At the Forefront of Green Engine Technology
The MAN B&W ME-GI and ME-LGI dual fuel concepts
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At the Forefront of Green Engine Technology
Introduction

Today the choice of engine technology is most often based on estimated fuel cost, the availability of the fuel and the implementation of still more strict SOX and NOX emission regulations worldwide. The demand for optimisation of the energy efficiency design index (EEDI) in order to limit CO2 emission is also an important factor [1,2].

In response to this MAN Diesel & Turbo (MDT) has added another green engine to their engine portfolio, the ME-LGI (liquid gas injection) engine. The engine is based on decades of research and experience from the ME-GI (gas injection) and the well-proven ME-engine. The first commercial two-stroke dual fuel ME-GI marine engine was ordered in 2013, but the research that eventually led to this engine began in the 1990s at the MDT Diesel Research Centre in Copenhagen. At the time of writing, 142 ME-GI and eight GIE (gas injection ethane) engines are either in the MDT order book or installed onboard. Tests on the first commercial LGI engine on methanol which demonstrated the liquid gas injection concept took place in 2015 in Japan. At the time of writing the MDT order book counts nine of these engines, where two are options. None of the fuels for the GI/GIE and LGI engine types contain sulphur, simply because it is not present or it is only present in small amounts which are removed in order to avoid corrosion. This makes the fuel suitable for voyages passing through SECA areas, and it also lowers the emission of CO2 since burning of low carbon fuels generates less CO2.

A quick tour of the technological differences between the GI and LGI concept

The MAN B&W ME-LGI engine is the dual fuel solution for low flashpoint liquid fuels (LFL) as opposed to the ME-GI engine where the fuel is injected in the gaseous state, see Table 1.

The GI and LGI engines can be delivered in different versions depending on the desired fuel type. Although, the state and type of the fuel dictates some differences in technology, the GI and LGI engine principles rest on the shoulders of the ME engine. Another option is that it is possible to retrofit existing two-stroke engines to GI or LGI service.

The principle of non-premixed combustion or diesel type combustion is the important common denominator for the GI and LGI engines also when running on natural gas (NG) and LFL. Both engine types are based on principles from the two-stroke engine operated on MDO or HFO, where the fuel is injected and burned directly as opposed to the premixed or Otto type combustion. In the latter air and fuel are premixed at a lower temperature and pressure and subsequently compressed in the cylinder and ignited by a spark or pilot fuel oil injection. The major challenge is premature ignition or engine knocking and the restrictions it has on the engine design (e.g. gas quality, strict control with the air/fuel ratio and limitations on compression ratio).

The ME-GI and ME-LGI engines are able to run 100% maximum continuous rating (MCR) on NG and LFL/HFO/MDO, respectively, and also burn any ratio of NG or LFL and fuel. The minimum pilot oil percentage is 5% when the engine is running on methanol. The ME-GI engine is started on diesel and at 10% engine load a changeover to gas operation can take place. Thus, the GI and LGI versions of the marine engines offer the ship owners a high degree of fuel flexibility [3].

Table 1: An overview of the GI/LGI engines, designations and fuel types

<table>
<thead>
<tr>
<th>GI-engine versions and designations</th>
<th>The GI engine runs on methane (CH4) and the GIE engine on ethane (C2H6). The gas is delivered in pipeline or stored as compressed natural gas (CNG) in high-pressure tanks.</th>
<th>Methane/ethane stored as a supercooled (cryogenic) liquid, i.e. liquefied natural gas (LNG).</th>
</tr>
</thead>
<tbody>
<tr>
<td>LGI-engine versions and designations</td>
<td>The LGI/GI engine runs on methanol (CH3OH).</td>
<td>Ethanol (C2H5OH)</td>
</tr>
</tbody>
</table>
Besides, both engine series are Tier III NO\textsubscript{x} compliant, with the internal engine process EGR (exhaust gas recirculation) or the SCR (selective catalytic reduction) after-treatment method, and Tier III SO\textsubscript{x} compliant in combination with an exhaust gas cleaning system (EGCS) or operation on low-sulphur fuels (0.1 % or less) as main or pilot oil [1].

**The fuel supply systems**

In principle the overall fuel system design of GI and LGI engines have many similarities, but differences exist when it comes to differences in fuel properties, see Table 2, for example gas versus liquid and the different specific chemical properties of the various types of fuel. Compared to diesel, the viscosity of LFL and NG fuel is much lower, hence lubrication of the moving parts is necessary.

The GI and LGI dual fuel systems can be divided into:

1) An auxiliary system consisting of bunker tanks, the fuel gas/LFL supply system and the main valve train, where the latter provides a separation of the fuel supply and fuel injection system on the engine.

2) A fuel chain supply pipe arrangement and a fuel injection system. The main valve train also provides the possibility to purge the system with an inert gas, often N\textsubscript{2}.

The detailed layout of the fuel supply system depends on the type of ship and the type of storage system.

