MAN B&W ME-LGIP dual-fuel engines

MAN Energy Solutions
Future in the making

Dual-fuel technology reshapes
the future two-stroke engine operation

MAN B&W ME-LGIP dual-fuel engines

Dual-fuel technology reshapes the future two-stroke engine operation

Content

This paper describes the most recent fuel-cost optimised and environmentally friendly dual-fuel two-stroke engine from MAN Energy Solutions, the MAN B&W ME-LGIP. The paper concerns the complete system, from tank and supply to injection. The feasibility of LPG operation compared to HFO operation is investigated for three different vessel types. The LGIP concept is also suitable as a retrofit solution, applicable for more than 3000 ME-C type engines in service.

In July 2018, MAN Energy Solutions' (MAN ES) order book for two-stroke low-speed dual-fuel engines passed 210 engine orders. This achievement proves the customers confidence in the dual-fuel engine concept.

In 2018, the world's first order for the ME-LGIP dual-fuel MAN B&W engine for operation on liquefied petroleum gas (LPG) was placed by Exmar with its 2 + 8 orders of the 6G60ME-LGIP engine for their new very large gas carriers (VLGCs). These ships will be built at Hanjin Subic Shipyard in the Philippines.

This order proves that the market has acknowledged the advantages of the two-stroke dual-fuel engines utilising the diesel cycle combustion process to burn gas, and LPG is now another fuel option that can been used in the two-stroke dual-fuel gas engine portfolio.

When initiating the development of engines for operation on LPG, a close study on available technologies was carried out and it was decided to use the ME-LGI injection concept for injection of LPG, i.e. utilising the diesel combustion principle, which is also applied for other low flashpoint fuels such as methanol.

The diesel combustion cycle offers a very stable combustion with very low cycle-to-cycle combustion pressure variations, thereby maintaining an equal distribution of load on all cylinders and with an insignificant fuel slip. In a diesel process, the fuel gas is injected when the piston is close to the top position and burned immediately during the injection. A two-stroke gas diesel engine therefore has the same fundamental characteristics as any conventional two-stroke diesel engine in terms of fuel efficiency, power density, load acceptance and low emission of hydrocarbons. Fundamentally, any gas quality may be burned in a gas diesel engine, with the limits set only by the fuel supply and fuel injection systems and with the gas quality affecting neither fuel efficiency nor engine power.

This means that the LPG engine has a well-controlled combustion process, which is one pre-condition for handling fast load changes as well as stable LPG running during heavy weather, tropical and arctic conditions. During such conditions, the engine will also be able to follow load changes without loss of engine efficiency. It should be noted that heavy weather conditions occur in most parts of the world on a regular basis. In the North Sea for example, this condition occurs around 20% of the time, making it imperative that the engine is able to operate satisfactory under these conditions.

The ME-LGI concept offered today for LPG operation is not new as MAN ES has already received orders for 11 methanol engines based on the ME-LGI engine concept. Seven of the methanol engines are already in operation, and by July 2018, they had achieved more than 25,000 running hours on methanol.

The scope of this paper is to describe the engine technology behind the LPG system on the ME-LGIP engine, including the LPG fuel supply system and the auxiliaries related to running the LPG engine. In early July 2018, the world's first two-stroke LGIP engine was successfully operated on LPG on the research engine at MAN ES' Research Centre in Copenhagen. This paper further describes the results from the very first engine tests to the latest design of the ME-LGIP concept on the engine.

This paper also describes retrofit opportunities of MAN B&W ME-C engines, which can all be equipped with LGIP components and become LPG-fuelled ME-GI engines. The ME-LGIP engines are included in MAN ES' two-stroke engine programme offering gas engines for all kind of ships utilising two-stroke engine propulsion.

LPG engines and environmental regulations

The costs of fuel for operation within stricter shipping and environmental regulations in the marine market, led MAN ES to identify the need to develop a range of engine technology platforms that enable vessels to run on alternative fuels, which offer enhanced environmental benefits at reduced cost.

The first order regarding application of this novel technology for LPG is for gas carriers traditionally operating with conventional fuel-burning engines. With a viable, convenient and comparatively cheap fuel already on board, it makes sense to save time for bunkering by using a fraction of the cargo to power the vessel, which brings important environmental side benefits. In this respect, the ability of the ME-LGIP engine to run on LPG, a sulphur-free fuel, offers great potential for compliant ship operation within SECA zones.

Both new and coming emission legislations have also contributed to the interest in gas as an alternative fuel compared to HFO, MDO and MGO. The emission legislation is mainly designed to protect coastal areas from SO_X and NO_X emissions, but the introduction of the energy efficiency design index (EEDI) in 2013, using fuel carbon content as a calculation tool, and the latest outcome of the IMO meeting held in April 2018 shows that CO_2 emissions are still very much in focus. The use of LPG as the fuel in MAN B&W two-stroke engines will reduce the CO_2 emission by up to 13%, when compared to MDO and up to 18% when compared to HFO. As an additional feature, the LPG engine has great potential for being a solution to handle the volatile organic compound (VOC) issue in shuttle tankers and other crude oil carriers as the engine holds novel options for burning the liquid volatile organic compound (LVOC) of the VOC. The engine can burn any mixtures of propane and butane, and furthermore, the mixture can contain significant amounts of ethane. All heavier hydrocarbons normally contained in the LVOC can also be used.

IMO has lately agreed to look into ways of reducing VOC emission, and it is expected that all VOC has to be either used as fuel on board or burned in a gas combustion unit (GCU).

Concept descriptions

MAN B&W ME-LGIP engines are designed for dual-fuel operation with LPG as low-flashpoint fuel.

The LPG conditions at the engine must be:

- Pressure: 50 ± 2 bar
- Temperature: 25-55°C
- Filtrated to a level of 10 micron absolute.

LPG is supplied from an LPG tank to the low-flashpoint fuel supply system (LFSS) shown in Fig. 1, which provides the required LPG fuel conditions at the injection valve. During operation, a certain amount of the LPG is returned to the LPG tank via a recirculation line. The same recirculation line is used to recover LPG from the engine, whenever the LPG operation is stopped.

Detailed descriptions of the components in the fuel injection and LPG auxiliary systems are given in the following sections.

