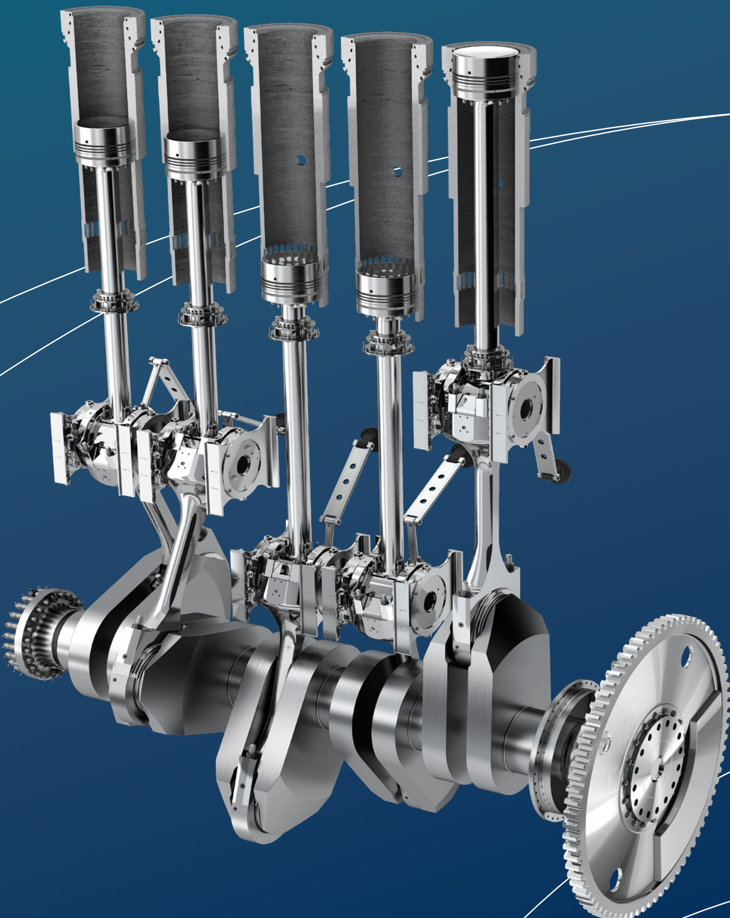
X-DF by WinGD

Low-pressure X-DF Engines FAQ



WIN GD

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Introduction

X-DF engines are designed to undercut present emission legislation being the most environmentally sustainable solution presently available with low cost, high efficiency and reliable low-pressure gas technology.

What is the running experience of X-DF engines in the field?

The first X-DF engines entered commercial operations in 2016 (5RT-flex50DF on the Terntank vessel Ternsund). In mid-2017 the first LNGC, powered by two 6X62DF, set sail. Many more vessels have followed since indicating great satisfaction from owners and charterers.

The X-DF concept has proven to meet the requirements of merchant ship propulsion in a reliable, safe and economical way. The increasing order intake with multiple repeat orders is an indication of this reliability. For further, up-to-date details on the running experience of WinGD X-DF engines please visit our website at www.wingd.com.

1. Concept & performance

1.1. What are the concepts of low-pressure X-DF engines and high-pressure gas engines?

Low-pressure X-DF technology is based on the lean-burn principle (Otto cycle), in which fuel and air are premixed and burned at a high air-to-fuel ratio, a concept widely used on medium-speed and high-speed dual fuel engines.

Before piston compression occurs, the gas enters into the combustion chamber via a low pressure feed. Depending on engine power this pressure ranges - From 6 bar(g) up to 13.3 bar(g) for bore size up to 72 cm (gas lower heating value (LHV) and engine rating dependant), and up to 15 bar(g) for bore size greater than 72 cm.

It is recommended to select the maximum supply pressure based on the project specific requirements. Detailed information can be found in the Marine Installation Manual available online at wingd.com.

In contrast, high-pressure gas engines are based on the diesel combustion process in which gas is injected into the combustion chamber when the piston is at the top dead centre position. This requires a high pressure gas injection of 300 bar(g) to overcome compression pressure.

1.2. What are the main benefits of low-pressure X-DF engines compared to high-pressure gas engines?

The X-DF low-pressure concept provides several benefits compared to the high-pressure gas engine, see Table 1.

Table 1: X-DF and high-pressure dual-fuel engine comparison.

