New Optimization of ME-GI Dual Fuel Engines for LNG Carriers and Marine Vessels in General*

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This paper introduces the latest development and technical explanation of ME-GI dual fuel two-stroke engines and gas fuel supply system for gas application on LNG/LPG carriers and marine vessels in general.

In cooperation with well-known and experienced gas handling partners, MAN Diesel offers safe and reliable high-efficient prime movers for LNG carriers.

By optimising the engine and gas supply systems using state-of-the-art technology, in cooperation with our gas system partners, we have actively lowered investment and operational costs, and generally improved system efficiency. Thereby, a positive effect has been achieved on the total fuel consumption as well as the overall environmental impact on the surroundings.

1. Introduction

MAN Diesel has shown that dual fuel engines can be more than just economically sound – dual fuel engines are also safe, reliable and environmentally desirable, as a result of the experience obtained through many years from two-stroke diesel engines for the marine market for single as well as double-propeller vessels in all types of commercial application.

Beyond the whole question of price, safety, reliability and availability are the main parameters when shipowners and operators select prime movers for vessels in their fleets.

MAN Diesel therefore cooperates closely with gas supply manufacturers such as Burckhardt Compression, Cryostar and Hamworthy to ensure that the gas supply system covers a number of specific values.

As of January 2008, MAN Diesel has 90 two-stroke MAN B&W S70ME-C engines on order for 45 LNG carriers for the Qatar gas project. However, all these engines are ordered for operation on liquid fuels, i.e. HFO, DO, and GO, as are more than 15,000 MC/ME type engines worldwide for different applications for the marine market.

The technology for a gas driven two-stroke ME-GI engine is available – and ready to install.

Different applications can call for different gas supply systems, and recent projects have shown that operators and shipowners demand an alternative to the gas compressor solutions. Therefore, MAN Diesel is based on both gas compressor and high-pressure pumps.

Both solutions can be applied with the reliquefaction used, depending on the actual application requirements and the operator’s requests. This paper describes the technology and the design of the gas compressor and the high-pressure pump. The reliquefaction process will also be further elaborated, see Fig. 1.

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2. The ME-GI

2.1 ME-GI Engine

The MC/ME engine family has been on the market since 1982. The engines have been in service for almost any marine application for container vessels, VLCCs, ULCCs, tankers, bulk carriers and general cargo vessels.

The reasons for choosing the two-stroke MC/ME engines are many: High thermal efficiency, overall low operational costs, high reliability, availability, safety, and the fact that it is a simple and robust solution.

The MC/ME engine is a well-proven product in the industry. The GI (Gas Injection) solution was developed in parallel and was finished for testing in the early 1990s. In 1994, the first GI engine, a 12K80MC-GI-S, was put into service on a power plant at Chiba, Tokyo, Japan. So far, the Chiba engine has operated as a peak load plant for almost 20,000 hours on high-pressure gas.

At the same time, in 1994, all major classification societies approved the GI concept for stationary and marine applications.

Technically, there is only little difference between fuel and gas burning engines, but the GI engine provides optimal fuel flexibility. Fig. 2 shows the components that need to be modified for gas operation.

The gas supply line is designed with ventilated double-wall piping and HC sensors for safety shutdown.

For control of the gas engine, the GI control and safety system is an add-on system to the well-proven ME control system.

The complete gas control system has been developed in close cooperation with Burckhardt Compression AG and Kongsberg.

Apart from these systems on the engine, the engine and auxiliaries will comprise some new units. The most important ones, apart from the gas supply system, are listed below:

The new units are:
- Ventilation system for venting the space between the inner and outer pipe of the double-wall piping.
- Sealing oil system, delivering sealing oil to the gas valves separating control oil and gas.
- Gas supply system with gas compressor or high-pressure pump.
- Inert gas system that enables purging of the gas system on the engine with inert gas.

2.2 ME-GI Injection System

Dual fuel operation requires the injection of both pilot fuel and gas fuel into the combustion chamber.