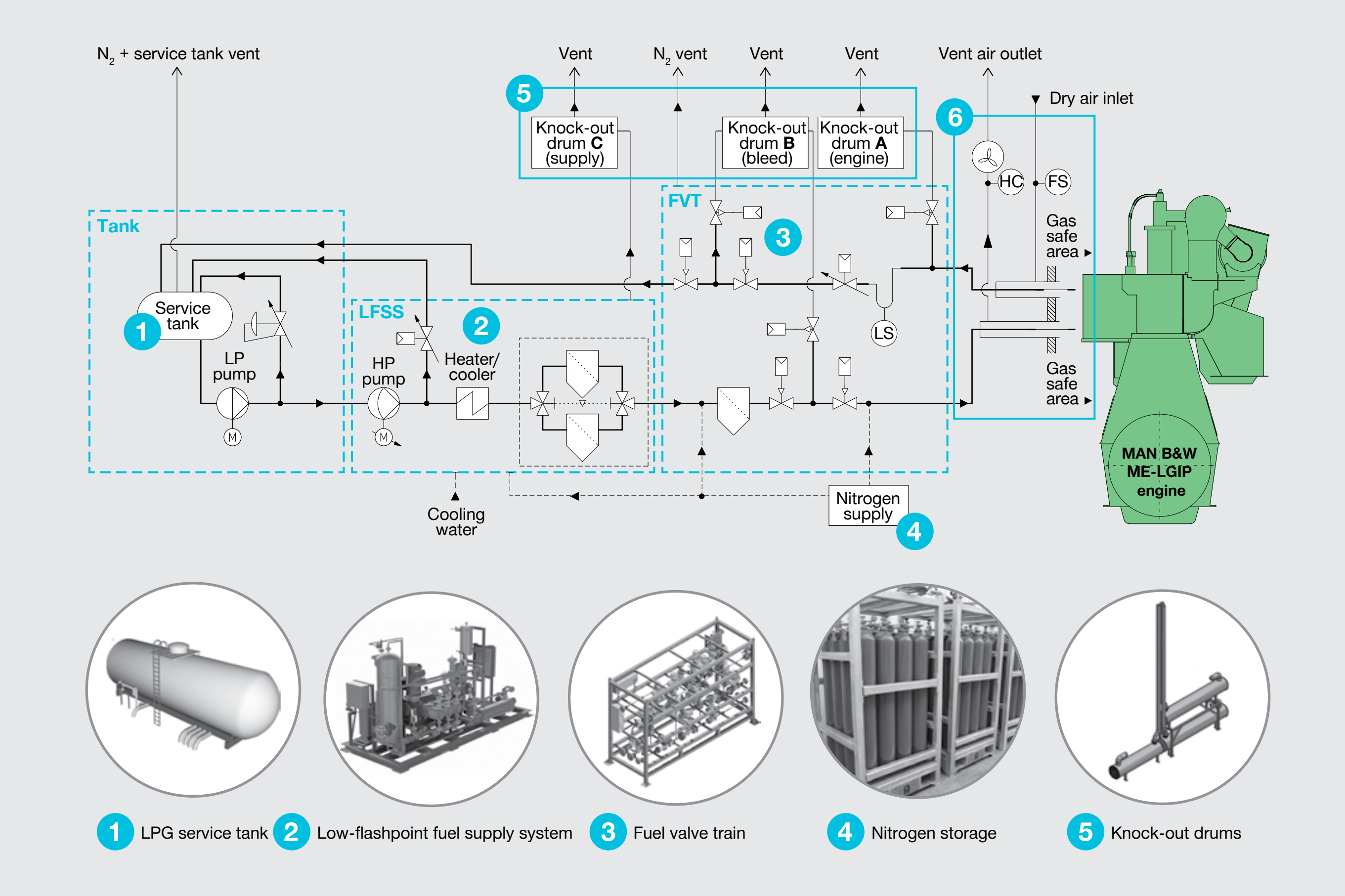


Fig. 1: Conceptual diagram of the ME-LGIP supply system at the Research Centre in Copenhagen.

Fuel injection system design

The main components for the LGIP system are the LPG injector (FBIV-P), the gas control blocks, pipes and the accumulators. In general, the ME-LGIP is designed as an add-on system to the ME engine, similar to the concept for ME-GI (LNG) and LGIM (methanol).

The FBIV-P shown in Fig. 2a is the LPG injection valve. FBIV-P is an abbreviation of fuel booster injection valve for propane, and it is designed with two main functions:

1. To pressurise or boost the LPG to the desired injection pressure
2. To ensure the correct timing and duration of the LPG injection.

The LPG pressurisation is controlled by the electronic window valve (ELWI), which provides a window function and the injection timing is controlled by the electronic gas injection valve (ELGI). In order to provide additional safety, separate control units in the engine control system (ECS) are used to control these two valves, independently.

The function of the FBIV-P is as follows: Liquid LPG is supplied to the FBIV-P plunger chamber at a pressure of 50 bar. The chamber fills up and returns the plunger to the top position as shown in Fig 2b (yellow). High-pressure hydraulic oil boosts and increases the

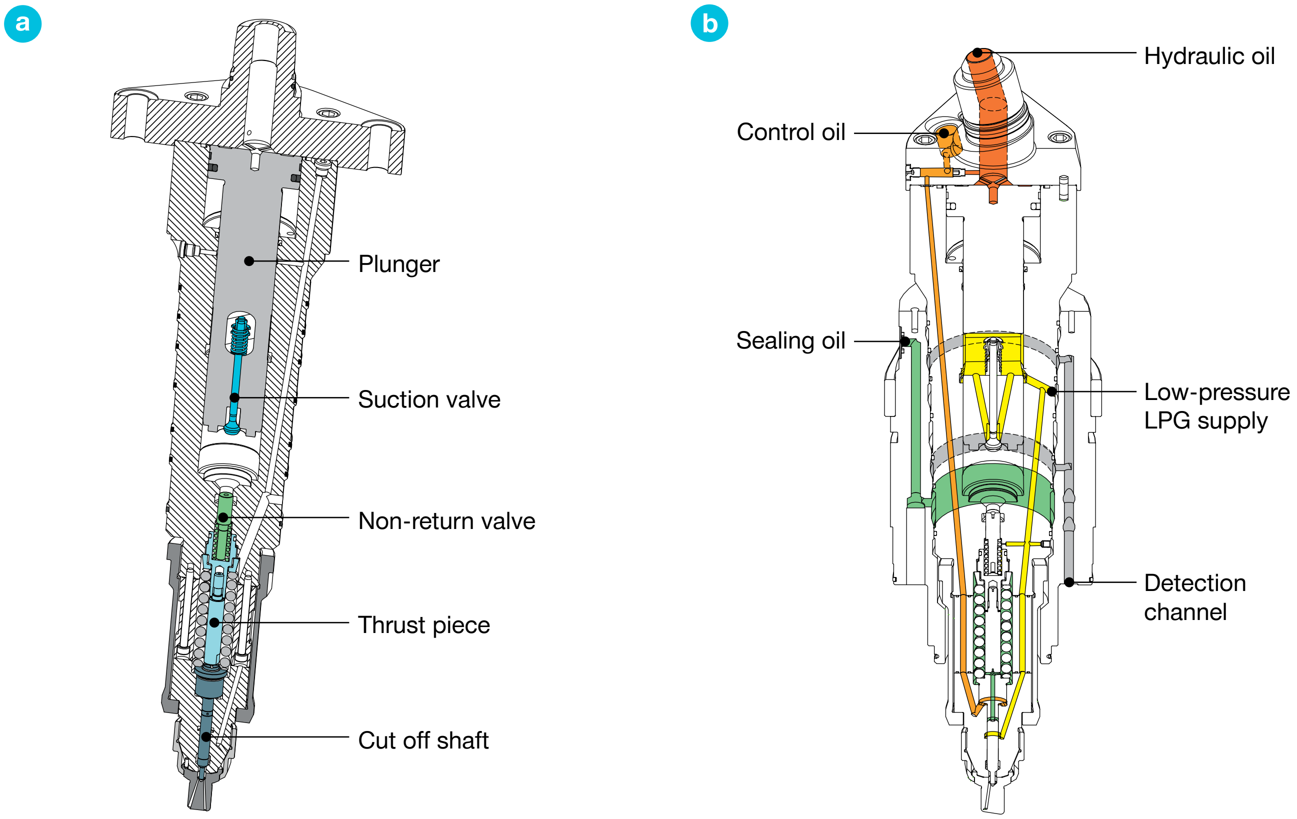


Fig. 2a and 2b: FBIV-P

LPG pressure to 600-700 bar, which is the injection pressure, see Fig. 2c (orange). When 80 bar is reached during the pressurisation, the non-return valve, (NRT) opens. The NRT is part of the safety requirements, it secures against any unintentional supply of LPG to the combustion chamber by the 50 bar supply pressure.

To secure that LPG cannot penetrate into the hydraulic oil, the two systems are separated with sealing oil as shown in Fig. 2d (green). The design concept allows sealing oil of 80 bar to separate the 50 bar LPG supply line from the hydraulic oil.

The sealing oil system is a single-line system, which means that there is no circulation of the oil. Sealing oil, which is supplied at 300 bar from the ME-system, is reduced to 80 bar and the small amount of sealing oil transferred to the LPG supply line is mixed with LPG and combusted in the engine.

To empty the FBIV-P of LPG, nitrogen is used. This is supplied through the LPG lines by making a change-over in the fuel valve train (FVT). Purging does thereby not require additional valves etc., as only the normal supply and return lines are used in order to return the LPG to the tank.

Furthermore, the safety concept requires that all LPG lines in the engine room are designed with double-wall piping with a ventilated outer pipe. Any potential leak from seals is vented to the outer pipe in order to avoid the risk of leakage to the engine room. Hydrocarbon (HC) sensors monitor for leakages and an alarm is raised if an LPG leakage is detected.

