery space of category A.
- The boundaries of the fuel preparation space towards other machinery spaces of category A, control stations and cargo areas must be at least A-60 type.
- Boundaries of A-60 type must also be considered for accommodations (up to the navigation bridge), service spaces, control spaces, machinery spaces and escape routes which are facing methanol tanks on open decks.
- The methanol tanks must be separated by a cofferdam of at least 600 mm with insulation of at least A-60 type from the machinery space of category A.
- The bunkering station must also use insulation of A-60 type except for spaces with little fire risk where the standard insulation can be used.
- Methanol tanks on open decks must be provided with a fixed fire-fighting system of alcohol-resistant foam type. This system must cover the area below the methanol tank where a spill can be expected. In addition, a fixed water spray system must be provided for diluting potential spills, for cooling and for fire prevention.
- The bunkering station must be provided with a fixed fire-fighting system of alcohol-resistant foam type. In addition, a dry chemical powder extinguisher (or equivalent) must be located near the entrance to the bunkering station.
- Machinery space and fuel preparation space must be protected by a fixed fire-fighting system. The medium used by this system must be suitable for methanol.
- Machinery space of category A (including the fuel preparation space), a fixed fire-fighting system of alcohol-resistant foam type must also be provided to protect the tank top and bilge areas under the floor.

A fixed fire detection and fire alarm system must be provided for all compartments containing methanol FSS. Suitable detectors must be selected based on methanol fire characteristics. Smoke detectors must be used in combination with other detectors which can more effectively detect methanol (see subsection 2.1.2).

3.8 Control, monitoring and safety system

The safety functions of the methanol fuel system must be arranged in a dedicated control, monitoring and safety system that is independent of the fuel control system. Control and monitoring instruments must be provided to prevent unacceptable loss of power, in the event of a single failure of the methanol storage and supply system.

This system must be arranged to automatically isolate the methanol fuel system, upon failure and/or fault conditions. For X-DF-M engines, each FSS must be fitted with its own independent control, monitoring and safety system.

3.8.1 Bunkering and methanol tanks

For overflow control, each methanol tank must be fitted with a level gauging device. In addition, visual and audible high-liquid level and high-high-liquid level alarms must be provided. In case of a high-high liquid level alarm, a shut-off valve is automatically activated to prevent excessive liquid pressure in the bunkering line, as well as the tank from becoming full.

The bunkering station must be controlled from a safe remote location, where it is possible to control the level and to operate the remote-control valves. From this location, overfill alarms and automatic shutdown must also be visible. If the ventilation of the double-wall bunkering lines stops, an audible and visual alarm must be activated at the bunkering control location. If methanol leakage is detected in the double-wall bunkering lines, an audible and visual alarm and emergency shutdown of the bunkering valve must automatically be activated. For further information on the control and monitoring parameters trigged by alarms, seeTable 3-6 (as stated in MSC.1/Circ.1621, 15.10).

3.8.2 Gas detection provisions

A permanently installed gas detector must be provided for the following:

- fuel preparation space
- annular spaces of the double-wall methanol pipes
- machinery spaces containing fuel equipment or consumers
- enclosed spaces where methanol vapours can accumulate
- cofferdams surrounding methanol tanks
- air locks.

An audible and visible alarm must be activated at a fuel vapour concentration of 20% of the Lower Explosion Limit (LEL). The control, monitoring and safety system must be activated if two gas detectors measure simultaneously at least 40% of the LEL. For further information on the control and monitoring parameters trigged by alarms, seeTable 3-6 (as stated in MSC.1/Circ.1621, 15.10).

3.8.3 Fire detection provisions

Fire detection in machinery spaces must provide audible and visual alarms on the navigation bridge, the central control station (e.g. engine control room), as well as locally.

3.8.4 Ventilation provisions

Any loss of the required ventilating capacity must provide audible and visual alarms on the navigation bridge, the central control station (e.g. engine control room), as well as locally.

Table 3-6: Control and monitoring of the methanol fuel system

Parameter	Alarm	Automatic shutdown of tank valve	Automatic shutdown of master valve	Automatic shutdown of bunkering valve
High-liquid-level methanol tank	X			X
High-high-liquid-level methanol tank	X			X
Loss of ventilation in annular space in bunkering line	X			X
Gas detection in annular space in bunkering line	X			X
Loss of ventilation in ventilated areas	X			
Manual shutdown				X
Liquid methanol detection in annular space of double-wall bunkering line	X			X
Vapour detection annular space	X			
Vapour detection in cofferdams surrounding methanol tanks (<20% of LEL)	X			
Vapour detection in airlocks	X			
Vapour detection in cofferdams surrounding methanol tanks (two detectors >40% of LEL)	X	X		X
Vapour detection in annular space surrounding methanol pipes (<20% of LEL)	X			
Vapour detection in annular space surrounding methanol pipes (>40 % of LEL)	X	X	X	
Liquid detection in annular space surrounding methanol pipes	X	X	X	
Liquid leak detection in engine room	X	X		
Liquid leak detection in fuel preparation space	X	X		
Liquid leakage detection in cofferdams surrounding methanol tanks	X			

4 Engine Design Criteria

4.1 Fuel operating modes

The engine is designed for continuous service on methanol and diesel. Depending on the selected option, different operating modes are available within specific engine power ranges.