Different types of valves are used for this purpose. Two are fitted for gas injection and two for pilot fuel. The auxiliary medium required for both fuel and gas operation is as follows:
- High-pressure gas supply
- Fuel oil supply (pilot oil)
- Control oil supply for actuation of gas injection valves
- Sealing oil supply.

2.3 Engine operating modes

One of the advantages of the ME-GI engine is its fuel flexibility, from which different vessels for marine application and especially LNG vessels can benefit from burning the gas with a variation in the heat value is perfect for the diesel working principle. A two-stroke, high-pressure gas injection engine is able to burn those different fuels without a drop in the thermal efficiency of the engine. The control concept comprises three different fuel modes: (see
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Fig. 3). 
- Fuel-oil-only mode
- Minimum-fuel mode
- Specified gas mode

For LNG carriers, the engine can operate in the following modes:

- Fuel-oil-only mode
  - Well known from the ME engine.
  - Operating the engine in this mode can only be done on fuel oil.

- Minimum-fuel mode
  - Developed for gas operation, and it can only be started manually by an operator on the Gas Main Operating Panel in the control room.
  - In this mode, the control system will allow any ratio between fuel oil and gas fuel, with a minimum preset amount of fuel oil to be used.
  - The preset minimum amount of fuel oil (pilot oil) to be used is 51%. Both heavy fuel oil and marine diesel oil can be used as pilot oil. The min. pilot oil percentage is calculated from 100% engine load, and is constant in the load range from 25-100%.
  - Below 25% load, MAN Diesel is not able to guarantee a stable gas and pilot oil combustion. When the engine reaches this lower limit, the engine returns to fuel-oil-only mode.

- Specified gas mode
  - Offered to give the operator the option to inject a fixed amount of gas fuel. The ME control system will add up with fuel oil until the required load for operation is reached.

3. Emission Control

3.1 ME-GI engines

Compared with HFO operation, gas gives a cleaner exhaust. Having very low or no sulphur, SOx-sulphur oxides are negligible in the exhaust gas. Particulates will be reduced considerably as well as the emission of NOx and CO2.

Table 1 lists an arbitrary comparison of emissions from an HFO burning and a gas burning 70-bore ME engine.

<table>
<thead>
<tr>
<th>Estimated emissions 6S70ME-C</th>
<th>Estimated emissions 6S70ME-GI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load 100% g/kWh</td>
<td>Load 100% g/kWh</td>
</tr>
<tr>
<td>CO2</td>
<td>577</td>
</tr>
<tr>
<td>O2 (%)</td>
<td>1,359</td>
</tr>
<tr>
<td>CO</td>
<td>0.64</td>
</tr>
<tr>
<td>NOx</td>
<td>11.58</td>
</tr>
<tr>
<td>HC</td>
<td>0.19</td>
</tr>
<tr>
<td>SOx</td>
<td>10.96</td>
</tr>
<tr>
<td>PM (mg/m³)</td>
<td>0.54</td>
</tr>
</tbody>
</table>

All typical NOx reduction techniques can be used on an ME-GI engine, except water emulsification. In the ultimate event, an SCR catalyst can cut NOx emissions by up to 98%, as was experienced on the stationary 12K80MC-GI in Chiba, Japan.

In the marine market, five vessels with MAN B&W two-stroke engines are in operation with SCR, and this is also the case on 15 power stations. All in the range of reducing NOx by 94-98%.

The expected ECAs (Emission Controlled Areas) in 2010, 2015 and 2020 are illustrated in Fig. 12.

Practically all major trading harbours are included in the expected IMO program. The red being the ECAs that are already in force, and which will be tightened further in 2010, and followed by the ECAs planned for 2015 and 2020. The regulations are expected to cover a distance from shore of between 100 to 200 nautical miles, which means that the vessels must operate on low-sulphur fuel for a considerable amount of time.