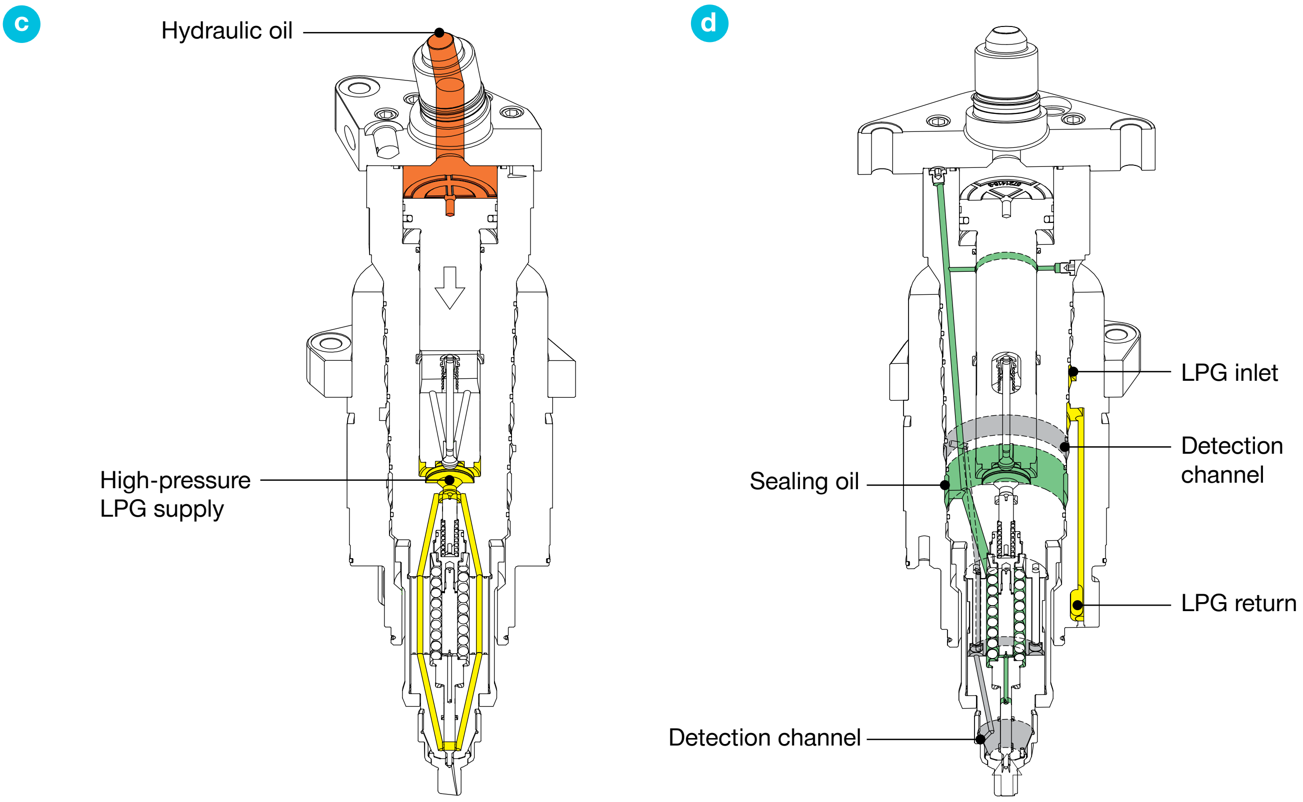


Fig. 2c and 2d: FBIV-P

LPG auxiliary system design

The main components of the ME-LGIP supply system shown in Fig. 1 are:

1. LGP service tank
2. Vent systems and knock-out drums
3. Low-flashpoint fuel supply system
4. Fuel valve train
5. Nitrogen system
6. Double-walled ventilation system

The following sections describe the main components of the LPG supply system and the sequences of LPG operation.

LPG service tank

During ME-LGIP operation, the recirculated LPG will be heated in the engine and it may contain traces of oil from the injection valves. In order to prevent oil contamination of cargo or fuel tanks, the recirculated LPG must be returned to a dedicated service tank of a certain size. During purging of the engine, the same tank can be used for nitrogen separation and bleed off from the recovered LPG. The tank capacity and design pressure are functions of the overall system setup.

From the service tank, a built-in or external low-pressure pump will supply the pressure needed for the high-pressure pump in the LFSS.

Low-flashpoint fuel supply system

The LFSS will contain the equipment needed to ensure the required temperature, pressure and fuel quality on the engine, i.e. a high-pressure pump, a heater and filters. Furthermore, the LFSS contains the valves and control systems to maintain the pressure and temperature at varying engine consumptions.

A number of suppliers already offer LFSS, for example Alfa Laval, Wärtsila, Babcock and TGE. Furthermore, MAN ES is in the process of developing a pump unit that can be integrated in the overall system.

Fuel valve train

The FVT represents the interface between the ME-LGIP engine and the auxiliary systems. The FVT is intended for safe isolation of the engine during shutdown and maintenance and provides nitrogen purging functionalities. The purging functionality ensures a safe environment on the engine after shutdown.

The FVT has the quality standard necessary for reliable safety functions, and ultimately it ensures a safe and reliable operation of the ME-LGIP engine. Therefore, MAN ES reviews an FVT design in order for any potential FVT vendor to become an approved supplier.

The company Eltronic, which has extensive experience with ME-GI dual fuel engines from MAN ES, has developed the prototype LPG FVT for Research Centre Copenhagen, and they have an FVT available for commercial purposes. The commercial LPG version will be split in a supply valve train and a return valve train for increased flexibility in the ship design process.

Nitrogen system

Nitrogen needs to be available for purging after normal ME-LGIP operation and for the purpose of gas freeing prior to maintenance and tightness testing after maintenance. Therefore, the nitrogen system must be able to deliver a certain flow at a pressure higher than the service tank pressure.

The required nitrogen setup can be achieved by a nitrogen booster and bottle bank if the vessel already has a nitrogen generator on board. Alternatively, a skid containing nitrogen generation, booster and storage facilities can be made available from various suppliers.

Vent systems and knock-out drums

The vent system consists of a number of vent masts with knock-out drums, which in the event of a system leakage and shut down of LPG operation, ensure that no liquid is released via the vent system. Furthermore, in the event that the return line is blocked during engine stop, the engine must be able to release the on-engine LPG volume to a knock-out drum, which must be sized for this purpose. The vent systems must be separated to ensure that safe isolation of the engine is not bypassed by the vent system.

Double-wall ventilation system

In order to detect leakages from the engine room systems and direct these to a safe location, the LPG systems and piping inside the engine room are double walled. A constant flow of ventilation air is kept in the outer pipe in accordance with IMO requirements. The system is already used on other MAN B&W dual fuel engines. A constant supply of dry air ensures the corrosion resistance of the system.

Sequences of ME-LGIP operation

The main sequences and the corresponding functions of the LPG fuel system are described in Fig. 3 and in the following section.

When the engine is not in LPG operation, the LPG fuel systems inside the engine room are depressurised and completely isolated from the supply and return systems by means of the double block and bleed arrangements in the FVT. Prior to every start, as shown in the first part of Fig. 3, the systems will be pressurised by nitrogen in order verify the tightness of the system.

The second part of Fig. 3 shows the fuel system during LPG operation. LPG is supplied from the LPG tank via the fuel supply system to the engine. A small portion is continuously recirculated to the LPG fuel tank to constantly maintain the required fuel condition on the engine.