Low-pressure X-DF engines	High-pressure gas engines
Low-pressure gas supply means low investment costs for the Fuel Gas Supply System (FGSS), low electrical power consumption and low maintenance costs	High-pressure gas supply means more expensive Fuel Gas Supply System (compressors and/or pumps, components etc.), higher electrical energy consumption and higher maintenance costs
Low pilot fuel quantity, ranging from 0.5 - 1% of total energy consumption over engine power	Higher pilot fuel quantity, ranging from 0.5 - 8% of total energy consumption over engine power
X-DF engines can be operated on gas down to 5% power. Start/stop is requested in diesel mode. Manoeuvring for vessels with CPP could be in gas mode, if accepted by class rules	High-pressure gas engines can only be operated when engine power is above 10% in gas mode
Low NOx emissions, Tier III compliant without exhaust gas treatment system	Tier II compliant only and an exhaust gas treatment system like EGR or SCR is needed for Tier III compliance
Particulate matter emissions are significantly reduced compared to diesel engines	Particulate matter emissions still significant

Given the benefits mentioned in the table, low-pressure gas admission technology has been widely adopted by the marine market as an industry standard on both medium and low-speed engines.

1.3. Fuel consumption comparison between LP and HP

The engine, fuel gas supply system, auxiliary systems, selected Tier III technology etc. all have significant influence on the overall energy requirement for the ship propulsion system and must be calculated when making the consumption comparisons. In most cases, low-pressure systems have an advantage.

1.4. X-DF engines have reduced output compared to standard low-speed diesel engines. What are the consequences?

X-DF engines have been designed to avoid pre-ignition and knocking risks, so the maximum rating has been reduced compared to their conventional peers.

The rating field of the X-DF engines covers most of the applications that typically apply de-rated output. This means that for most applications, no additional cylinders, other than for the standard low-speed diesel engine, are required. However, even in cases with an additional cylinder, the additional costs are more than covered with the achieved savings of the low-pressure fuel gas system.

1.5. Why is less pilot fuel sufficient for X-DF engines when compared to high-pressure gas engines?

X-DF engines require less pilot fuel due to their unique pre-chamber technology - a clear advantage over the high-pressure gas engine injection concept.

Table 2: Specific pilot-fuel consumption comparison between X-DF and high-pressure gas engine (based on an engine bore range of about 70 cm).

	X-DF engine	High-pressure gas engine
Pilot fuel consumption [g/kWh]	0.8 g/kWh @ 100 % power 1.8 g/kWh @ 30 % power	0.8 - 5 g/kWh @ 100% power* 1.9 - 11 g/kWh @ 30% power* * depending on selected pilot oil energy fraction

2. Engine operation

2.1. How does the fuel change work: from gas to diesel and vice versa?

When an X-DF engine runs in gas mode, a trip to diesel mode is available on request at any engine power; it is instantaneous and without any loss of engine power or speed. The trip to diesel mode happens automatically if required by the engine control or safety system.

When an X-DF engine runs in diesel mode, transfer to gas mode is available upon request, at engine power in the range of 10 % to 80 % without any loss of power or speed. (see Figure 1).

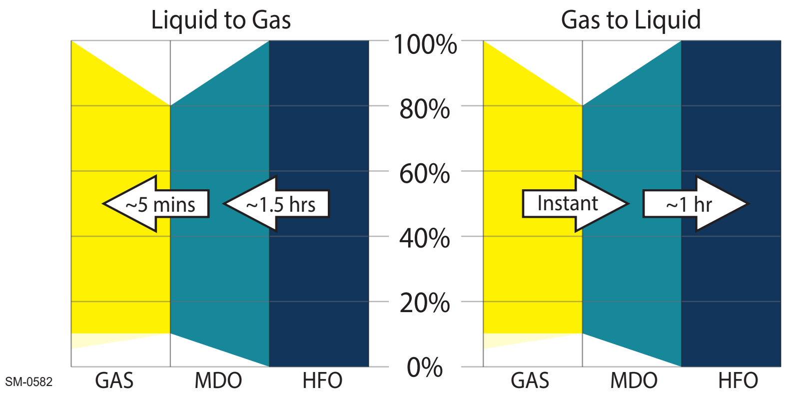

Figure 1: Changeover procedure between different fuels: Gas, MDO and HFO.

During the changeover procedure from gas to diesel, the cylinder lubricating oil does not need to be changed and can remain on low-BN (Base Number) oil as specified for X-DF engines. In cases where higher sulphur liquid fuels are used during diesel or fuel sharing mode, the 'integrated Automatic Cylinder-oil Transfer' (iCAT) system will automatically change the lubricating oil to high-BN.

2.2. Which engine power range is available in gas mode?

While the engine is operating in gas mode the engine power can be varied in the range of 5% to 100%. This means from "Slow" up to "Full Speed", independent of driving a Fixed Pitch Propeller (FPP) or a Controllable Pitch Propeller (CPP). For "starting/stopping" the class rules require the engine to run in diesel mode only. This is also required for "reversing" when driving an FPP.