As an alternative to SCR in the attempt to lower the NOx emission level, MAN Diesel has developed an engine internal EGR system (Exhaust Gas Recirculation). The latest tests conducted in our research centre have shown a NOx reduction that meets the Tier III requirements with a
relatively small penalty in energy consumption.

The EGR system (see Fig. 4) has now been integrated on an A.P. Moeller vessel for full scale testing before being introduced to the marine market.

Fig. 4 MAN Diesel EGR unit for MAN B&W low speed engines

3.2 Cutting CO2 emissions by WHR (Waste Heat Recovery)
By utilizing the engine waste heat, the thermal efficiency of the engine can reach 55%. Waste heat is primarily taken from the engine exhaust gas via power and/or steam turbines. The higher the fuel cost, the higher is the interest for using waste heat recovery systems, and a high number of systems is in service on power stations and marine vessels.

In addition to lowering the overall HFO/gas consumption, all emission component levels are lowered as well. MAN Diesel is looking to develop the application of waste heat recovery systems even further.

4. BOG Reliquefaction System from Hamworthy

Both Hamworthy and Cryostar can supply reliquefaction plants and high pressure pump systems. The principle of the boil-off gas compression in the Mark III version will be different compared with previous generations of LNG reliquefaction systems. Boil-off gas (BOG) is evacuated from the LNG tanks by a three-stage centrifugal type BOG compressor with subsequent cooling after each stage.

The BOG with vapour header temperature is preheated up to near ambient temperature in a heat exchanger upstream the BOG-compressor. This allows application of conventional compressors, since there is no requirement for cryogenic materials. This cooler configuration ensures that the heat from the compression work can be water cooled in the intermediate stage – and in the after-coolers. The BOG is preheated in a heat exchanger utilising the high-pressure nitrogen stream taken downstream the nitrogen compander after the cooler. A patent is pending for the Mark III system with pre-heater and ambient BOG compression.

At this pressure, vapour is cooled to about –160°C in a cryogenic plate-fin heat exchanger downstream the BOG-compressor. This ensures condensation of hydrocarbons to LNG.

A special feature of the Hamworthy reliquefaction process is that for LNG with a high content of nitrogen, not all the nitrogen is condensed at –160°C.

Nitrogen gas is compressed in a compander unit (3-stage centrifugal compressor and single expander on a common gearbox).

After the third-stage cooler, the stream is split into two different streams. One stream is used to pre-heat the BOG in a separate heat exchanger (pre-heater), and the other is led to the “warm” part of the cryogenic heat exchanger. After heating the BOG, the two streams are mixed again and reintroduced into the cold box core. If the fuel gas supply system is integrated with the reliquefaction plant, a third nitrogen stream is taken out after the cooler.

In the cryogenic heat exchanger, the nitrogen is pre-cooled and then expanded to almost compressor suction pressure. The gas leaves the expander at a temperature below –160°C and is returned to the “cold” part of the cryogenic heat exchanger.

The cold nitrogen continues through the “warm” part of the cryogenic heat exchanger, see Fig. 5.

Fig 5 Process integration between LNG relquefaction and fuel gas supply system for dual fuel ME-GI engine
5. LNG High-pressure Liquid Pump System

Condensate from the BOG reliquefaction system or LNG from the cargo tanks supplied with the cargo pumps is sent to the fuel gas supply system. This system consists of a booster pump, a high-pressure pump and a heater unit.

After pumping LNG to the pressure required, LNG above the supercritical pressure is heated in a heat exchanger (LNG vaporizer) to the temperature required. The high-pressure gas is then fed to the dual-fuel engine, see Fig. 6.

Fig. 6: High-pressure gas supply system from Hamworthy, including two LNG pumps and vaporizer. Size 7 x 3 x 2m

The discharge pressure of the high-pressure pump is typically 300 bar at design stage.

The system is based on an evaporation of LNG at high pressure with heat exchanging by means of an intermediate brine loop. Engine jacket water or steam is used as the heating medium. In order not to use jacket water or steam from the engine room directly in the heat exchanging with LNG, a closed brine loop is used to heat the LNG. This prevents the risk of getting LNG in the engine room in case of an internal leakage in the vaporizer.