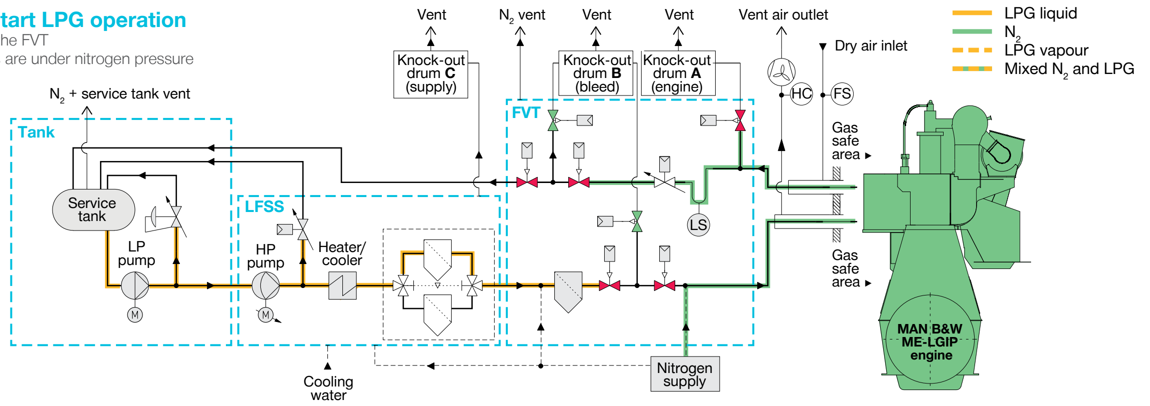
When LPG operation is stopped, as shown in the third part of Fig. 3, the LPG on the engine is transferred to the LPG tank by means of nitrogen pressure, which will push back the LPG. When purging is complete, the FVT will once again ensure that the engine room systems are isolated from the supply and return systems.

Thereafter, the engine systems will be depressurised, see the fourth part of Fig. 3. Only a minor amount of LPG will be released via the vent masts during the depressurisation process. The knock-out drums will ensure that under no circumstances liquid is released via the vent masts.

Throughout the entire operation, the double-walled ventilation system, which is well-known from MAN ES’ existing dual fuel engines, will detect any LPG leakage and direct it away from the engine room.

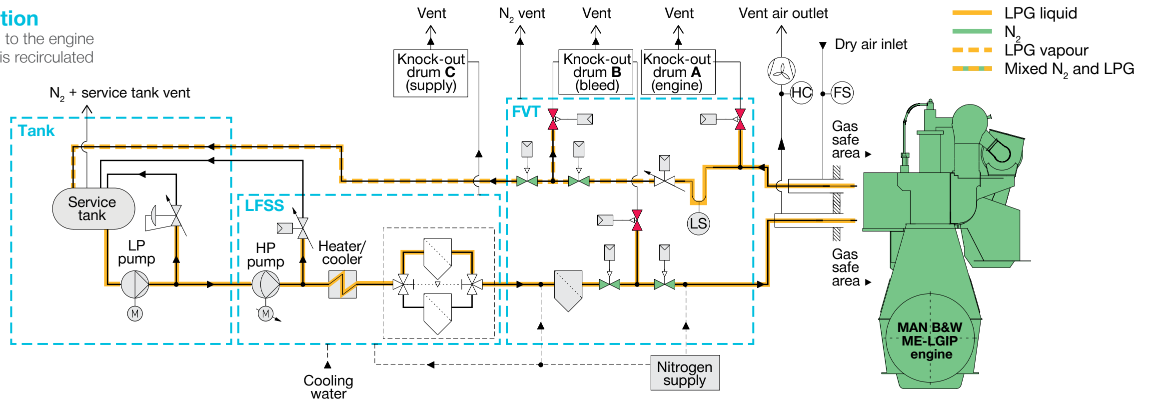
1 Ready to start LPG operation

LPG is filled to the FVT
Engine systems are under nitrogen pressure



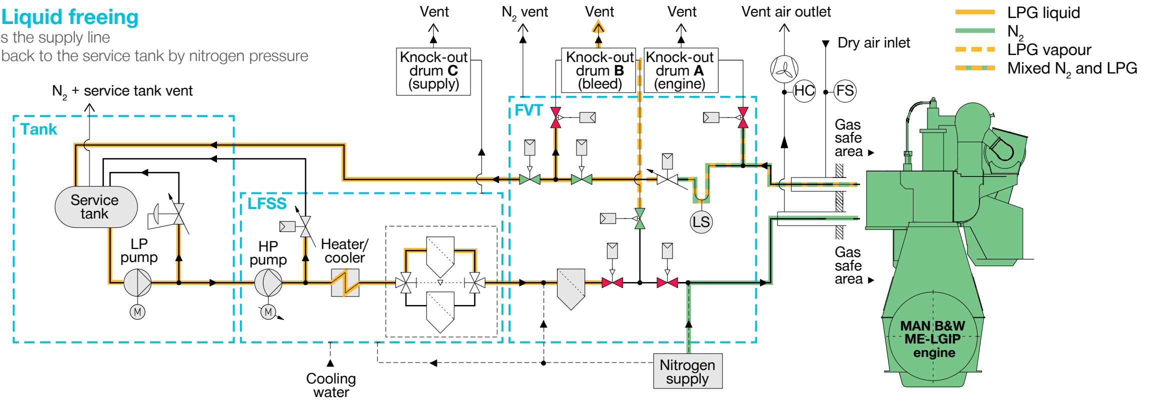
2 LPG operation

LPG is supplied to the engine
A small portion is recirculated



3 LPG stop: Liquid freeing

The FVT isolates the supply line
LPG is pushed back to the service tank by nitrogen pressure



4 LPG stop: Depressurisation

The FVT isolates the return line
Nitrogen pressure and any LPG remains are vented

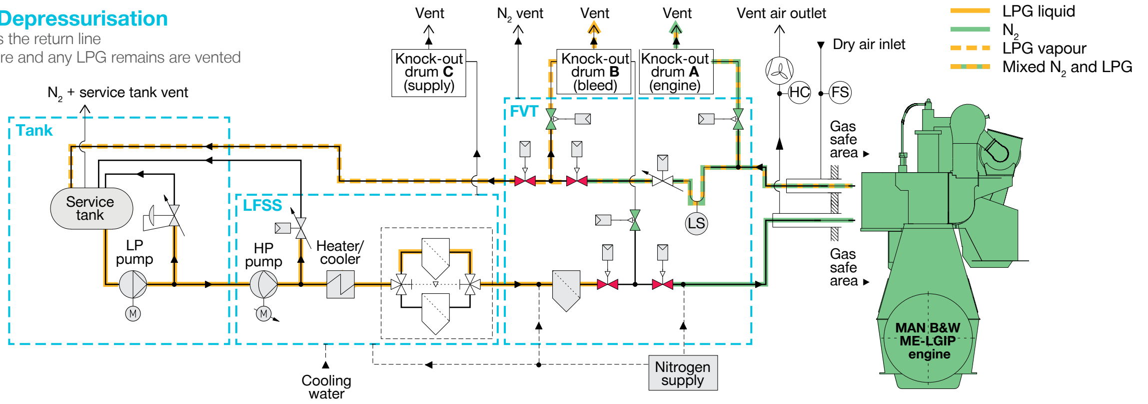


Fig. 3: Principle flow diagram for ME-LGIP auxiliary system.

Test results

The LPG tests on the 4T50ME-X research engine in Copenhagen have covered a plethora of different tests over an extended period of time. The tests were divided into several different sections according to the purpose of the individual tests.

The first part of the tests was called LPG system function test and it contained various function tests intended at getting the LPG operational. This included testing of the LPG supply system, both for safety and basic functionality. It also included checking of the entire LGIP system for leakages of LPG to the outer pipe ventilation. Several control software tests were performed to verify that all safety aspects are dealt with correctly.

Fundamental engine operation events, like starting and stopping LPG running as well as load changes, were fine-tuned to improve engine operation. Fig. 4 shows the engine speed, load and ordered LPG injection duration, respectively. The graphs show engine start and stop with LPG operation in-between.

The engine was started at 14:27, on the time scale of the graphs, and ramped up to 25% load while running on diesel. The LPG system was then started and after 14:34, the requested LPG injection started to increase (blue curve). At 14:36, the diesel injection was changed to minimum pilot oil and all load variations were henceforth handled by changing the LPG injection duration. Around 14:40, the engine load was increased from 25 to 50% load while running on LPG. Finally, the LPG running was ended around 14:48 and the engine was completely stopped at 14:56.