In principle, once an engine operating a CPP has switched to gas mode there should be no need to return to diesel mode until the engine operation is finished in the next port.

2.3. What is the difference in load acceptance between X-DF engines and conventional low-speed diesel engine?

The load acceptance capability of X-DF engines is similar to that of conventional low-speed diesel engines.

2.4. What is the difference in load fluctuation capability between X-DF engines and conventional low-speed diesel engines?

The load fluctuation capability of X-DF engines is similar to that of conventional low-speed diesel engines.

The operational experience of vessels in service has shown that load fluctuations caused by heavy sea conditions are within the design limits and consequently no changeover to diesel mode is required.

2.5. Does gas quality in terms of Lower Heating Value (LHV) have an impact on low-pressure X-DF engines?

The Lower Heating Value (LHV) has no impact on engine performance and output in the range of 28 MJ/Nm3 to 36 MJ/Nm3 (volumetric LHV).

2.6. Does gas quality in terms of methane number (MN) have an impact on X-DF engines?

The engines can operate on a Methane Number (MN) as low as 65 with full power output which is an MN lower than the globally available LNG for bunkering. Accordingly, in practice, there is no impact of MN to the available power output of the engine. Also, in tropical conditions, full power output is available with MN≥65 due to the automatic activation of the Dynamic Combustion Control (DCC), see following section 2.7. Lower MN might influence DCC activation to be triggered earlier, i.e. already at lower engine load and at higher rates.

DCC allows full engine power output independent of ambient conditions and engine ratings.

2.7. What is Dynamic Combustion Control (DCC)?

WinGD has introduced Dynamic Combustion Control (DCC) to ensure efficient gas combustion and full power output under any operating conditions. The engine remains IMO Tier III compliant even with maximum DCC share amounts.

DCC is a specific engine control feature that maintains the firing pressure at an efficient and safe level. It is automatically activated by an algorithm that continuously monitors cylinder pressures. At high engine power, warm and humid ambient conditions and/or low Methane Number, the cylinder pressure could exceed the normal operation range. In this case a small quantity of diesel (between 3% and 15% of energy input) is injected by the main fuel injectors which helps to rectify the air-fuel gas ratio (lambda) by reducing the gas amount as well as by increasing the air supply from the turbocharger.

The brake specific energy consumption (BSEC) of the engine remains the same with DCC active. The gas consumption decreases at the same rate as the liquid fuel consumption increases.

DCC is included in the engine control system software of all X-DF engines and is IMO Tier III certified.

3. CAPEX (Capital Expenditure)

3.1. Why does The X-DF solution have lower CAPEX than the high-pressure gas engine solution?

Though the prices of the engines are similar, the cost of the Fuel Gas Supply System (FGSS), such as compressors, pumps, evaporators, heat exchangers, piping system, sensors, valves, etc. is significantly lower for an X-DF engine than for a high-pressure gas engine installation. Furthermore, the X-DF solution is Tier III compliant without any exhaust gas treatment - this is needed to achieve Tier III compliancy with a high-pressure gas engine.

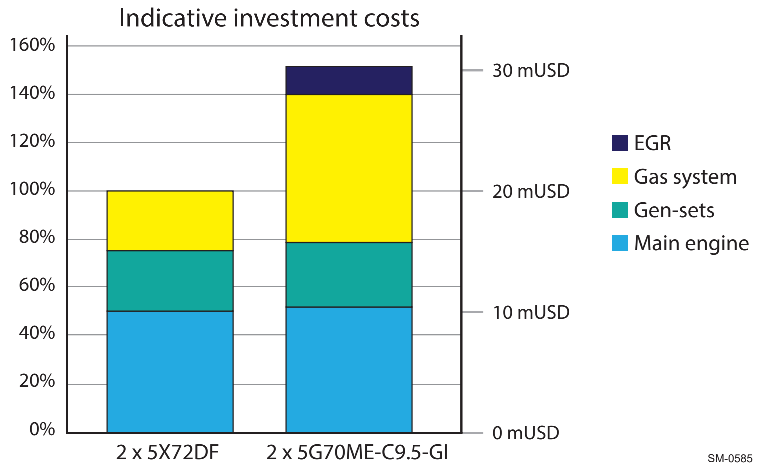

Figure 2: CAPEX comparison between X-DF engine and high-pressure gas engine for a 180,000 m3 LNGC.