It is assumed that the gas supply system will be installed in the cargo compressor room together with the BOG reliquefaction plant.

6. Gas Compressor

The ME-GI propulsion engine together with a compressor gas supply system will utilize the BOG (boil-off gas) coming from the ship storage tanks on LNG carriers. The key component of the fuel gas supply is the Laby®-GI fuel gas compressor from Burckhardt Compression. The pressure range of 150-300 bar will cover the main operating range required by the ME-GI dual fuel engines from MAN Diesel.

6.1 Design concept

The concept described here is based on the installation of two Laby®-GI fuel gas compressors each capable of handling 100% of the emerging BOG. The diesel engines themselves will thereby consume 50% each of the compressed gas. The main compressor will be operating continuously and the second unit can be started manually in case of a malfunction in order to provide full redundancy.

There are many parameters influencing the design of an efficient fuel gas system. The most important the temperature, pressure and composition of the BOG. The gas supply system on top of designed to handle forced BOG (fBOG or nBOG), the simultaneous delivery of low pressure gas to the gas combustion unit (GCU), parallel reliquefaction of BOG and many more.

6.2 Fuel gas compressor engineering

The engineering of the compressor plant is a very important issue when it comes to optimum performance and reliability. Static and dynamic mechanical analysis, analysis of thermal stress as well as pulsation and vibration issues of the compressor and related equipment such as gas piping, pulsation vessels, gas coolers, etc. are standard procedures when it comes to an evaluation by Burckhardt Compression.

6.3 Compressor safety

The safety of the entire system is proven by various HAZID/HAZOP studies performed by shipyards like Daewoo Shipbuilding and Marine Engineering, Samsung Heavy Industries or Hyundai Heavy Industries, by fleet operators like Nakilat, ExxonMobil, Shell, Chevron, BG or Conoco Philips, and by certification societies like DNV, ABS and Lloyd’s Register. The results and have been fully implemented in the control concept.

6.4 Control requirements for the fuel gas system

The primary function of the compressor control system is to ensure that the required discharge pressure is always available to match the demand of the main propulsion diesel engines. In doing so, the control system must adequately
handle the gas supply variables, such as tank pressure, BOG rate (laden and ballast voyage), gas composition and gas suction temperature.

6.5 Power saving mode
Economic regulation of a multi-stage compressor is most efficiently executed using gas recycle around the first stage of compression. The ME-GI required set pressure is therefore taken as control input directly to the compressor first stage bypass valve, which will open or close until the actual compressor discharge pressure is equal to the set pressure. With this method of control, BOG delivery to the ME-GI is regulated without any direct measurement and control of the mass flow delivered. If none of the above control limits are active, the controller is able to regulate the mass flow in the range from zero to 100%, see Fig. 7.

6.6 Simulation and test
The concept, including the entire fuel gas system, ME-GI engine and relevant propulsion components, was successfully tested in a combined process simulation by Kongsberg Maritime.

6.7 Reliquefaction system and Laby®-GI compressor integration
Burckhardt Compression and Hamworthy Gas Systems have developed a solution that integrates the Laby®-GI compressor in the reliquefaction Mk III system from Hamworthy Gas Systems, (see Fig. 8). The Laby®-GI compressor will substitute the normal BOG low-duty compressor upstream the Mk III system. After the first or second stage, at 5-6 bar, the gas can be partly – or fully – diverted to the reliquefaction system. When the ME-GI engine is running in gas mode, the BOG is sent directly by the compressor to the engine, thereby bypassing the reliquefaction system. This bypassing of the reliquefaction system is expected during operation in ballast condition, and when there is too little BOG for fuelling the ME-GI engine.