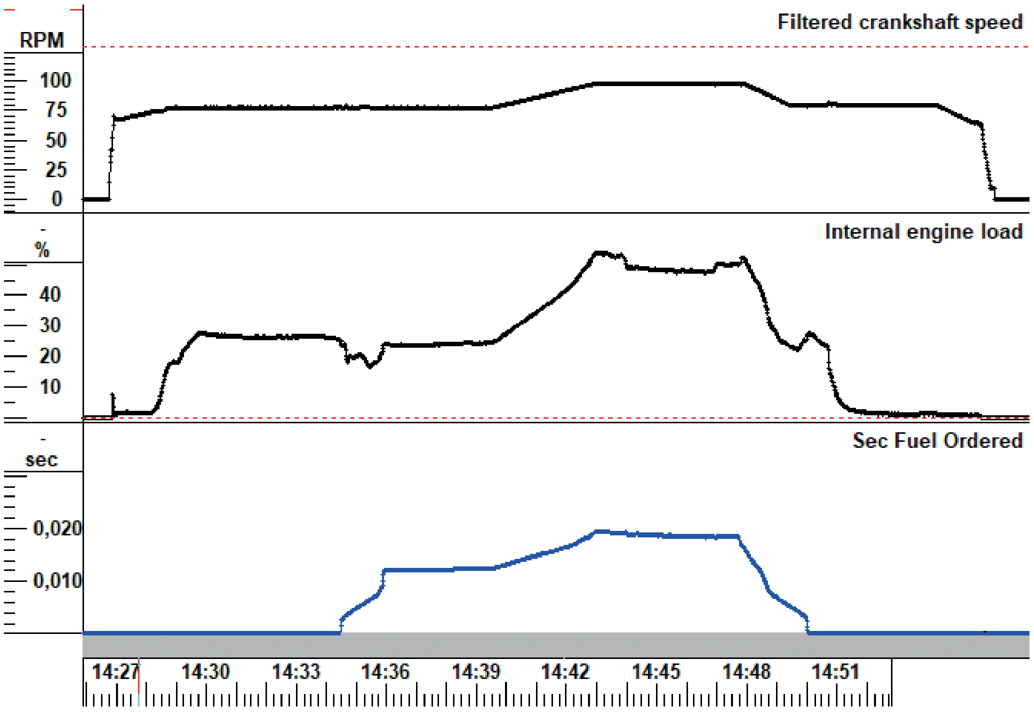


Fig. 4: Engine speed [rpm] (top), internal engine load [% of MCR] (middle) and the ordered LPG injection duration (bottom, blue). The timeline shows an event from start to stop of the engine with controlled LPG operation in-between, including starting and stopping of LPG operation and a load change.

The second part of the test program called Initial LPG Test contained performance tests with LPG, which gave an indication of how the engine would behave. Heat release curves for all four cylinders from the tests with LPG at 75% load are shown in Fig. 5. Even though there still are several parameters that needs adjustment in this test, it is after all the first of its kind. It is clear that the performance of the engine is acceptable in terms of fuel injection and combustion quality.

Comparing the heat release for LPG with that for diesel shows that the LPG heat release is well suited for this engine (see Fig. 6). The graphs also show that the initial rising flank of the LPG heat release has a bit lower rate of change relative to diesel and that increasing the LPG injection pressure can affect this. Thus, the LPG combustion is expected to behave quite similar to the well-known diesel combustion in a slow speed two-stroke marine diesel engine.

The engine stability is shown in Fig. 7. The tests shown were made at 75% load while running on LPG. Both the mean indicated pressure (MIP) and P_{max} show variations that are of the same magnitude and frequency as commonly seen, when running on diesel. The LPG combustion thus exhibits the same ignition stability and combustion quality as is experienced for our other dual-fuel engines already in service.

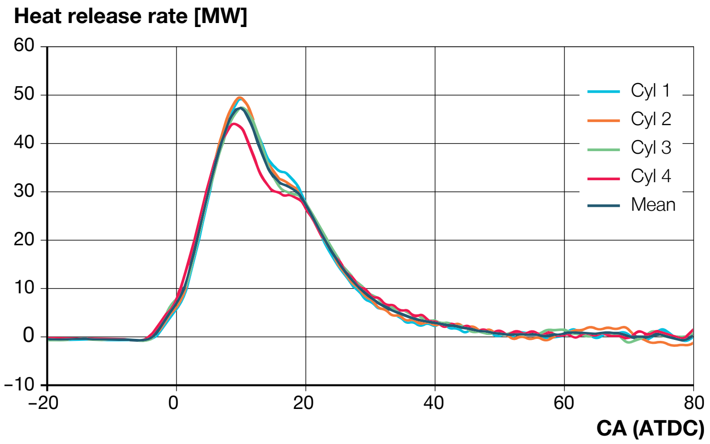


Fig. 5: Heat release rate in MW for each cylinder, and the average curve, calculated from the cylinder pressures. The engine was operating at 75% load with LPG and a small diesel pilot injection.

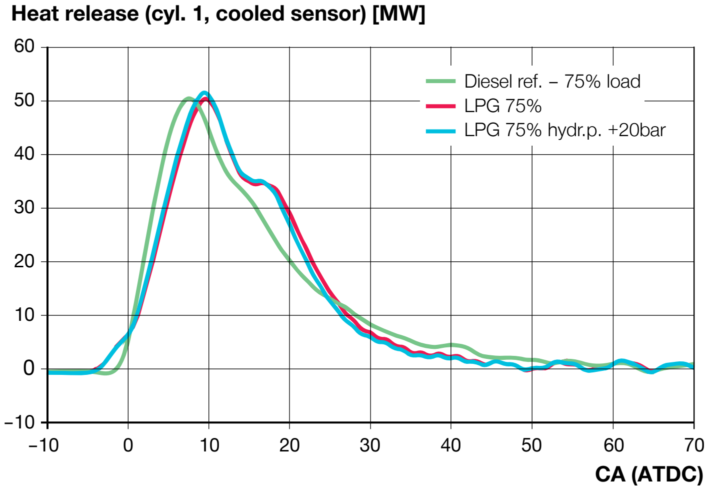


Fig. 6: Heat release for diesel (green), LPG (red) and LPG with an elevated injection pressure (blue).

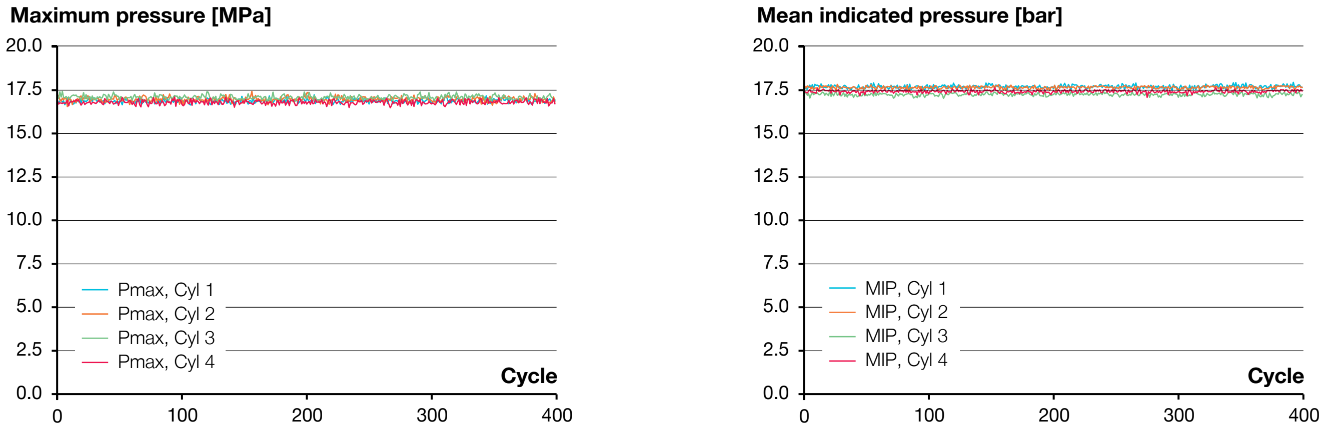


Fig. 7: Maximum pressure (left) and mean indicated pressure (right) for each of the 400 consecutive measurements, for all four cylinders. The figures show the engine stability while running on LPG.

The third part of the test program contained several different performance alterations that were needed in order to fine-tune the performance of the LPG operation.

Both injection parameters and performance layout were therefore adjusted to achieve acceptable NO_X emissions and combustion chamber temperatures at all loads.

