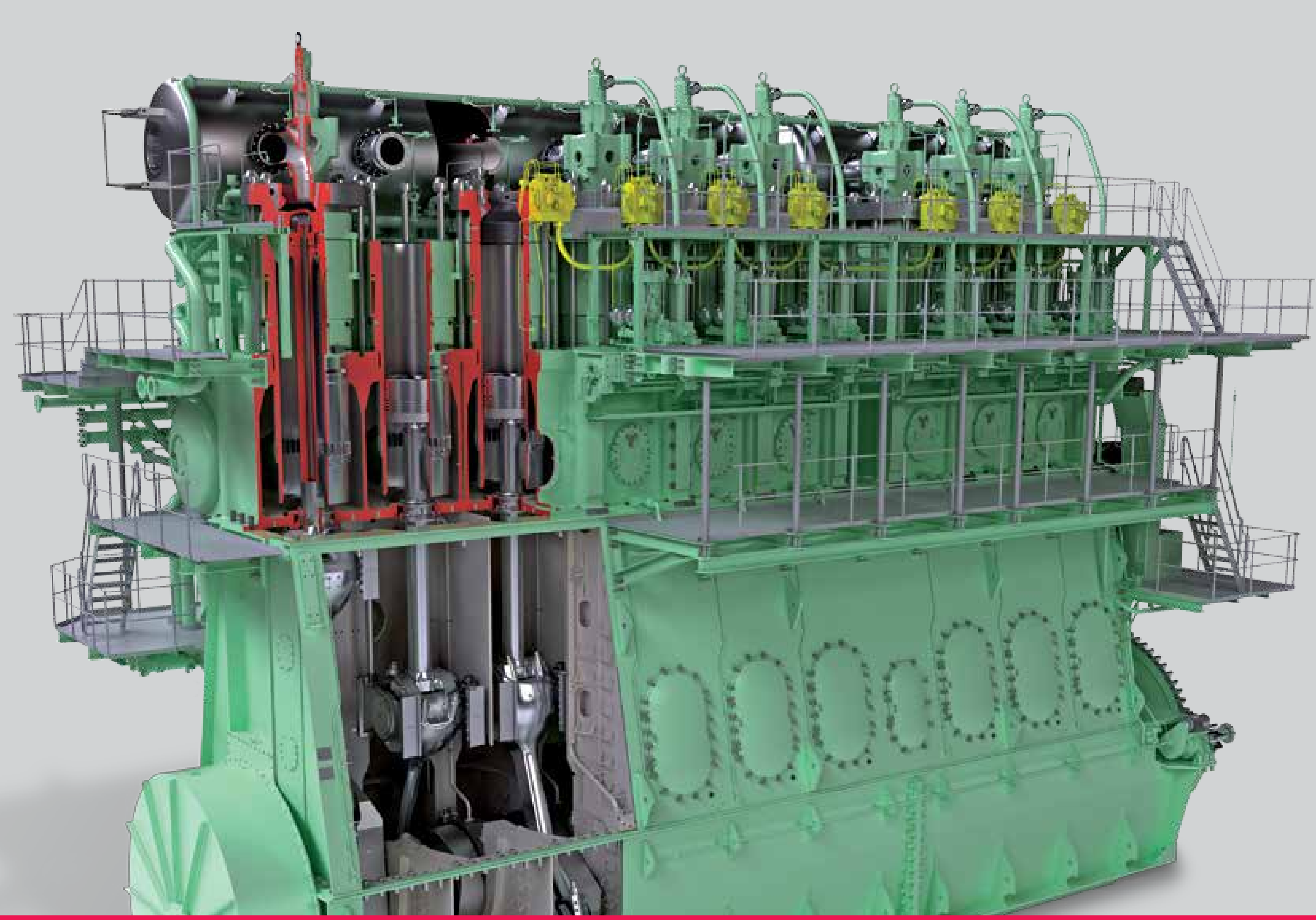


ME-GI Dual Fuel MAN B&W Engines

A Technical, Operational and Cost-effective Solution for Ships Fuelled by Gas

Engineering the Future – since 1758.

MAN Diesel & Turbo

Content

ME-GI Dual Fuel MAN B&W Engines

Abstract

Since 2012, MAN Diesel & Turbo has received significant orders for the gas-fuelled ME-GI engine. The first ME-GI engine specified was for two gas-fuelled container vessels ordered by the company TOTE. This first order is for an 8L70ME-C8-GI engine, sized for a 3,100 teu containership. It is the first of its kind, and it is an interesting fact that this is the first fully commercial vessel operating on natural gas which is built without any subsidies. The vessels will be built by NASSCO shipyard, and the first vessel is scheduled for delivery in 2015.

Furthermore, MAN Diesel & Turbo has received an order for 5 + 5 LNG carriers to Teekay. Also powered by ME-GI engines, these LNG carriers are to be built by DSME, and the first delivery will be in 2016. The target for Teekay has been to reduce both fuel oil consumption and maintenance costs.