The first major difference between the GI and LGI fuel system is found in the fuel supply systems, which deliver fuel to the engine within the requirements to temperature, flow and pressure. The GI engine requires a supply pressure of 300 bar or higher, as opposed to the LGI engine, which only requires up to 50 bar supply pressure. The exact numbers depend on the type of fuel and the specific operation point of the engine. The highly pressurised gas for the GI engine may be supplied in different ways, two of which are:

1) A compressor solution if the natural gas is available as gas (CNG) or a pipeline solution.

2) A cryogenic pump and vaporizer solution if the gas is available as LNG [3].

One of the options for a fuel supply system for the LGI engine is the low flashpoint liquid supply system (LFLSS). This is a conventional circulation fuel oil system as it is known from the ME engine, where the fuel oil is supplied from a service tank and subsequently boosted to the engine supply pressure, e.g. up to 50 bar when running on methanol.

**The fuel injection systems**

The high-pressure gas is supplied to the GI engine through the main valve train or gas valve train and double-walled and ventilated fuel gas pipes in the engine room. The double-walled pipes are ventilated by continuously exchanging and monitoring the air in the space between the inner and outer pipe. A gas leakage test is performed on the ventilated air by checking for hydrocarbons. In the event that a leakage is detected, a fuel switch to heavy fuel oil takes place. Thanks to the double-wall design and constant monitoring of the fuel pipes, the GI and LGI engine rooms can be designed as ordinary engine rooms according to the IMO regulation “Gas safe machinery” [3]. The safety

<table>
<thead>
<tr>
<th>Fuel</th>
<th>LPG</th>
<th>Methanol</th>
<th>Ethanol</th>
<th>DME</th>
<th>Ethane</th>
<th>Methane</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower heating value (MJ/kg)</td>
<td>46</td>
<td>19.9</td>
<td>27</td>
<td>28.7</td>
<td>47</td>
<td>50</td>
<td>42.7</td>
</tr>
<tr>
<td>Boiling temperature (°C at 1 bar)</td>
<td>-43-(-1)</td>
<td>65</td>
<td>78</td>
<td>-24.9</td>
<td>-89.0</td>
<td>-162</td>
<td>180-360</td>
</tr>
<tr>
<td>Kinematic viscosity (cSt at 20°C)</td>
<td>0.17-0.24</td>
<td>0.74</td>
<td>1.2</td>
<td>0.2</td>
<td>0.18</td>
<td>0.12</td>
<td>2.5-3.0</td>
</tr>
<tr>
<td>Liquid density (kg/m³)</td>
<td>455-550</td>
<td>796</td>
<td>794</td>
<td>670</td>
<td>447 at T=60°C, P=510 bar</td>
<td>189 at T=50°C, P=300 bar</td>
<td>840</td>
</tr>
<tr>
<td>Vapour pressure (bar @ 20°C)</td>
<td>2.2-8.5</td>
<td>0.13</td>
<td>0.059</td>
<td>5.3</td>
<td>37.6</td>
<td>Not defined</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Critical temperature (°C)</td>
<td>97-152</td>
<td>239.4</td>
<td>241</td>
<td>127</td>
<td>32.2</td>
<td>-82.6</td>
<td>435</td>
</tr>
</tbody>
</table>

**Table 2:** Fuel properties for LFLs, gaseous fuels and diesel
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system makes it possible to purge the fuel system with \( N_2 \) before and after operating the engine on gas and in the event of gas operation failures. Besides, the fuel gas and LFL supply system can be pressurised with \( N_2 \) to test for leakages.

The LFLSS for the ME-LGI engine has been designed in a similar way with a fuel valve train, a chain pipe LFL supply system, double-walled and ventilated pipes with HC sensors and also a safety level switch to indicate a LFL leakage. A feature has been added to the LFL drain system; the drain piping in the engine room has been arranged in a manner that enables gravitational purging to the service tank. This first draining of the system is always followed by purging with \( N_2 \).

For the ME-GI engine the high-pressure gas is distributed via the chain pipe gas supply system to the gas control blocks on each cylinder (common rail injection type). To minimise the effect of pressure surges, the gas control blocks are equipped with an accumulator volume. The injection principle constitutes the second major difference between the GI and the LGI engine which will be explained in more detail later in the paper. Depending on the engine type the cylinder cover of the GI engine (see Fig. 1) is equipped with two or three gas injection valves and two or three pilot fuel valves. Internal bores in the cylinder cover leads the gas from the gas control block to the gas injection valves. GI and LGI engines use the conventional ME fuel system and fuel injection valves for both the main fuel injection and also the pilot oil injection. Research involving evaluation of the maximum combustion pressure has shown, so far, that the timing of pilot oil injection should be identical for the engines as well.

A vital part of the injection system is the gas control block, which communicates a safe administration and correct timing of gas to the engine from the engine control system. The control block contains two hydraulically actuated valves:

1) an electronic window/shut-down valve (ELWI – electronic window) which sets up a timing window in which the highly pressurised gas is allowed to flow to the gas injectors

2) an electronic gas injection valve (ELGI), which admits high-pressure hydraulic oil to the gas injection valves to cause these to open.