The final part of the test contained tests that were of a slightly lower priority. This included operating with a specified dual-fuel index, i.e. 50/50 of LPG and diesel, and other tests that were more of a basic research character. These tests are intended to deepen our fundamental understanding of LPG combustion in a low-speed two-stroke diesel engine.

Ship designs

Although LPG carriers are probably the most obvious candidates for the ME-LGIP engine, there are also other candidates. To show some effects of changing from oil to LPG operation, three example vessel types are considered: A very large LPG carrier (VLGC), a long range 1 (LR1) tanker and a very large crude oil carrier VLCC. The main data for the three example vessels are given in Table 1.

Data for the VLGC fuelled by HFO and LPG, respectively, is seen in the first column of Table 1. To prevent that contaminated LPG from the engine re-enters the LPG cargo tank, a service tank with an LPG capacity corresponding to 36 hours of NCR operation is added for the LPG fuelled case. Hence, LPG is periodically transferred from the cargo tanks to the on-deck service tank. Data for the LR1 oil tanker is seen in the second column. The fuel capacity is here equivalent to a full 40-day voyage. Data for the VLCC is seen in the third column and the fuel capacity is likewise set to match a 40-day voyage.

Vessel main data

Description	Unit	VLGC	LR1	VLCC
Vessel size		84,000 cbm	75,000 dwt	320,000 dwt
Length (Lpp)	[m]	218	211	328
Beam	[m]	36	37	62
Scantling draft	[m]	12.3	13.7	21.5
Engine type		7S60ME-C10.5	6S60ME-C10.5	7G80ME-C9.5
SMCR power	[kW]	12,400	10,000	26,000
NCR power	[kW]	11,160	9,000	16,900

Main fuel		HFO (3.5%)	LPG	HFO (3.5%)	LPG	HFO (3.5%)	LPG
NCR fuel consumption	[t/d]	46	40	37	32	67	58
Scrubber		Yes	No	Yes	No	Yes	No
Endurance (NCR)	[days]	40	40	40	40	40	40
LPG service tank size	[m^3]		121		0		0
LPG service tank endurance	[days]		1.5		0		0
LPG tank capacity	[m^3]				2,592		4,716

Table 1: Main data for the three vessels: VLGC, LR1 and VLCC.

Figs. 8-10 illustrate the size of the LPG tanks.

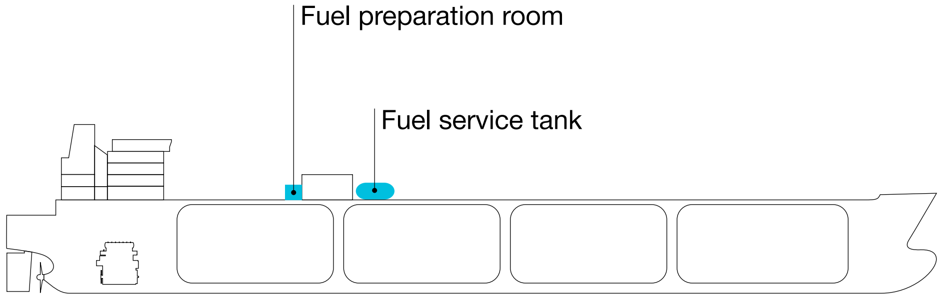


Fig. 8: A VLGC equipped with a small fuel service tank to store fuel for 1.5 days of travel, with a capacity of approximately 121 m^3. The fuel service tank dimensions are: diameter = 4 m, length = 10m.

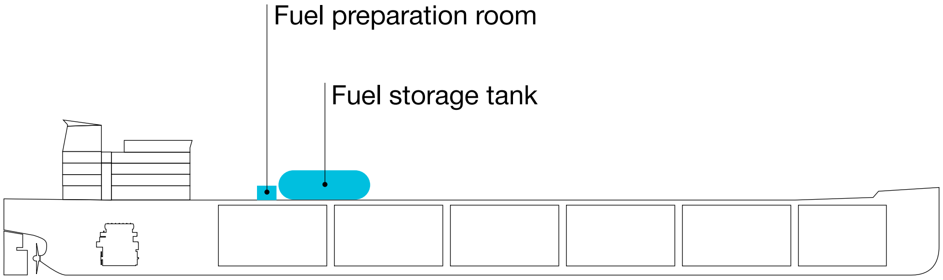


Fig. 9: An LR1 oil tanker equipped with two large fuel storage tanks (side by side) to store fuel for 40 days of travel, with a capacity of approximately 2,592 m^3. The fuel storage tank dimensions are: diameter = 8.5 m, length = 23m.

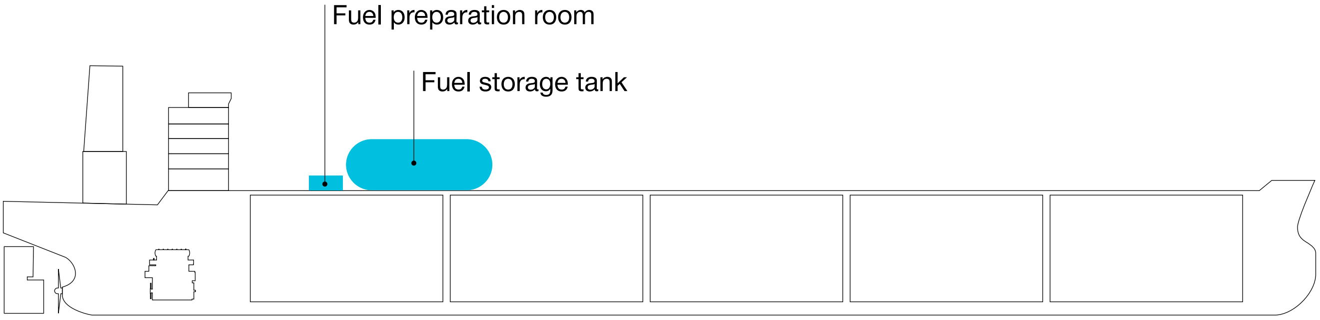


Fig. 10: A VLCC equipped with two large fuel storage tanks (side by side) to store fuel for 40 days of travel, with a capacity of approximately 4,716 m^3. The fuel storage tank dimensions are: diameter = 10 m, length = 30 m.

LPG as a means to achieve IMO compliance

For bulkers and tankers, it can in some cases be challenging to make a vessel design that will fulfil both IMO EEDI and IMO Minimum Propulsion Power (IMO MPP) requirements. This challenge is reduced by the use of LPG, and even more so, by the use of LNG. This is due to the lower carbon content in these fuels. Assuming that the propulsion power follows the propeller law, and if the vessel design is changed from oil fuelled to primarily LPG fuelled with unchanged engine efficiency, then it is possible to install approximately 20% more main engine power with an unchanged EEDI index, see Eq. 1. Numerical example with the LR1 tanker operating primarily on LPG, see Eq. 1.

That is, for the same EEDI index, the LPG fuelled ship can be equipped with 12,260 kW main engine power, whereas the oil fuelled ship can be equipped with 10,000 kW main engine power. Considering that 10,000 kW is about the maximum power that can be installed after 2020 due to the EEDI, when operating on HFO/MDO, and that the IMO MPP requirement according to assessment level 1 is 10,850 kW for the example LR1 tanker, then designing the vessel for LPG makes it possible to fulfil both EEDI and MPP easier, than if the vessel had been designed with HFO/MDO as the primary fuel.

As the EEDI regulations are continuously evaluated, the reader is advised to consult the latest resolutions. As of august 2018 these are available as shown in [1].

$$P_{\text{MCR, gas}} = P_{\text{MCR, oil}} \cdot \left(\frac{C_{\text{F, oil}} \cdot LHV_{\text{gas}}}{C_{\text{F, gas}} \cdot LHV_{\text{oil}}}\right)^{3/2}$$

$$P_{\text{MCR, LPG}} = 10{,}000\ \text{kW} \cdot \left(\frac{3{,}206 \cdot 46}{3{,}015 \cdot 42.7}\right)^{3/2} = 12{,}260\ \text{kW}$$

Eq. 1: Calculation of main engine power.