The first two ship types are rather different. The LNG carriers already have LNG on board, so the challenge for this ship type is to design an efficient gas supply system, taking the handling of boil-off gas (BOG) into consideration. The gas supply system should be able to handle the boil-off gas from the cargo tank and deliver it to the main engine as well as to the dual fuel gensets. The gas supply system must also be able to direct the BOG to the GCU in order to protect the tank if the pressure in the tanks gets too high.

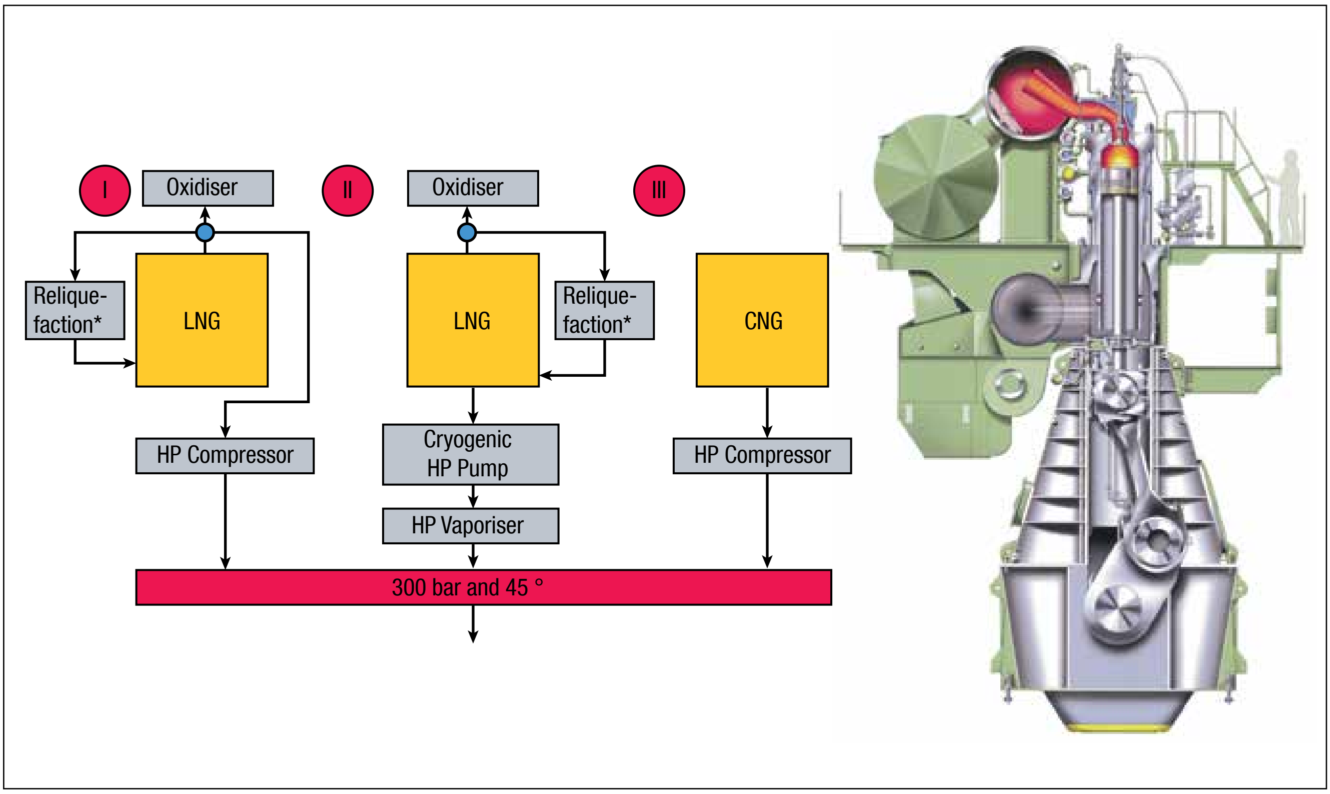


Fig. 1: Three different possibilities for generating high-pressure gas from NG

On the other hand, the gas-fuelled container vessels do not carry LNG on board, so LNG tanks and a gas supply system must be installed to deliver LNG to the ME-GI engine and the dual fuel gensets. Here, the challenge is to make a container ship design with sufficient space for the LNG tanks without losing any space for containers, see Fig. 2.

Both orders have changed the market conditions significantly as they will set a new standard for ship efficiency and low emissions. It is therefore expected that many other owners will follow this new trend and take up the competition.

Today, July 2014, more than 60 dual fuel gas engines are on order. The ME-GI engine is selected because of its high efficiency on both gas and fuel oil. The shipowner is always cost-competitive with his ship irrespective of which fuel is the cheapest. This is very important in today's market where we see conflicts come and go in the gas and oil rich regions.

The ME-GI offers a robust combustion solution with the highest fuel efficiency available in the market. The robust combustion also ensures a high efficiency with a negligible methane slip. 0.2% has been measured as a maximum when the engine was operating at low load.