Fig. 8 Integrated compressor and reliquefaction system

Tractebel Marine Gas Engineering and Burckhardt Compression are also developing a reliquefaction solution based on the Laby®-GI compressor. The principle concept is to use an ethylene-propylene cascade for reliquefaction. The ethylene will be compressed on the Laby®-GI, whereas the propylene will be compressed on a screw compressor. The BOG will be condensed against the ethylene at about –100°C/45 bar in a multi-stream heat exchanger, whereas the ethylene will be condensed against propylene at about –30°C/16 bar in the same heat exchanger. The propylene again will be condensed against sea water at about 40°C/17 bar in a common shell and tube heat exchanger (see Fig. 9).

Fig. 9 Combined ethylene and propylene reliquefaction
6.8 Sub-conclusions
The market demands a highly reliable gas supply system with individual design flexibility. Sizing options such as 50%, 75% or 100% fuel gas system based on engine demand in combination with alternative reliquefaction solution can easily be integrated into the Laby®-GI design. That shows that this compressor is a most adaptable solution for the ME-GI propulsion system regarding fuel flexibility.

High reliability and low maintenance add to keep the lifecycle costs on a very low level. Preventive maintenance and service work can easily be done by the crew as the Laby®-GI compressor system is the simplest and non-complex fuel gas system available. The first Laby®-GI compressor will be installed on a floating storage and regasification unit (FSRU) in fourth quarter 2009.

Fig. 10: Fully skid-mounted Laby®-GI unit

7. ME-GI for LPG Application
The ME-GI has mainly been considered for LNG carriers, but recent years’ fluctuation in energy prices and the ever-tighter requirements for lowering engine emissions have increased the interest for using gas as fuel in other ship types, and LPG as fuel on LPG carriers is also a possibility.

The high-pressure gas injection system used on the ME-GI engine has the advantage of being insensitive to the gas composition as well as the variation in the gas composition. It is well known that the engine can burn lean gas and also gas containing higher hydrocarbons.

The LPG normally consists of higher hydrocarbons like propane and butane, and these can therefore be used as fuel without changing the engine’s performance in terms of speed, thermal efficiency and power output, while maintaining the same rating as for the fuel oil burning engine.

The basic ME engine series applies to the ME-GI/LPG as well, and the new components and auxiliaries remain unchanged in scope when compared with the ME-GI engine type designed for NG (natural gas), see also the section on ME-GI engines for LNG carriers. Some design changes to auxiliaries and components are of course necessary, since the density of LPG fuel is higher than the density of NG. As a result of this difference, the GI/LPG components can be designed much smaller, but at the same time, the LPG needs to be pressurized to a pressure of 550 bar instead of 250-300 bar for NG. This pressure is necessary to achieve a full atomization of the liquid in the nozzles of the injection valves. In comparison, HFO, which has a slightly higher density, requires an injection pressure of 600-800 bar. The temperature has to be controlled as well, and the engine requires a temperature of approx. 35°C.

Hamworthy Gas System (HGS) has participated in the development of a gas supply system for LPG carriers. HGS is a “natural” supplier of such a system, since they have a long experience in designing reliquefaction plants for LPG carriers. They have detailed knowledge on this ship type.

On LPG carriers, the LPG is stored in cargo tanks. The cargo is normally owned by the shipowner, while the operator is responsible for the operation of the ship. Under these circumstances, both parties normally want to have a separation of the cargo and the fuel. MAN Diesel therefore expects that it will probably be preferred to have an additional installation of an LPG fuel pressure tank on top of the deck, which is fully separated from the cargo.

The gas supply system developed, see Fig. 11, offers the possibility of using the fuel directly from the cargo or from the fuel tank on deck. If a fuel tank is installed, it is recommended to insulate the fuel tank and control the temperature and pressure in the tanks. From the fuel tank, the LPG is transported via a low temperature/low pressure pump, in which the normal temperature for propane in the cargo is around −42°C. After the low-pressure pump, the pressure is above 11 bar and the LPG fuel is heated to 20-25°C. Normal cooling water can be used for this purpose. Finally, the LPG is pressurized in a high-pressure pump to the required injection pressure of 550 bar. The amount of energy used by the pumps is quite small and corresponds to
an approx. 0.5-1% reduction in efficiency of the engine.