The following list includes the operating modes available for the methanol engine:

- methanol mode
- diesel mode.

Further details are currently under development.

4.2 Injection concept

4.2.1 Main fuel injection

Considering the ignition proprieties of methanol, a high-pressure injection system is applied. This enables an optimum combustion process.

The system comprises:

- methanol supply pipes
- methanol injectors
- Methanol Booster Units (MBUs).

4.2.1.1 Methanol supply pipes

Methanol is supplied to the engine at a pressure of about 13 bar(g) through double-wall supply pipes. If a fuel rail is provided in a fuel box, no double-wall pipes are required since the fuel box fulfils already the second barrier protection.

4.2.1.2 Methanol injection system

The methanol injection system consists of methanol supply at low pressure, actuation oil rail, MBUs and spring-controlled injectors. The actuation oil rail is pressurised by mechanical pumps connected to the crankshaft gear and provide a constant pressure up to 300 bar. A rail valve commands the opening of a slide valve within the MBU which enables the actuation oil to flow within the unit and press the piston which amplifies methanol pressure from 13 bar to about 600 bar. Methanol at high pressure then opens the needle of the spring-controlled injector and finally combusts in the cylinder.

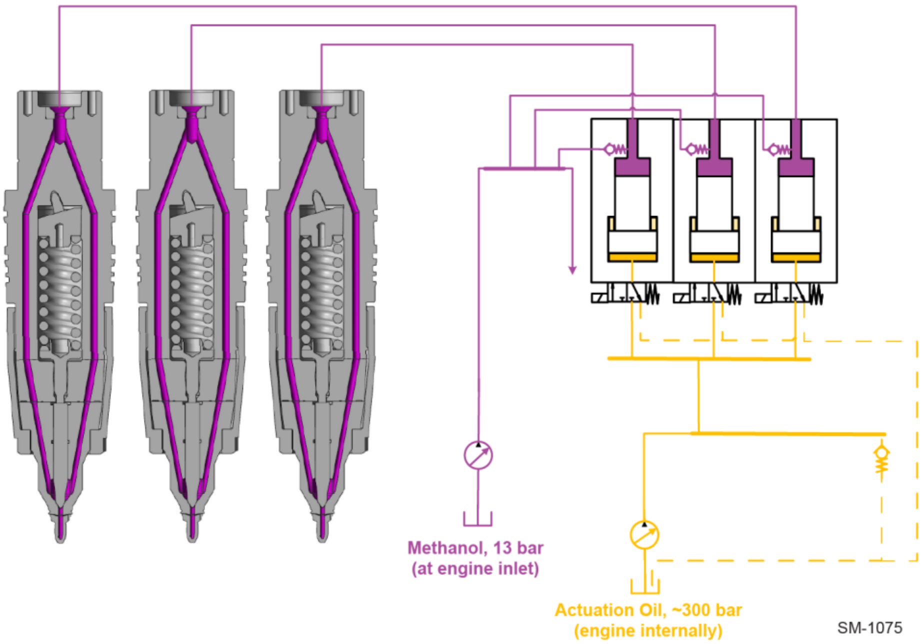

Figure 4-1 Methanol injection system

Each cylinder is equipped with 3 methanol injectors, 3 diesel injectors and 1 MBU block, which includes 3 rail valves, 3 slide valves and 3 amplifiers (pistons) (1 set per injector), in order to control separately and independently (or isolate) each methanol injector.

4.2.1.3 Methanol injectors

Spring-loaded injectors dedicated to methanol are located on the cylinder cover. Injection start, duration and stop is commanded via the MBU. Annular air is channelled through the injector body to ensure collection and detection of potential leakages in case of damage/failure.

4.2.2 Pilot fuel injection

The pilot fuel injection is provided by the main diesel injectors. No dedicated pilot injectors for methanol operations are required and the back-up diesel injection system serves both scopes (methanol piloting and diesel back-up mode).

4.3 Double barrier concept for methanol

4.3.1 Annular space concept

The methanol fuel system must be arranged in a way that any methanol release and consequences thereof are minimised. For this reason, the double barrier concept is followed for the piping system. In this concept, the piping system is protected by a gas- and liquid-tight outer pipe or duct.