This paper describes the technology behind the gas-fuelled ME-GI engine, and the requirements to the gas supply system.

Introduction

Future fuels for ships are a reality today. The new order for a »Jones Act« gas-fuelled container vessel has set a new standard. A new LNG bunkering station will be built in connection with this order, and other ships will also be allowed access to the LNG. The very low gas price in the US is making it highly attractive to invest in gas-powered ships. Current gas prices offer savings of almost 50% in fuel costs compared with heavy fuel oil (HFO). A comparison with marine gas oil (MGO), which is needed when ships operate in emission control areas (ECAs), makes the investment even better. It is therefore expected that the two container vessels will be operated on gas both inside and outside ECA zones. Therefore, it makes sense to use gas as the fuel for both operational scenarios.

LNG safety regulations covering the delivery process are under way, and several LNG bunkering terminals are being prepared outside the US, e.g. in the Baltic region. Furthermore, the locations of LNG terminals in the Mediterranean Sea, in Singapore and in East Asia are under discussion. LNG as a fuel will undoubtedly soon become a reality worldwide.

For LNG carriers, the supply of LNG is a lot easier since the LNG supply is already on board, and there is a long tradition for handling LNG in a safe manner. For other ship types, rules and procedures for handling LNG on board are under development. The experience from LNG operation in Norway seems to set the new standard.

MAN Diesel & Turbo (MDT) has performed a full scale test on the 4T50ME-GI research engine in Copenhagen. This was done to demonstrate that the engine was able to fulfil Tier II and, later on, Tier III in combination with the MDT-developed EGR system. Another important purpose was to demonstrate that the engine can operate on high-pressure gas delivered from a fuel gas supply system comprising an LNG pump and a vaporizer.

In February 2010, MAN Diesel & Turbo signed a development agreement with Korea's Daewoo Shipbuilding & Marine

Fig. 2: New TOTE container vessel powered by MAN B&W dual fuel ME-GI

Fig. 3: LNG vessels

Engineering Co., Ltd. (DSME) to jointly develop and exploit the adaptation of DSME's high-pressure cryogenic gas-supply system for integration with the ME-GI test engine. Both the new engine design and the gas supply system from DSME will be equipped on board the TOTE container vessel, see Fig. 2.

However, different applications can call for different gas supply systems, and a number of projects have shown that operators and shipowners demand alternative solutions. Therefore, MDT aims to have a number of different gas supply systems prepared, tested and available. MDT is therefore in close cooperation with other gas supply manufacturers, such as Burckhardt Compression, TGE, Cryostar, HHI, SHI, MHI, and Hamworthy. MDT has already scheduled and completed new joint tests with some of these manufactures at different locations.

MAN Diesel & Turbo and others have shown that dual fuel engines can be more than just an economically sound choice for LNG carriers, VLCC and container vessels. Dual fuel engines are also safe, reliable and environmentally desirable as a result of the experience obtained over many years from two-stroke diesel engines for the marine market for single as well as twin-propeller vessels in all types of commercial application.

More specifically for LNG carriers, the type of optimum gas supply system seems to depend on the type of trade of the LNG carrier, e.g. operation as a carrier train between two destinations or spot market trading.

In January 2011, 90 MAN B&W two-stroke S70ME-C engines were delivered for 45 LNG carriers for the Qatar gas project. Another eight engines are on order also for LNG carriers, and have been prepared for a later GI conversion. All these engines are, however, ordered for operation on liquid fuels, i.e. HFO, MDO, and MGO as are more than 17,000 MC/ME type engines worldwide for different marine market applications.

In December 2012, 4 + 6 type 5G70ME-B9.2-GI engines were ordered for Teekay. In June 2013, another four engines were ordered. It is worth noting that the owner chose the new G-type engine, which operates with a lower rpm. New available propeller types can take advantage of this, and improve the propulsion efficiency, see picture of LNG vessels in Fig. 3. The system for handling the boil-off gas can be combined with the engine gas supply system in many different ways, thereby offering many possibilities, especially for LNG carriers. But basically, two different solutions are available for LNG carriers. Figs. 4 and 5 illustrate the two different system configurations. One system where a piston compressor feeds the ME-GI with high-pressure fuel gas, and one system where an LNG pump and a vaporizer feed the ME-GI with high-pressure gas. The two systems are offered in many different configurations, and from different manufactures. This paper describes the different possibilities.

Teekay sees a benefit in both options, and they have decided to combine the compressor and the HP LNG pump solution. Besides redundancy, this combination offers a very efficient gas supply system. In laden condition, when there is sufficient energy in the BOG, the highly efficient low-rpm compressor delivers gas to the engine as well as to the dual fuel gensets. In ballast condition, the HP LNG pump is also operated, see also the picture of the hybrid solution in Fig. 6. A full or partial reliquefaction system can be combined if there is still an excess of gas. The hybrid solution taking advantage of the G-type engine gives fuel savings of 15-20% when compared with the best DFDE standard of today.