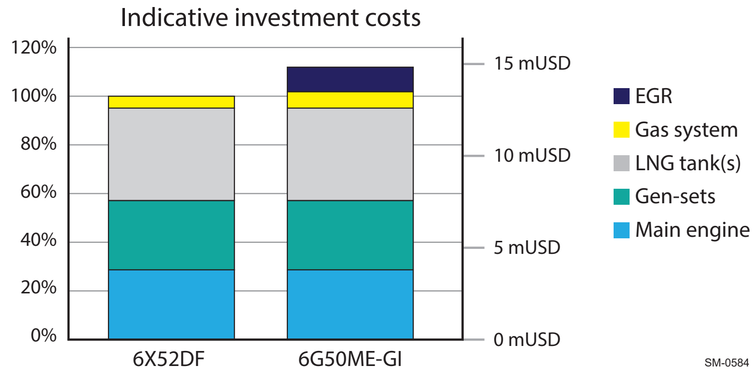

Figure 3: CAPEX comparison between X-DF engines and high-pressure gas engines for a 55,000 dwt tanker with a 50 cm-bore size engine.

4. OPEX (Operating Expenditure)

4.1. Why does the X-DF solution have lower OPEX than the high-pressure gas engine solution?

OPEX consists of consumables and maintenance costs.

Consumables

The liquid pilot fuel consumption of X-DF engines is lower than that of a high-pressure gas engine. This means that more energy is supplied to the engine via the fuel gas compared to a high-pressure engine.

The OPEX comparison between a low-pressure X-DF propulsion solution and a high-pressure gas engine propulsion solution requires a detailed analysis taking the following aspects into consideration:

- Main engine consumption
- The ship's operational profile
- Energy consumption of the fuel gas supply system (compressors, pumps, etc.)
- Additional generator engine load (parasitic load)
- Running hours in ECA areas (Tier III mode)
- Fuel penalty for Tier III mode (high-pressure gas engines only)
- Costs of LNG, MDO, MGO, HFO, NaOH or UREA

A low-pressure X-DF engine propulsion solution has similar accumulated daily consumable costs as a high-pressure gas engine propulsion solution even though the gas consumption of the main engine is higher.

When operating in Tier III areas, the low-pressure X-DF propulsion solution results in lower consumable costs than the high-pressure gas engine solution as no exhaust gas treatment is needed for compliance. X-DF always features ultra-low NOx and particulate emissions without generating any extra costs. The X-DF has no increased consumption, unlike high-pressure gas engines which require EGR/SCR, increasing the energy consumption on the engine significantly and requiring additional consumables.

The energy consumed by the gas supply system (such as the compressors and/or pumps) is less for a system operated at low pressure.

Maintenance

Fuel gas supply system related components are designed for low-pressure only (e.g. pipe class PN16 or similar is selected). The same as with initial CAPEX costs, this reduces the required spare parts costs. It allows simple and safe maintenance procedures compared to a high-pressure system. The crew can safely and independently perform most maintenance tasks during normal port stays. A simple gas system pressure test takes only a few minutes compared to hours on a high-pressure supply system.

5. Engine safety

5.1. What is knocking? And does it limit engine operation in any way?

The combustion in an engine chamber aims to burn the air-fuel mixture progressively and smoothly from the point of ignition outwards. However, at high pressures, spontaneous ignition can occur within the air-fuel without the ignition of this flame front.

These instantaneous and uncontrolled releases of energy cause pressure waves to propagate through the combustion chamber. These pressure waves can cause the combustion chamber to resonate at a natural frequency, resulting in a typical audible noise known as "knock", giving rise to the name "knocking".

In contrast to medium and high-speed Otto-cycle engines, knocking has not been seen to affect X-DF engines, therefore having no effect on performance. Operating the engine with a very lean gas mixture, i.e. a high air-gas ratio (lambda), combined with low scavenge air temperatures, limit the possibility of knocking. The dominant limiting factor for X-DF is early ignition and fast combustion and the resulting maximum cylinder pressure, which is controlled with DCC.

The control system of the X-DF engine monitors the combustion and is capable of taking corrective actions without the need of an operator.

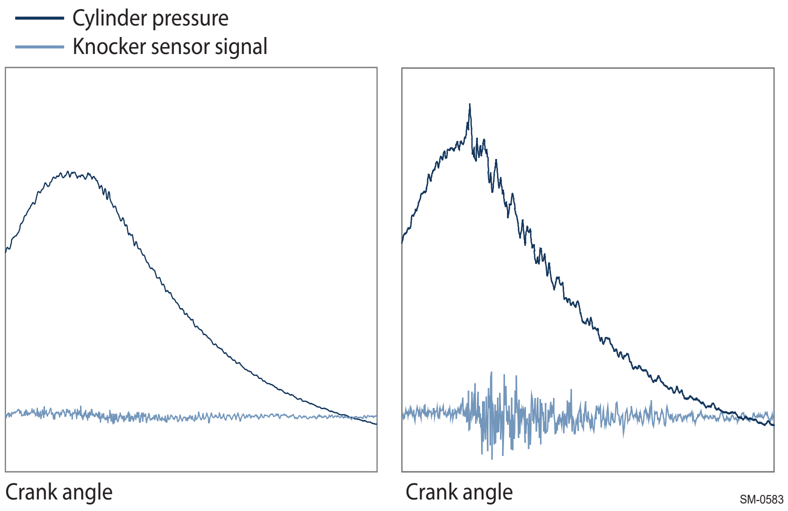

Figure 4: Cylinder pressure and knocking sensor signal for normal gas operation and for knocking condition (as seen under specially applied testing settings).