For safety reasons the window/shut-down valve is placed in series with the gas injection valves; this ensures that the ELGI valve does not supply gas to the engine outside the proper timing window. In the event of a gas shutdown, the ELWI will block the gas supply to the injector valves. The two hydraulic valves are electronically controlled by the gas injection engine control system (GI-ECS).

When the ELGI valve causes the gas injectors to open, a gas jet is injected into the combustion chamber at a high pressure (methane 300 bar and ethane 400 bar). The gas jet is ignited by injecting a small amount of fuel oil.
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(pilot oil) before the gas injection. This pilot oil is used to control the ignition of fuel oil and gas.

The timing of gas and LFL injection is identical for the GI and the LGI engine, whereas the nozzle design and injection profiles differ for the two fuel types. The optimised gas/LFL injection profiles and injection directions are determined by running tests and simulations where the temperature of the piston, cylinder liner and exhaust valve are monitored and evaluated. The aim is to keep vital indicators of the combustion process (i.e. the maximum pressure and heat release rate) the same for the ME, ME-GI and LGI engine.

Another vital system, the sealing oil system, prevents pollution of the hydraulic oil with fuel gas. The sealing oil system provides sealing oil to the window valve and the fuel gas injection valves.

The cylinder cover of the LGI engine (see Fig. 2) is equipped with the LGI control block, two or three fuel booster injector valves (FBIV), mounted in bushings, and two or three pilot oil injectors depending on the engine size. The LFL control block contains the pilot control valves for the window/shutdown valve similar to the GI system and the pilot control valve for LFL injection (ELFI-L – electronic fuel injection - liquid). The ELBI valve sets up the timing window and the ELFI-L controls the supply of hydraulic oil to the fuel oil pressure booster, where the hydraulic oil via a piston generates the injection pressure. The LFL is also ignited by injecting pilot oil before LFL injection. To summarise (see Table 3): The GI engine is of the common rail injection type where the pressure in the supply system and accumulators are constantly equal to the injection pressure. The gas injection valves are opened with hydraulic oil, whereas in the LGI engine the injection pressure is generated in the fuel oil booster injection valves.

The GI-ECS and LGI-ECS systems are add-ons integrated with the standard electronic engine control system (ECS) of the ME engine. The GI-ECS controls the gas injection and the handling of gas on the engine and in the machine room, and similarly with the LGI-ECS.

The technological differences between the LGI and GI engine are summarised in Table 3.

Conclusion

The ME-GI engine, the GI-ECS system and related auxiliary systems have been approved by the classification societies. Besides, the ME-GI has proven its green value and the combustion optimisation results show a NOx emission level comparable to that of an engine running on diesel, however, with a lower specific gas fuel consumption (SGFC) on gas.

Since the SOx emission level depends on the fuel oil quality and pilot oil consumption, the difference in emissions

Two FBIVs and two pilot fuel valves
between the GI and LGI engine are negligible. The PM emissions of the GI engine are lower than when running on diesel. The PM emissions of the LGI engine have not been measured yet, but a similar reduction is expected.

The first container ship in the world with an engine running on LNG is powered by an MAN B&W ME-GI dual fuel engine. The ship, the MV *Isla Bella* (owned by Totem Ocean Trailer Express (TOTE)), was launched in 2015. Recently, the two MAN B&W S70ME-C HFO-burning engines of the LNG carrier the MV *Rasheeda* (owned by the company Nakilat of Qatar) have been converted to the dual-fuel ME-GI concept.

The first commercial ME-LGI engine (7S50ME-B9.3-LGI) was running on methanol during a demonstration in Japan. During the demonstration, a changeover from DO to methanol was carried out and the load was increased to 50-75% followed by load variations and finally a changeover to DO. The engine is bound for a vessel owned by Mitsui O.S.K. Lines, Ltd. This ship together with sister vessels with LGI engines will enter service April 2015.

### List of definitions/abbreviations

- **CNG**: compressed natural gas
- **EEDI**: energy efficiency design index
- **EGCS**: exhaust gas cleaning system
- **EGR**: exhaust gas recirculation
- **ELBI**: electronic block injection
- **ELFI-L**: electronic fuel injection (timing and admission of hydraulic oil to FBIV, injection pressure is generated inside the FBIV)
- **ELGI**: electronic gas injection (timing and opening of the gas injection valve)
- **ELWI**: electronic window
- **FBIV**: fuel booster injection valve
- **FGSS**: fuel gas supply system
- **FGL**: fuel gas supply system
- **LFL**: low flashpoint liquid
- **LFLSS**: low flashpoint liquid supply system
- **LNG**: liquefied natural gas
- **SCR**: selective catalytic reduction

### References


2. Reduction of SO₂, NOₓ and Particulate Matter from Ships with Diesel Engines, The Danish Environmental Protection Agency

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