Feasibility

Fuel costs are the biggest expense for operation of a ship. The dual fuel technology on MAN B&W two-stroke marine engines has opened up for usage of a range of gaseous and low-flashpoint fuels together with conventional fuel oils.

The fuel prices for some of these gaseous fuels are shown together with the price of conventional fuel oil for the last 13 years in Fig. 11.

The prices show large fluctuations. The prices for the gaseous fuels are energy prices at terminals and do not include additional costs that will appear if they are delivered through a conventional bunker company in commercial harbours. Doubling or halving the price within a year is considered part of normal price fluctuations. The fuel oil prices follow the crude oil price and there is a relative stable ratio between the price of HFO and MGO, LNG, propane and methanol, however, also show fluctuations in the relative price. These fluctuations come from the recent large production, processing and export of shale gases from the US. The price of the new 0.5% sulphur fuel (LSFO) to be used globally after 2020 is still unknown. But it is expected to settle at 10-20% below the price of MGO.

In 2016 MAN ES made a study together with DNV GL concerning fuel costs for an LR1 tanker using FO, LNG, LPG and methanol [2]. The conclusion found at that time was that a high price fuel scenario with the largest price differences between the oil fuel and the gaseous fuels made both LPG and LNG financially attractive fuels considering the fuel costs and the additional installation expenses for the dual-fuel engine and systems.

In the present paper, a comparative study of operating expenses (opex) for a VLGC with a 6G60ME-C main engine and three different main fuel solutions is made:

1. 6G60ME-C9.5 Tier III and 0.5% LSFO, the LSFO solution
2. 6G60ME-C9.5 Tier III and HFO in combination with a SO_x scrubber, the HFO + SO_x scrubber solution
3. 6G60ME-C9.5 LGIP dual fuel engine, the LGIP solution

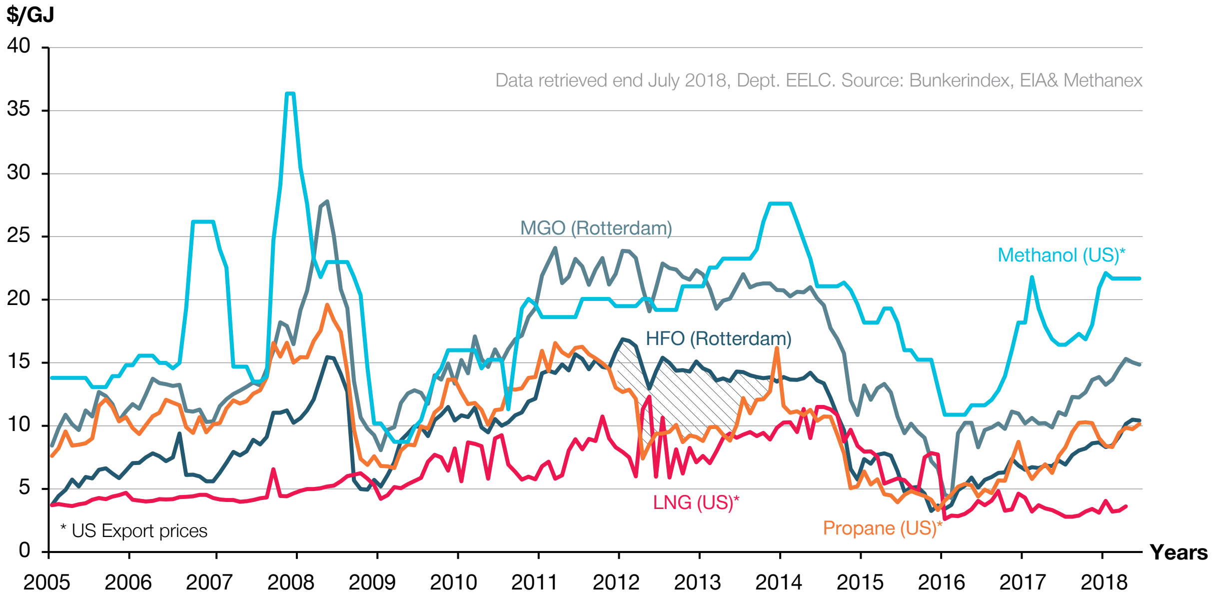


Fig. 11: Fuel price fluctuations for some gaseous fuels and conventional fuel during the last 13 years.

Fuel prices and capital expenses

6G60ME-C	Fuel price [USD/GJ]	LCV [MW/kg]	Fuel price [USD/ton]	Comments
HFO + SO_X scrubber	10	41.8	418	
MGO	15	42.7	641	
VLSFO	13	42.7	544	85% of MGO price
LPG	10	46.0	460	Today's price at US terminal
	Δ capex Mill USD			
ME-LGIP	4.5			
SO_X scrubber	3.2			

Table 2: Fuel prices, lower calorific values (LCVs) and difference in capex.

The LSFO and HFO + SO_X scrubber solutions are using MGO in Tier III areas and the LGIP solution is using LPG in Tier II and III areas. The fuel prices and capital expenses (capex) used in the calculations are shown in Table 2.

To illustrate the effect of price dispersion between FO and LPG, the calculation has been carried out with two LPG price levels, i.e. 100% and 90%. The basis for the calculation is an operating pattern with 15% in Tier III mode, operating hours and load profiles as shown in Fig 12.

The selected Tier III technology is an EGR bypass solution for all three cases.

The HFO + SO_X scrubber solution has been included because of today's uncertainties about fuel oil prices after 2020. Price scenarios made today for price and availability of HFO and LSFO after 2020 show large savings on a HFO + SO_X scrubber solution compared to a LSFO solution. Today, around 50% of new buildings are ordered with a SO_X scrubber for HFO operation.

The ship with HFO and SO_X scrubber and the ship with an LGIP engine come with an increased price compared to a ship, which fulfils the 2020 sulphur requirements by operating only on 0.5% LSFO. We estimate the additional costs for a VLGC with LGIP engine and dual fuel capability to be approx. 4.5 mill USD and the ship with a SO_X scrubber to be approx. 3.2 mill USD. These are rough estimates as it is much dependant on the yard's pricing.

The calculated opex is presented as net present values (NPVs) of the accumulated savings as a function of time compared to the LSFO solution. Fig. 13 shows that the saving from opex obtained by the HFO + SO_X scrubber solution is the same as for the ship with the LGIP solution, which is due to almost identical fuel prices per energy unit, i.e. USD/GJ for HFO and LPG.

The two solutions give cost savings of 6-7 mill USD over a 15-year period compared to the 0.5% LSFO solution. It is also seen that the additional capex has a payback period of 4 years for the HFO + SO_X scrubber solution and 5.5 years for the ME-LGIP solution. The different payback periods are due to the difference in capex. To illustrate the sensitivity of the LPG prices NPV is shown also for LPG with a 10% reduced price.

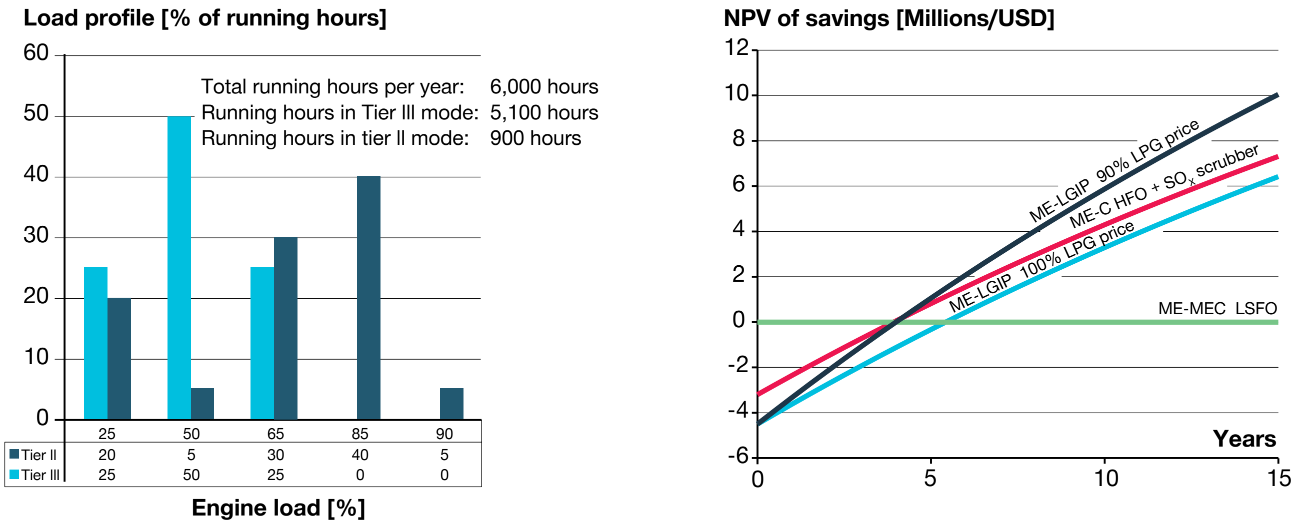


Fig. 12: Operating pattern. Fig. 13: NPV of savings for ME-C with HFO and scrubber and an ME-LGIP engine.