5.2. How does the X-DF engine detect and manage gas leakage in the piston underside?

X-DF engines have various engine control and safety functions designed to detect gas leakage and to control abnormal engine behaviour.

Leakage of gas fuel into the piston underside could occur due to a Gas Admission Valve (GAV) remaining stuck open (will not close) or a blow-by on the piston rings. Both cases are monitored and detected by the engine control system:

Severe leakage results in high firing pressure of the affected cylinder from early ignition and fast combustion of the excessive gas amount. It will be detected by the cylinder balancing and exhaust gas temperature monitoring systems. Severe leakages could even trigger the knocking sensor.

The rail valve actuated GAV is monitored constantly by the valve stroke sensor. Should the GAV for unknown reasons stay open for a prolonged period of time, the safety system triggers a gas trip (i.e. trip to diesel) immediately.

A gas detection sensor is mounted in the piston underside compartment, constantly monitoring the composition of the scavenging air. Should it detect an increase in the gas concentration, the safety system will first sound an alarm, and in the case of continued increasing amounts of gas, a gas trip.

The sensor monitoring the cylinder pressure also acts as a detection feature. Should the cylinder pressure deviate beyond a certain preset threshold on one cylinder, an alarm (i.e. offset reached) will be triggered.

The gas piping in the engine room and on the engine are constantly monitored to detect leakages. The gas piping is double-walled and the annular space is constantly ventilated. Two gas concentration sensors detect any possible gas leakage and activates an alarm that trips the engine to diesel mode (see Figure 5 and Figure 6).

X-DF field experience has demonstrated excellent results and flawless operation of the above system, resulting in very stable gas mode operation.

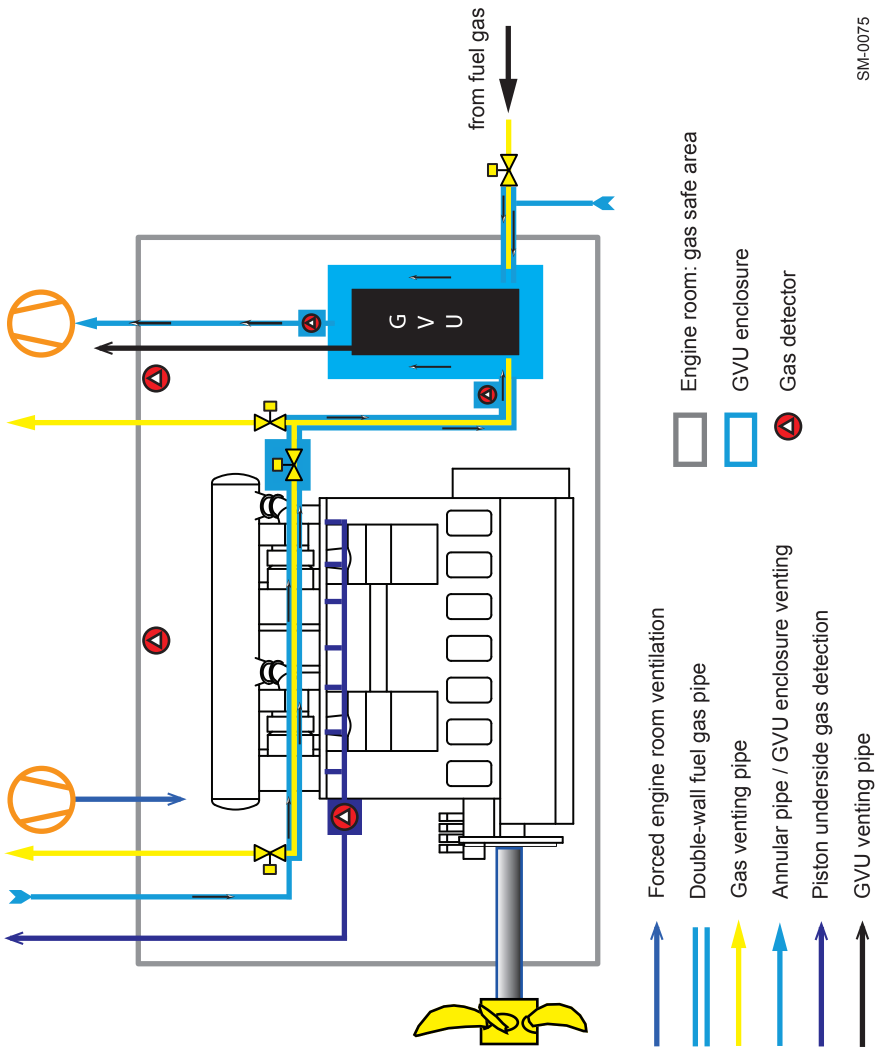

Figure 5: Installation concept of gas safe engine room, for engines with external GVU (Gas Valve Unit).