![Fig. 11 LPG supply system for the ME-GI engine](image)

We have estimated the additional cost of including a gas supply system and the additional GI components on the engine, and we have found the price increase to be around 20-30% of the engine price. The shipyard installation cost comes on top of this figure. However, propane/butane prices can fluctuate greatly depending on i.e. unforeseen economic, political and climatic factors. With the gas option, it is possible to gain profit both at times where gas prices are low, compared with HFO, and also when the opposite is the case.

With the ME-GI engine, the most cost-effective fuel operation solution can be chosen whenever there is a shift in the prices of HFO and LPG.

The comparison of emission levels shows that there are benefits in the full range when using LPG as fuel. A 17% reduction in CO₂, 12% reduction in NOₓ, 92% reduction in SOₓ and 37% reduction in particulates, see also Table 2.

Table 2 Emission comparison between HFO burning K50MC-C and LPG burning S50ME-GI

| Estimated emissions HFO 3500 S.RW 1 6k50MC-C | Estimated emissions 8% pilot oil 46% propane & 46% butane 6s50ME-GI |
| Load 100% g/kWh | Load 100% g/kWh |
| CO₂ | CO₂ | CO₂ |
| O₂ (%) | 1,223 | O₂ (%) | 1,255 |
| CO | 0.71 | CO | 0.89 |
| NOₓ | 11.97 | NOₓ | 10.51 |
| HC | 0.28 | HC | 0.57 |
| SOₓ | 10.57 | SOₓ | 0.85 |
| PM (mg/m³) | 0.49 | PM (mg/m³) | 0.31 |

8. ME-GI for Container Ships and Bulk Carriers

The fuel prices are per tradition fluctuating and, typically, gas is cheaper than HFO. With the ECAs introduced already, and with many more emission controlled areas to come, the dual fuel ability becomes very attractive.

In sulphur controlled areas, gas will compete on price and the availability of low-sulphur distillates, which are more expensive than the traditionally used HFO.

Fig. 12 shows the areas with sulphur restrictions, i.e. ECA areas, today and in the future, and the most important trading routes and ports.

To introduce NG operation on other major ships, the LNG/LPG logistics and infrastructure must be prepared. MAN Diesel is investigating and cooperating to explore the possibilities and requirements to having NG filing stations available in the most important ports.

If the propulsion of the vessel is done by an ME-C or ME engine, then it would also be possible to convert it to run on gas.

On the car ferry *Glutra*, which is fuelled by LNG from an LNG tank that has been fitted into the vessel, the system used has shown that solutions do exist for fitting-in an LNG tank system. However, further work is required by the shipyard to investigate the different LNG tank installation possibilities on larger ships. The space required for the LNG tanks is almost 2.5 times the size of an HFO tank system, due to lower derating and the heavy insulation required to keep the LNG cold.

The GI engine requires pressurized gas at a max. pressure of 250-300 bar. The technology to pressurize the LNG and evaporate it at this high pressure is available, and solutions have been developed by HGS.

The French company Cryostar, known from its cryogenic expertise, has been developing the gas supply system to be equipped on ships with natural gas available as LNG. Cryostar has found that the following equipment is needed for the gas supply system:

- reciprocating LNG pump for high pressure application
- automatic pump management system
- heliflow heat exchanger
- buffer capacity system
The gas supply system utilizes a Cryostar LNG pump, which is fed by the LNG spray pumps placed in the LNG tank, and with a head, sufficient to be used as booster. The Cryostar HPP reciprocating pumps are driven through Variable Frequency Drives (VFD), so that the pump speed can be adjusted to follow the engine load diagram that reflects the fuel demand of the engine.