Since 2004, MDT has worked with Burckhardt Compression, who developed and designed the ME-GI gas supply system in detail, using the Laby GI compressor. In 2009, Burckhardt Compression got the first order for a Laby-GI compressor, a full scale demonstration test was done, and quite recently the Laby-GI was successfully installed on an FSRU and handed over to the owner. During this work, we have acknowledged how important it is to enter a new market with a manufacturer who also places safety, reliability and customer satisfaction high on the agenda for design and production of their components.

Hamworthy and MDT have worked closely on a number of different projects over the years, especially on the reliquefaction side. Today, Hamworthy offers gas supply systems using either the Laby-GI compressor or a system based on the LNG pump solution.

MDT has also had a long cooperation with Cryostar. Cryostar has been very successful in the cryogenic business for decades, where their Cryogenic

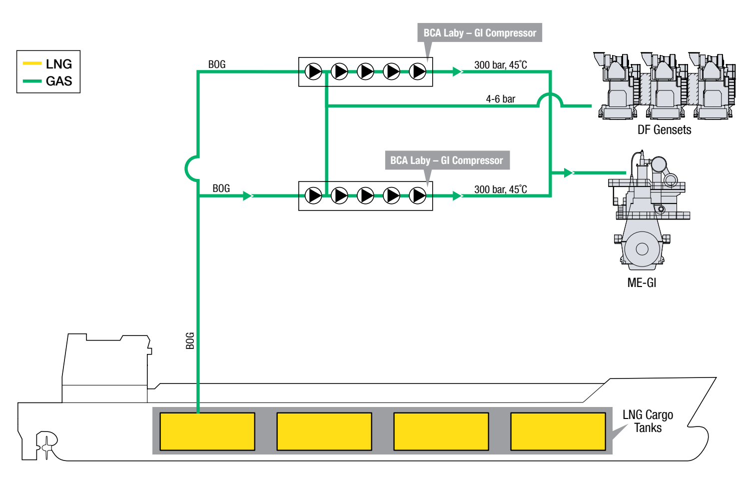


Fig. 4: ME-GI engine with Laby-GI compressor system (reliquefaction unit not shown)