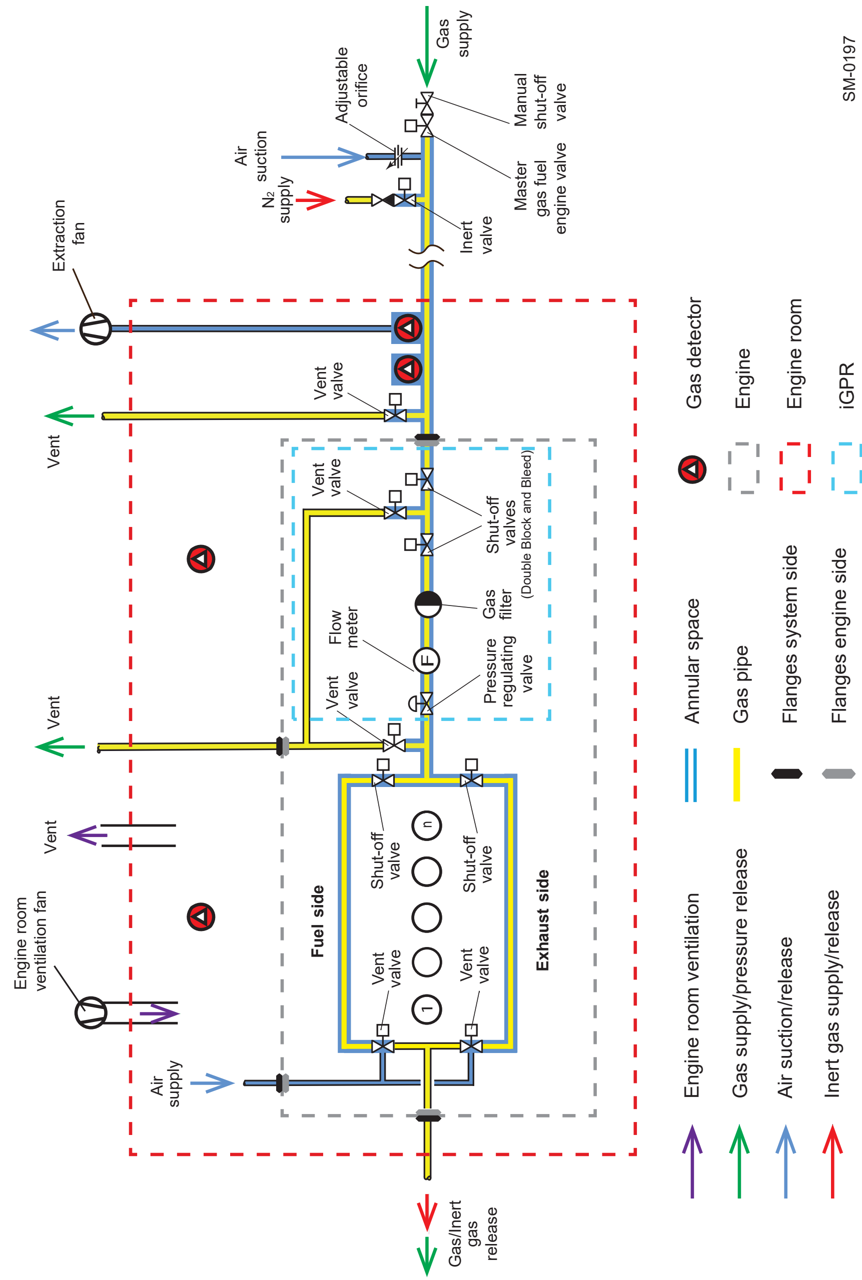

Figure 6: : Installation concept of gas safe engine room, for engines with iGPR (integrated Gas Pressure Regulation).

6. Emissions

6.1. How do X-DF engines comply with IMO Tier III NO_X emission limits in gas mode?

In gas mode, low-pressure dual-fuel engines operate according to the Otto cycle, i.e. the fuel-gas and air are homogeneously pre-mixed in the combustion chamber before ignition.