Fig. 12 IMO emission restricted areas – ECAs in July 2009

Fig. 13 Emission reduction: alternative fuel LNG ME-GI for container ship
At this time, it is expected that one high-pressure pump is installed, no redundancy is necessary, but this can be discussed with the shipowner. Redundancy in the fuel choice already exists with the ME-GI.

The Cryostar high-pressure LNG pump will be used to increase the pressure to a maximum of 250-300 bar and pass the LNG through a heliflow heat exchanger. The gas is evaporated and transferred to a 300 bar buffer capacity system. The buffer system is needed for dampening out pulsations in the system.

Depending on the layout of the system, the buffer volume could also be included in the high-pressure pipe volume. The heliflow heat exchanger requires a heat source to vaporize the LNG, and this can be taken as hot water directly from the cooling system of the ME-GI. Alternative steam can be used to heat the LNG.

The energy required by the HPP LNG pump is very low, and corresponds to approx. 0.5% reduction of the efficiency of the ME-GI engine compared with an ME-C engine.

8.1 LNG tank systems
For merchant ships, several possibilities of equipping the ship with an LNG tank are available. For smaller ship sizes, prefabricated vacuum-isolated cryogenic tanks can be found in a wide range of sizes with an allowable working pressure of up to 20 bar. Some of these tanks have been installed and are already in operation on ferries and supply vessels.

For bigger ships, several other possibilities exist, some of which are listed below:

- Membrane tank design.
  Dominating for LNG carriers, but vulnerable to sloshing. BOR range
  0.14-0.2%/day.
- Spherical tanks, i.e. Moss type.
  Self-supporting and invulnerable to sloshing, but space problems and very few manufacturers.
  BOR 0.14-0.2%/day.
- IHI type B tanks.
  Self-supporting and invulnerable to sloshing.
  Low-pressure tanks, and built on a license in some yards.
  BOR 0.14-0.2%/day.
- TGE type C tanks.
  Single or bilobe design, 4 bang pressure vessel tank design (up to 50 travelling days), self-supporting and invulnerable to sloshing.
  BOR 0.21-0.23%/day.

The IHI B-type tank design and the C-type design from TGE seem to be the most promising for larger conventional ships. Common for both tank designs is that it is possible to operate the ship with a partially filled tank, which is a basic requirement when the tank is used for fuel storage. Both of the designs can be used for LPG fuel as well.

The above tank designs have advantages and disadvantages. For instance, in the IHI design it is possible to adapt the tank form to follow the shape of the ship, see Fig. 14. Practically any tank size can be chosen. In the TGE design, on the other hand, the hull form can only be followed to some extent if the bilobe design is used, see Fig. 15. The maximum tank size in the bilobe design is in the range of 20,000 cum.
Another advantage of the TGE tank design is the ability to accumulate the BOG in the tank during operation, thanks to its allowable working pressure of up to 5-6 bar. If a tank design without this possibility is used, an alternative method to handle BOG has to be incorporated in the fuel gas supply system. A list of alternative possibilities in combination with the gas supply system offered by Cryostar is shown in Fig. 16.

Fig. 16: Fuel gas supply system using an HP LNG pump solution from Cryostar

With this in mind, it can be concluded that the technology for a gas driven two-stroke ME-GI engine is available. What is needed is a visionary pioneer within the transport business to take the lead.

8.2 Requirements for classification

When entering the LNG market with the combined two-stroke and reliquefaction solution, it was discovered that there is a big difference in the requirements from operators and classification societies.

Being used to cooperating with the classification societies on other commercial ships, the rules and design recommendations for the various applications in the LNG market are new when it comes to diesel engine propulsion. In regard to safety, the high availability and reliability offered when using the two-stroke engine generally fulfill the requirements, but as gas delivery and pick-up in the terminals is carried out within a very narrow time window, redundancy is therefore essential to the operators.

As such, a two-engine ME-GI solution is the new choice, with its high efficiency, availability and reliability, as the traditional HFO burning engines.