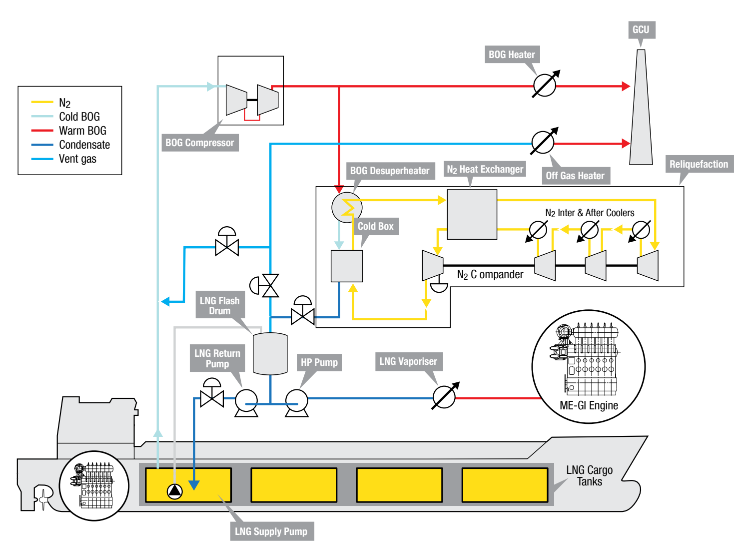


Fig. 5: Components to be modified: ME-GI compared to an ME engine

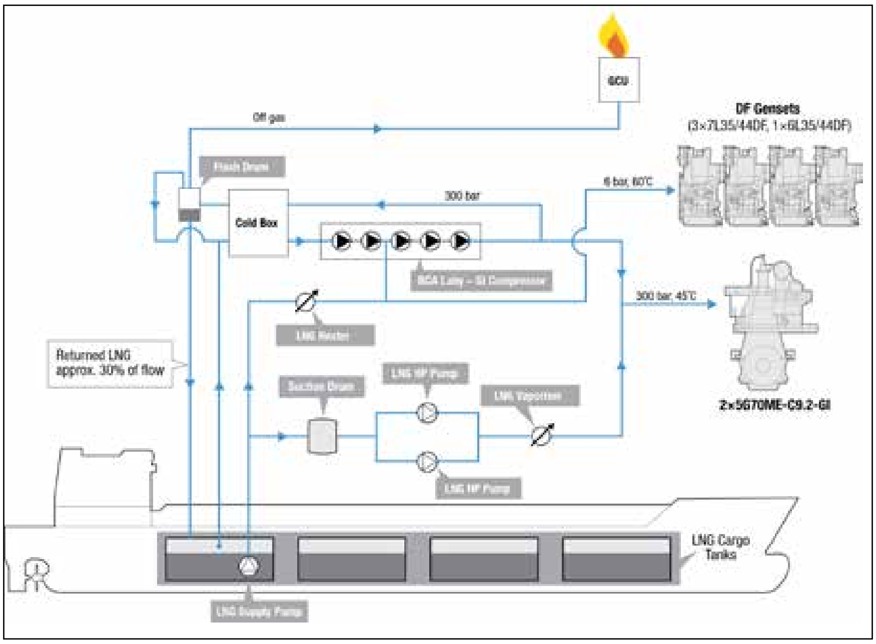


Fig. 6: HP compressor and HP pump with partial reliquefaction

pump system has been used and installed on land-based production facilities. Already back in 2006, Cryostar and MDT invented and developed the high-pressure gas supply system, comprising an LNG pump and a vaporizer. In 2009, Cryostar demonstrated their ME-GI gas supply system at their facilities in France.

TGE and MDT have worked together for a relatively short period. But in this short time, TGE has demonstrated that they have extensive knowledge of cryogenic gasses, and that they have a detailed understanding of all safety aspects related to the use of cryogenic gasses. TGE offers both a reliquefaction plant combined with the Laby-GI compressor, and a gas supply system for LNG fuelled ships based on the LNG pump technology. TGE has also developed gas supply systems for owners interested in using LPG.

HHI and Mitsui are part of our licensee family, and both licensees have announced that they have prepared their test beds for the building of ME-GI engines. Gas installations have been prepared on their test bed facilities, followed by full-scale installation and testing of an ME-GI. In this connection, HHI developed their own gas supply system design, which they also offer to other shipyards. Mitsui uses a gas supply system developed by MHI for their gas test facilities. Both gas supply systems have been successfully demonstrated together with a full scale test of the ME-GI engine.

ME-GI Concept

The MC/ME engine family has been on the market since 1982. The engines have been in service on almost any type of marine application on container vessels, tankers of all sizes, bulk carriers, car carriers, RoRo and general cargo vessels.

There are many good reasons for choosing the two-stroke direct-coupled ME engine types, e.g. high thermal efficiency, reliability, availability and safety, and the fact that it is a simple and robust solution that offers the same load response when operating on fuel gas.

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. The Chiba engine has operated as a peak load plant for almost 20,000 hours on high-pressure gas. In 2003 the engine was converted to kerosene operation due to the prices on the gas fuel.

In 1994, all major classification societies approved the GI concept for stationary and marine applications. This was repeated in December 2012 for the newest design of the ME-GI. The type approval test was carried out on the test bed facilities at HHI, and using the fuel gas supply system built by HHI.

Technically, there is only little difference between fuel and gas burning engines, but the GI engine provides an optimal fuel flexibility. Fig. 7 shows the components that need to be modified and added on the engine to allow it to operate on gas.

The gas supply line is designed with ventilated double-wall piping including HC sensors for safety shutdown. For control of the gas engine, the GI control and safety system added to the well-proven ME control system.

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

New units:

- Ventilation system for venting the space between the inner and outer pipe wall of the double-wall piping
- Sealing oil system, delivering sealing oil to the gas valves separating control oil and gas. This system is fully integrated on the engine, and the shipyard no longer needs to consider this installation.
- Inert gas system that enables purging of the gas system on the engine with inert gas.
- Control and safety system, comprising a hydrocarbon analyser for checking the hydrocarbon content of the air in the double-wall gas pipes.

The GI control and safety system is designed to fail to safe condition. All failures detected during gas fuel running, including failures of the control system itself, will result in a gas fuel stop and change-over to HFO fuel operation. Blow-out and gas-freeing purging of the high-pressure gas pipes and of the complete gas supply system follows. The change-over to fuel oil mode is done without any power loss on the engine. Recent tests have shown that a normal gas stop takes place completely bumpless, i.e. it is simply not