A failure of one barrier cannot lead to a leak from the piping system into the surrounding area. This prevents danger to the persons on board, to the environment and to the ship.

Currently, the X-DF-M engines are equipped with the annular space ventilation concept. The annular space between the inner and outer pipe must have mechanical ventilation of extraction type with minimum capacity of 30 air changes per hour, and be ventilated to the open air, after passing a gas detector. The double-wall enclosure must be connected to a suitable drainage tank allowing collection and detection of any possible leakage.
Inerting of the annular space may be accepted as an alternative to ventilation. Suitable alarms must be provided to indicate a loss of inert gas pressure between the pipes.

4.3.2 Sealing concept

Methanol could get in contact with system oil only in two components: (1) methanol injection valve and (2) MBU.

In the methanol injection valve (1) high pressure fuel is separated from the system oil by a groove around the needle where low pressure fuel is fed. Above the groove, lubrication oil is fed to the spring chamber at higher pressure than the low-pressure fuel feed.

In the MBU (2) high pressure fuel which goes through the plunger clearance is collected in a fuel return groove. Secondly, a sealing oil barrier separates the low-pressure fuel from the actuation oil. Sealing oil is at higher pressure than the low-pressure fuel and leaks through the plunger clearance into methanol and not vice versa. Methanol and a low quantity of sealing oil is then consumed in the engine.

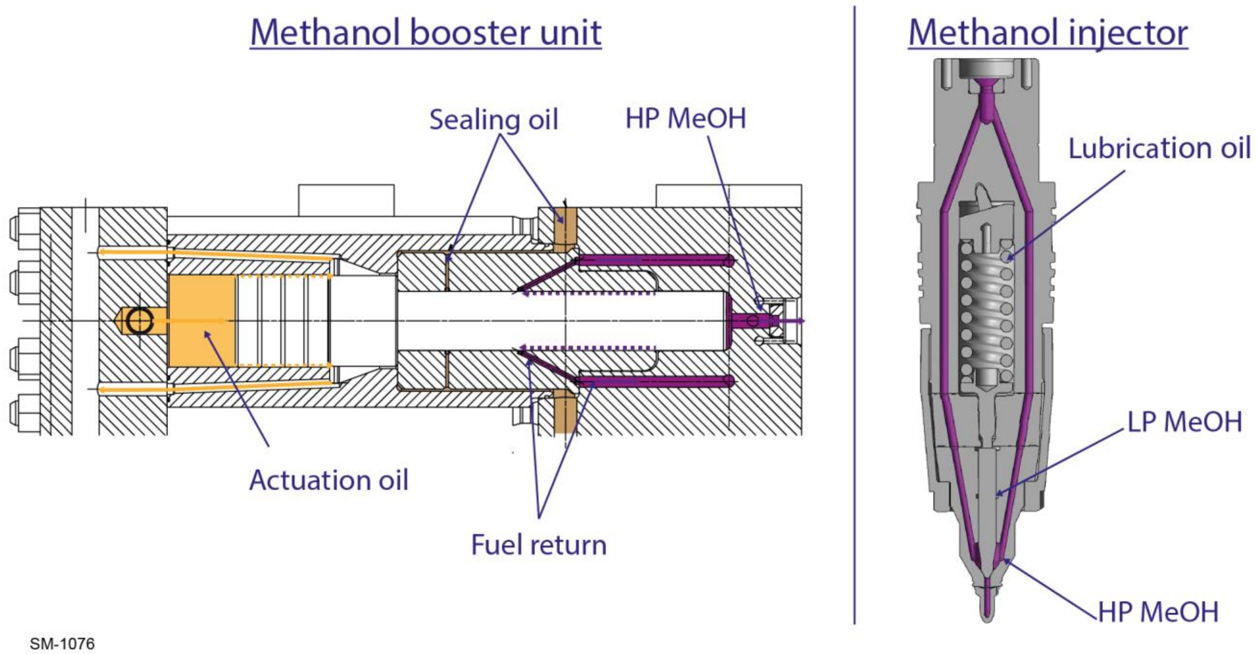

Figure 4-2 Methanol booster unit and injector

5 Emissions

WinGD methanol engines meet the IMO Tier II NO_x emission levels in both methanol mode and diesel mode. The engines also meet IMO Tier III NO_x levels in both modes through exhaust gas aftertreatment (e.g. Selective Catalytic Reduction (SCR)).

Methanol combustion results in lower NO_x emissions compared to diesel combustion. Furthermore, it burns efficiently, producing fewer residual products, such as soot, during combustion process.