Together with the high amounts of air, this results in lean premixed combustion with a much more uniform temperature distribution throughout the combustion chamber than on engines that operate according to the Diesel cycle. In those engines, gas or liquid fuel is injected into the combustion chamber close to the end of or after compression. Consequently, the combustion occurs in a mixing-controlled or diffusion regime at conditions close to stoichiometry and the formation of NOx is promoted due to the existence of high-temperature regions close to the flame.

The lower peak temperatures of the X-DF engines reduce NOx emissions below the respective IMO Tier III limit.

X-DF engines do not require any further NOx reduction systems, such as Exhaust Gas Recirculation (EGR) or Selective Catalytic Reduction (SCR), which are applied to Diesel cycle engines in order to achieve compliance with Tier III NOx emissions limits.

6.2. Are low-pressure X-DF engines also compliant with IMO Tier III during manoeuvring, starting and stopping?

Yes. The compliance of X-DF engines with IMO Tier III is not affected by any procedures applicable during manoeuvring, starting and stopping.

For safety reasons, the IGF code and IACS rules require that engine starting, stopping and reversing for manoeuvring must be carried out in diesel operating mode.

Therefore, corresponding control strategies are defined and clearly documented as Auxiliary Control Devices (ACD), in accordance with the “IMO Guidance on the application of Regulation 13 of MARPOL Annex VI Tier III requirements to dual-fuel and gas-fuelled engines”.

6.3. How much methane is emitted by X-DF engines?

Every combustion engine emits unburned hydrocarbon regardless of the process and the size of the engine. Eventually unburned methane (CH4) forms part of the total hydrocarbon (THC) emissions present in the exhaust of these engines.

As a matter of principle, low-pressure X-DF engines have considerably lower THC and hence also methane emissions (commonly also designated as “methane slip”) compared to four-stroke medium- and high-speed dual-fuel engines. This low methane emission level is inherent to low-speed two-stroke engine physics and is achieved by optimising the engine’s internal combustion process as well as the combustion chamber design .

Figure 7 shows the range of methane emission results from measurements on various X-DF engines. Methane emissions are engine-size dependent, with higher values for the smaller bore size engines. Relative emissions are also higher at lower power levels.

The area displayed in Figure 7 represents the methane emitted across the entire WinDG X-DF portfolio.

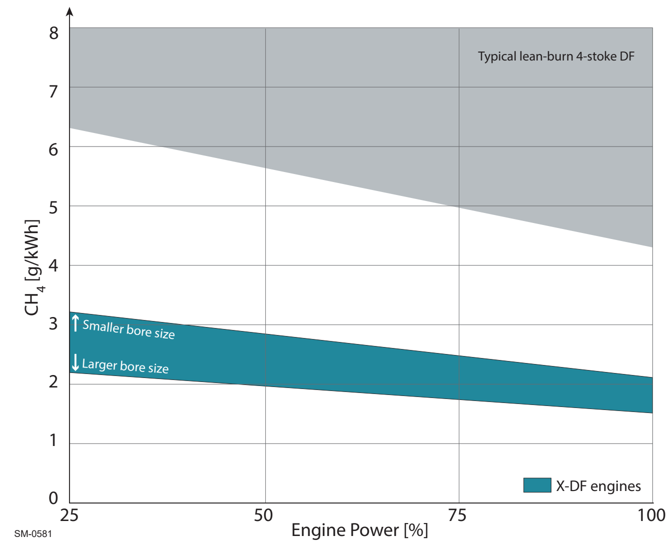

Figure 7: Methane emissions of X-DF engines operated in gas mode compared to typical data from lean-burn 4-stroke DF engine.

For more details refer to: Weisser, G., Nylund, I., Schneiter, D.: “Greenhouse Gas (GHG) Emissions from LNG Engines, Review of the Two-Stroke Engine Emission Footprint”, CIMAC paper No. 426, Vancouver, 2019, available for download at: https://www.wingd.com/en/documents/general/papers/greenhouse-gas-emissions-from-lng-engines-cimac2019-paper-426-g-weisser/

6.4. What are the consequences of methane emissions?

Methane is a greenhouse gas that contributes to global warming. Compared to CO_2, its impact is considerably more severe, specifically in the short term. Therefore, losses of methane to the atmosphere during fuel production, transportation or during the combustion process should be kept at a minimum and proper gas extraction and handling throughout the transportation and utilisation chain is hence important to achieve a positive greenhouse gas balance.

Note that the impact of methane is reduced over time, as its lifetime in the atmosphere is limited. Its global warming potential is typically quantified by referencing it to that of CO_2 (CO_2 equivalent), based on a 100-year or a 20-year basis. In the IPCC reports / Kyoto Protocol it is recommended to consider the 100-year period for determining the climate change impact as the long-term effect on global warming is the key focus.