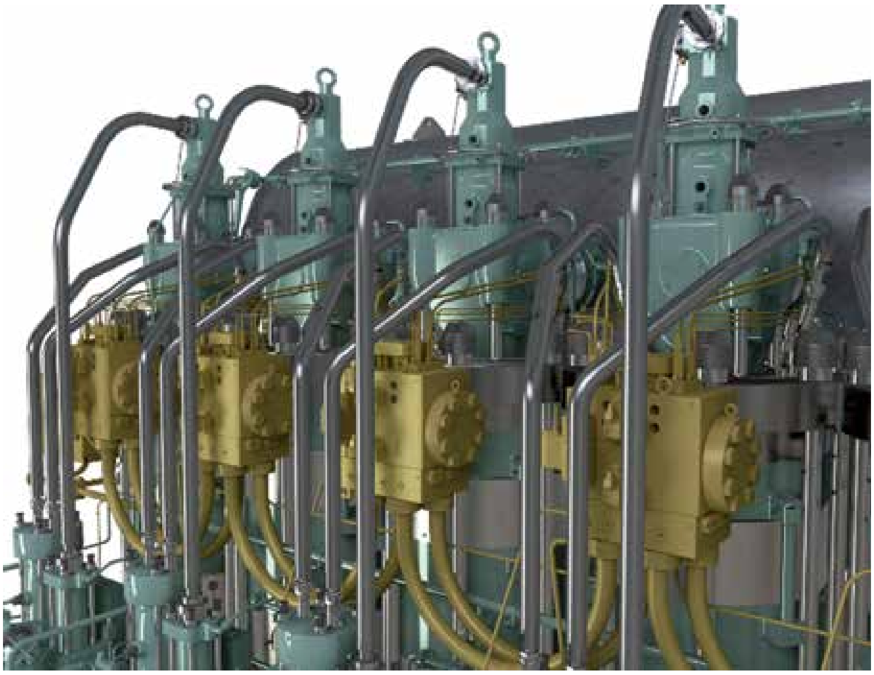


Fig. 7: New gas module

possible to hear which type of fuel is being burned.

The high-pressure gas supply flows through the main “chain” pipe that connects each cylinder’s gas valve block and accumulator. This “chain” pipe design (see Fig. 6) performs two important tasks:

- They separate each cylinder unit from the rest in terms of gas dynamics, utilising the well-proven design philosophy of the ME engine’s fuel oil system.
- They act as flexible connections between the stiff main pipe system and the engine structure, safeguarding against extra stresses in the chain pipes caused by the inevitable differences in thermal expansion of the gas pipe system and the engine structure.

The buffer tank, containing about 20 times the injection amount per stroke at the maximum continuous rating (MCR), also performs two important tasks:

- It supplies the gas amount for injection at a slight, but predetermined, pressure drop.
- It forms an important part of the safety system.

Because the gas supply piping is of the common rail design, the gas injection valve must be controlled by an auxiliary control oil system. This, in principle, consists of the ME hydraulic control oil system and an ELGI & ELWI (electronic gas injection) valve system, supplying high-pressure control oil to the gas injection valve, thereby controlling the timing and opening of the gas valve.

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.

The gas injection valve design is shown in Fig. 8. This valve complies with traditional design principles of the compact design. Gas is admitted to the gas injection valve through bores in the cylinder cover. To prevent a gas leakage between the cylinder cover/gas injection valve and the valve housing/spindle guide, sealing rings made of temperature and gas resistant material have been installed. Any gas leakage through the gas sealing rings will be led through bores in the gas injection valve to the space between the inner and the outer shield pipe of the double-wall gas piping system, where the leakage will be detected by HC sensors.

The gas acts continuously on the valve spindle at a max. pressure of about 300 bar. To prevent gas from entering the control oil actuation system via the clearance around the spindle, the spindle is sealed with sealing oil at a pressure higher than the gas pressure (25-50 bar higher).

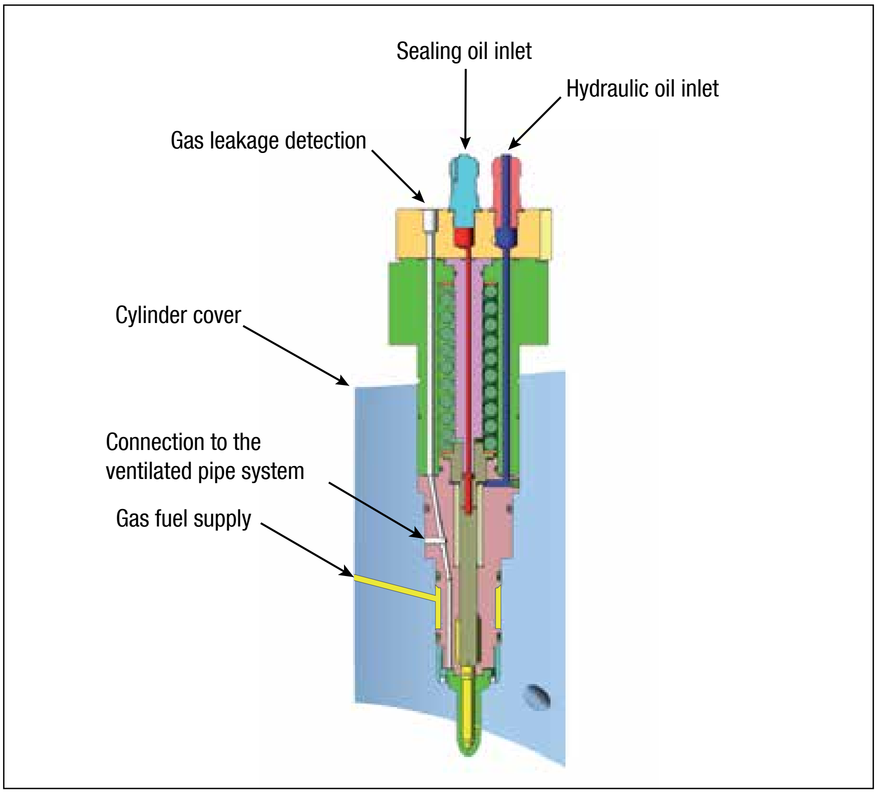


Fig. 8: Gas injection valve – ME-GI engine

The pilot oil valve is a standard ME fuel oil valve without any changes, except for the nozzle. Both HFO, MGO and MDO can be used as pilot oil.