The above analysis shows that a solution with HFO and a SO_X scrubber will have approximately the same opex as the solution with LPG fuel based on today's prices for LPG and HFO. However, future fluctuations in fuel oil and LPG prices will change the picture, and changes are expected because the crude oil price is influenced by the global economic and political situation. On top of that the new restrictions of max. 0.5% sulphur in the marine fuels from 2020 has made the future price level of HFO, MGO and the new LSFO quite uncertain.

Today an ME-LGIP engine can be an optimal choice for propulsion of a VLGC, although opex will be similar to the HFO + SO_X scrubber solution due to the benefits from below list of possibilities. The list has not been prioritised:

1. The ME-LGIP engine can use the ship cargo as fuel and it is capable of operating on a wide range of mixtures of propane, butane and ethane commonly found as cargo.

2. Using the ship's cargo as fuel will save time, fees and other expenses for bunkering.

3. LPG is a zero sulphur fuel meeting 2020 requirements and future possible even stricter demands for SO_X emission.

4. LPG has a lower carbon-to-hydrogen ratio than MDO and therefore a lower CO_2 emission per energy unit. When using LPG instead of MDO, the CO_2 emission drops by about 13%. The EEDI will decrease by the same amount.

5. Due to the lower carbon-to-hydrogen ratio for LPG compared to oil, it is possible to increase the main engine power while retaining an unchanged EEDI if LPG is used as the primary fuel instead of oil. Because higher main engine power also leads to a higher EEDI reference speed for the vessel, the main engine power can be increased by about 20% without increasing the attained EEDI.

6. Scrubber solutions may in the future only be allowed as closed loop solutions due to concerns about scrubber effluent sent to the sea. This will increase the scrubber operating cost considerably due to NaOH consumption and sludge disposal.

7. With a dual fuel engine it is possible to select the fuel with the lowest price. The price gap between HFO and LPG for the years 2012-2014 indicated in Fig. 11 represents, for the VLGC investigated in this paper, a difference of 2.5 mill. USD in fuel costs for HFO versus LPG in favour of the LPG.

8. Accidental oil spills can be avoided to a greater extent. This issue has been neglected over the years, but recently this argument is often being highlighted by port authorities and when ships are operating near environmentally sensitive areas, like coral reefs, etc.

Retrofit opportunities

The new MAN B&W ME-LGIP concept is suitable as a potential retrofit solution, applicable for more than 3,000 existing ME-C type engines and MAN PrimeServ is ready to support shipowners and operators with converting existing ME-C engines into ME-LGIP engines.

The most obvious candidates for LGIP conversion is the existing fleet of LPG carriers. But subject to availability of the global LPG bunker supply chain, the LPG conversion concept can be applied to other types of vessels as well.

The LPG supply chain has been available for many years as there is a substantial network of smaller LPG carriers below 6,000 m3 of LPG. In principle, the majority of the small-size LPG carriers available in the market can be utilised as LPG bunker vessels.

The first vessel types to be converted are the LPG carriers or VLGC‘s having long transoceanic trading routes. In this segment, there are approximately 60 vessels all equipped with large bore ME-C engines. These conversion projects can benefit from the fact that LPG is already available on board as cargo. Therefore, part of the LFSS and tank systems are already available to some extent, keeping the conversion capex to a minimum.

For now, more than 3,000 vessels, such as tankers and other merchant ships with an ME-C engine with a bore size from 50 and up, can be converted into operating on alternative fuels like LPG. If the market demand for conversion of engines with bore size below 50 is significant, MAN PrimeServ is willing to investigate conversion options.

In general, the engine conversion is a process where an existing ME-C engine is converted to an ME-LGIP engine. The conversion process follows the predefined process in Fig. 14. Based on experience, the whole process takes up to 18 months.

During site survey the scope of supply is determined, followed by engineering, procurement and production. When all equipment is available and shipped to a repair yard, MAN PrimeServ can convert the vessels in close cooperation with shipyards all over the world.

MAN PrimeServ can provide a complete LPG conversion package including the following services:

- R&D, engineering
- Site survey, project management
- Engine hardware, including FVT
- Supervision of installation
- Test and commissioning
- Project management

The complete LGIP system consists, beside the engine conversion, of the LFSS and LPG bunker tank or integration into an existing cargo system.

The MAN PrimeServ scope is not only limited to conversion of the main engine but can also include the gas systems in partnership with MAN-ES Sweden (Cryo) or other prominent gas system providers in the world. In these cases, MAN PrimeServ can offer the conversion on a turnkey basis, taking full responsibility of the entire conversion project.

Converting into LPG is a future-proof decision – LPG is a safe and feasible low-sulphur bunker fuel for the future, an energy solution that MAN PrimeServ is proud to present.

Fig. 14: The engine conversion process.

Conclusion

This paper describes the ME-LGIP engine solution in details. Tests have confirmed that the new modified LPG fuel booster injection valve is working satisfactorily. The function test of the new engine has confirmed that the auxiliary system and the LGIP safety system are working satisfactorily. The initial performance tests have also been started. They show that the combustion stability of the engine is acceptable, but we have concluded that it can be further improved when more tests have been completed. The shape of the measured heat release curve from LPG combustion is similar to that of other types of gas fuel, so we expect to be able to achieve a higher engine efficiency with LPG compared to MDO.

We have looked at the possibility for LPG operation for several ship types and sizes and concluded that if LPG is selected as the primary fuel, a benefit in the EEDI of up to 13% can be obtained. In the future, this can be an important tool to meet the constantly stricter EEDI requirements, especially when designing tankers and bulk carriers. Today, this benefit can also be converted into more main engine power if required, so the engines can be rated with a higher power.

An NPV calculation of the savings has been completed for a VLGC, comparing operation on HFO + scrubber, LSFO, and LPG. When it comes to opex, the comparison shows an almost dead race between the solutions HFO + scrubber and LPG. However, a number of benefits from operational flexibility, emission control and fuel cost saving opportunities make LPG fuel a very attractive choice.

Today, more than 3000 ME-C engines in operation on HFO can be retrofitted to LPG operation. Converting an existing ship into operation on LPG will be cheaper than converting it to LNG. LPG and LNG have very similar emission advantages, and the same negligible fuel slip. However, even if it is very small for both, LPG will not count as a greenhouse gas in future regulation, as is expected to be the case for methane

Bibliography

1. www.imo.org → Our Work → Marine Environment → Pollution Prevention → Air Pollutant and GHG Emissions → Index of MEPC Resolutions and Guidelines related to MARPOL Annex VI → Guidelines related to Energy Efficiency of Ships

2. Cost and Benefits of Alternative Fuels for an LR1 Product Tanker, Key results from an DNV GL and MAN Diesel & Turbo joint study (5510-0196-00), 2016 https://marine.man-es.com/two-stroke/technical-papers

MAN Energy Solutions
2450 Copenhagen SV, Denmark
P +45 33 85 11 00
F +45 33 85 10 30
info-cph@man-es.com
www.man-es.com

5510-0210-00
Sep 2018 Printed in Denmark

MAN B&W ME-LGIP dual-fuel engines

MAN Energy Solutions
Future in the making

Dual-fuel technology reshapes
the future two-stroke engine operation