Compared with traditional diesel operated ships, the operators and ship-owners in the LNG industry generally have different goals and demands to their LNG tankers, and they often apply more strict design criteria than applied so far by the classification societies.

A Hazid investigation was therefore found to be the only way to secure that all situations are taken into account when using gas for propulsion, and that all necessary precautions have been taken to minimize any risk involved.

In 2005, HHI shipyard, HHI engine builder, BCA and MAN Diesel therefore worked out a hazard identification study conducted by Det Norske Veritas.

8.3 Actual tests and analysis of safety when operating on gas

The use of gas on a diesel engine calls for careful attention with regard to safety. For this reason, ventilated double-walled piping is a minimum requirement to the transportation of gas to the engine.

In addition to hazard considerations and calculations, it has been necessary to carry out tests, two of which were carried out some years ago before the installation and operation of the Chiba power plant 12K80MC-GI engine in 1994.

8.4 A crack in the double-wall inner pipe

The first test was performed by introducing a crack in the inner pipe to see if the outer pipe would stay intact. The test showed no penetration of the outer pipe, thus it could be concluded that the double-wall concept lived up to the expectations.

8.5 Pressure fluctuation

The second test was carried out to investigate the pressure fluctuations in the relatively long piping from the gas compressor to the engine.

By estimation of the necessary buffer volume in the piping system, the stroke and injection of gas were calculated to see when safe pressure fluctuations are achieved within given limits for optimal performance of the engines. The piping system has been designed on the basis of these calculations.

8.6 Main engine room safety

A recently finished investigation, initiated by a group of players in the LNG market, questioned the use of 250 bar gas in the engine room which, moreover, is located under the wheel house, where the crew is working and living.
Even though the risk of full rupture of both the inner and outer pipe at the same time is considered close to negligible and, in spite of the precautions introduced in the system design, MAN Diesel found it necessary to investigate the effect of such an accident, as the question still remains in part of the industry: what if a double-wall pipe fully ruptures and gas is released from a full opening and is ignited?

As specialists in the offshore industry, DNV was commissioned to simulate such a worst case situation, study the consequences and point to the appropriate countermeasures. DNV’s work comprised a CFD (computational fluid dynamics) simulation of the hazard of an explosion and subsequent fire, and an investigation of the risk of this event ever occurring and at what scale.

As input for the simulation, the volume of the engine room space, the location of major equipment, the air ventilation rate, and the location of the gas pipe and control room were the key input parameters.

Realistic gas leakage scenarios were defined, assuming a full breakage of the outer pipe and a large or small hole in the inner fuel pipe. Actions from the closure of the gas shutdown valves, the ventilation system and the ventilation conditions prior to and after detection were included in the analysis. The amount of gas in the fuel pipe limits the duration of the leak. Ignition of a leak causing an explosion or a fire is furthermore factored in, due to possible hot spots or electrical equipment that can give sparks in the engine room.

Calculations of the leak rate as a function of time, and the ventilation flow rates were performed and applied as input to the explosion and fire analyses.

9. Conclusion

To enter the market for a demanding application such as an LNG vessel calls for a high level of expertise and careful studies by the shipyard, the engine builder, the compressor maker as well as the engine designer.

A tailor-made ME-GI propulsion solution and fuel gas supply system is now available. This system optimizes the key application issues such as efficiency, economy, redundancy and safety. It is based on conventional, proven technology and can be applied with considerable benefit on LNG carriers.

For LPG carriers, an ME-GI solution for LPG fuel is also available, including a newly developed gas supply system from Hamworthy Gas Systems. This solution offers major benefits such as lower emission levels and lower fuel costs by utilizing the heavy fluctuation between LPG and FO prices.

Also for other ship types, technical solutions exist to use gaseous fuel. At present, the lack of LNG bunkering facilities seems to be the biggest hurdle to overcome. Projects are ongoing to establish LNG facilities, e.g. MEGALOC. Therefore, in some parts of the world, LNG will be available as fuel for ships in the near future.

References


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