The oil valve design allows operation solely on fuel oil up to MCR. The gas engine can be run on fuel oil at 100% load at any time, without stopping the engine. For prolonged operation on fuel oil, it is recommended to change the nozzles and gain an increase in efficiency of around 1% when running at full engine load.

As can be seen in Fig. 9 (GI injection system), the ME-GI injection system consists of:

- two fuel oil valves
- two fuel gas valves
- an ELGI (electronic gas injection valve) for opening and closing of the fuel gas valves
- a FIVA (fuel injection valve actuator) valve to control the injected fuel oil profile via the fuel oil valve
- an ELWI (electrical window and gas shutdown) valve to control the position of the window valve as an extra safety feature to prevent gas leakages and, thereby, ensuring a double-valve block towards the combustion chamber. Furthermore, it consists of the conventional fuel oil pressure booster, which supplies pilot oil in the dual fuel operation mode.

Safety features

Under normal operation, where no malfunctioning of the fuel oil valve is found, the fuel gas valve is opened at the correct crank angle position, and gas is injected. The gas is supplied directly into an ongoing combustion. Consequently, the risk of having unburnt gas that might slip past the piston rings and into the scavenge air receiver is considered to be unlikely. Monitoring of the scavenge air receiver pressure and the combustion condition also safeguards against such a situation.

The purpose is to be warned at an early stage if any gas leaks occur across the gas injection valves. The window valve has a double safety function, securing that gas injection into the combustion chamber, is only possible at the correct injection timing. In the event of a gas failure, it can also block the gas from entering the combustion chamber, thereby ensuring that only a very small amount of gas will enter.

The pressure sensor is located between the window valve and the gas injection valve. The small gas volume in the cylinder cover on each cylinder will reveal the gas pressure during one cycle. By this system, any abnormal gas flow will be detected immediately, whether due to seized gas injection valves, leaking gas valves or blocked gas valves. The gas supply will be stopped and the gas lines purged with inert gas. Also in this event, the engine will continue running on fuel oil only without any power loss.

Furthermore, the combustion pressures are constantly being monitored. In the event of too high a combustion pressure, the gas mode is stopped, and the engine returns to burning fuel oil only.

High-pressure double-wall piping

A common rail (constant pressure) gas supply system is to be fitted for high-pressure gas distribution to each valve block. Gas pipes are designed with double walls, with the outer shielding pipe designed so as to prevent gas outflow to the machinery spaces in the event of a rupture or leak in the inner gas pipe. The intervening space, including the space around valves, flanges, etc., is equipped with separate mechanical ventilation with a capacity of approx. 30

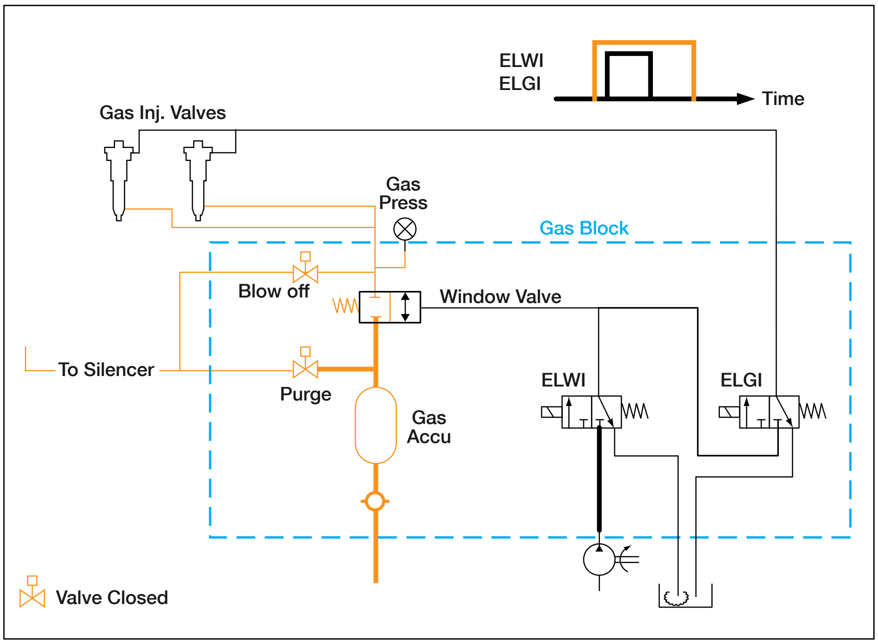


Fig. 9: ME-GI injection system

air changes per hour. The pressure in the intervening space is below that of the engine room with the (extractor) fan motors placed outside the ventilation ducts. The ventilation inlet air is taken from a non-hazardous area.