The values for calculating the CO_2 equivalent have changed over the years, based on more recent research results. The latest values are provided by the 5th IPCC report from 2014 (IPCC AR5). As it is very difficult to accurately predict the effect of all influencing factors, two different values are provided, based on different calculation methods. One includes additionally assumed "climate-carbon feedbacks" (cc fb) for non-CO_2 gases, which yield higher additional indirect warming effects (GWP100=34), while the other, with no climate-carbon feedback, does not (GWP100=28). IPCC AR5 suggests using factors with no climate-carbon-feedback due to the large uncertainty of the models. However, considering the origin of the methane – gas from fossil sources, the factor is increased to 30.

6.5. Is X-DF technology beneficial in terms of Green House Gas (GHG) emissions?

Yes. When comparing the GHG performance of X-DF engines running on LNG with propulsion systems running on residual fuels, two factors must be considered: The use of LNG is associated with 25-30% lower CO2 emissions during combustion, even though this benefit is reduced due to the emission of unburnt methane.

However, even when applying the above-mentioned conversion factor of 30, the total GHG balance is still reduced by about 15-20% which constitutes a clear improvement over conventional diesel engines. Figure 8 illustrates this by showing the contributions from carbon dioxide and methane with different shading.

6.6. What is WinGD doing to reduce methane slip?

WinGD has launched X-DF2.0 technology with the introduction of iCER – Intelligent Control by Exhaust Recycling. iCER technology delivers enhanced combustion control through the use of inert gas and reduces methane slip by up to 50%. iCER technology is an upgrade that is included in the X-DF2.0 engines.

WinGD's R&D efforts continue to focus on further reducing the engine's overall impact on the environment. Working together with ship owners, partners and other industry experts there is a strong commitment to further improvements in this area. More information on X-DF2.0 can be found at wingd.com.

6.7. How are methane emissions regulated?

At present, there is no regulation in place addressing emissions of methane from ocean-going vessels. Discussions at the IMO are currently focused on measures towards achieving the targets set forth in their initial strategy on reduction of GHG emissions from ships and methane emissions are to be taken into consideration in this context. However, there are no clear signals to date what outcomes can be expected and by when.

6.8. What is the overall environmental footprint of X-DF engines?

The total greenhouse gas balance is clearly positive compared to conventional diesel engines. At the same time, all emissions that are directly harmful to health and the environment, such as SOx, NOx and particulate matter, are also considerably reduced. X-DF engines are inherently compliant with all existing environmental standards. This is specifically important when comparing with other DF technologies (as seen in Figure 8). Propulsion systems with X-DF engines are currently the most environmentally sustainable solutions using fossil fuels.

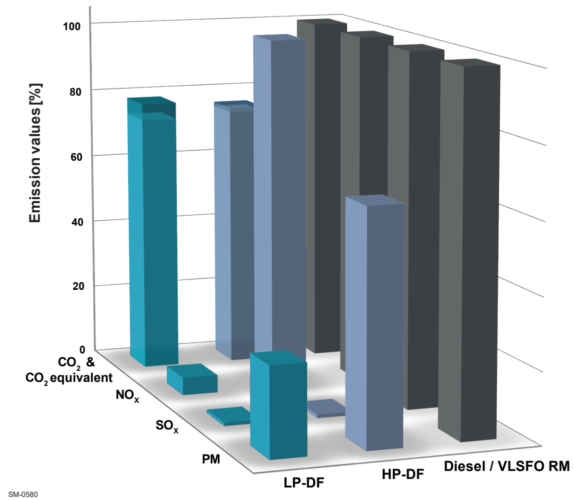

Figure 8: Emissions footprint of X-DF engines compared to diesel engine reference running on HFO at 0.5% S content and HP-DF technology, including CO2 equivalent of methane slip.

Only the use of non-fossil fuels (bio-fuels, synthetic fuels) or renewable energy sources (wind and solar power) will further reduce greenhouse gas emissions of vessel propulsion systems. LNG provides the advantage that gas from either bio-sources or Power-to-Gas sources can be mixed at any rate, supporting the gradual transition from fossil fuels to renewable fuels.

Winterthur Gas & Diesel Ltd. (WinGD) is a leading developer of two-stroke low-speed gas and diesel engines used for propulsion power in merchant shipping.

WinGD sets the industry standard for reliability, efficiency and environmental sustainability. WinGD provides designs, training and technical support to engine manufacturers, shipbuilders and ship operators worldwide.

WinGD is headquartered in Winterthur, Switzerland, where, as one of the earliest developers of diesel technology, it started the design of large internal combustion engines in 1893 under the "Sulzer" name.

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