Gas pipes are arranged in such a way that air is sucked into the double-wall piping system from around the pipe inlet. Next, the air is led to the individual gas valve control blocks, and then returned back to the chain pipe and into the atmosphere via the suction blower, see Figs. 10 and 11.

Ventilation air is exhausted to a fire-safe place. The double-wall piping system is designed so that every part is ventilated. All joints connected with sealings to a high-pressure gas volume are ventilated. Any gas leakage will therefore be led to the ventilated part of the double-wall piping system and be detected by the HC sensors.

The engine gas pipes are designed for a 50% higher pressure than the normal working pressure, and they are supported so as to avoid mechanical vibrations. Furthermore, the gas pipes are shielded against heavy items falling down, and on the engine side they are placed below the gas valve block in a chain pipe design. The pipes have been pressure tested at 1.5 times the working pressure. The design is to be all-welded, as far as practicable possible, using a conical metal-to-metal sealing. Flange connections are only used if necessary for servicing purposes.

The chain pipe design to the individual cylinders is designed with adequate flexibility to cope with the thermal expansion of the engine from cold to hot condition. The gas pipe system is also designed so as to avoid excessive gas pressure fluctuations during operation.

For the purpose of purging the system after gas use, the gas pipes are connected to an inert gas system with an inert gas pressure of 9 bar. In the event of a gas failure, the high-pressure pipe system is depressurised and, subsequently, purged automatically. During a normal gas stop, the automatic purging will be started after a period of up to 30 min. Time is therefore available for a quick restart in gas mode.

Maintenance of LNG carriers equipped with ME-GI system

Gas transportation contracts are typically long term and sailing schedules are tight. Missing a schedule can have far-reaching consequences. Our usual emphasis on maintenance will guarantee a high availability and smooth operation, and every effort is made to avoid any performance risk with an ME-GI engine as the prime mover.

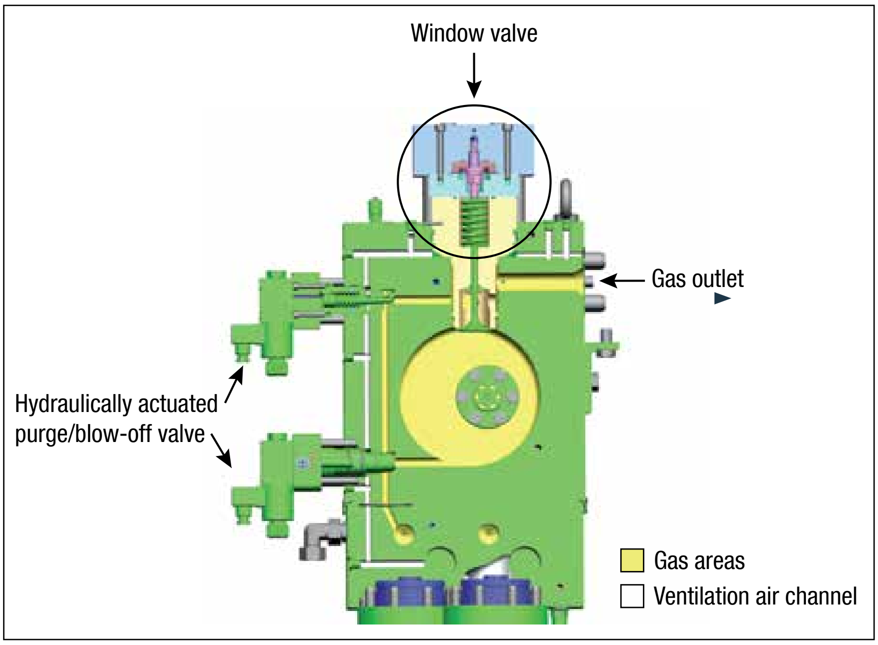


Fig. 10: Gas valve control block

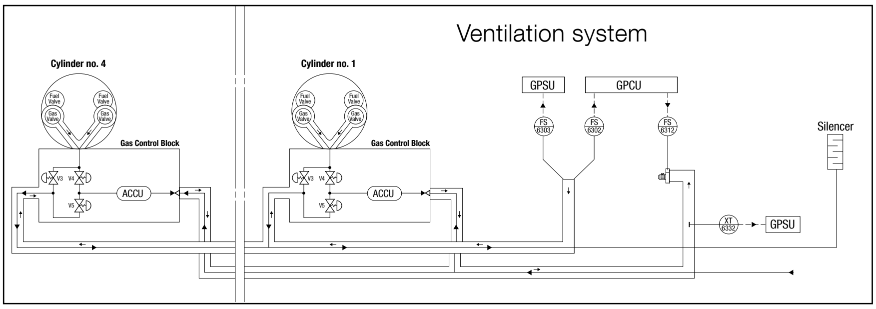


Fig. 11: Branching of gas piping system

The proper maintenance planning is essential to satisfy the vessel's operating needs.

Quite a significant number of contracts for LNG carriers have been signed. These new carriers feature efficient HFO burning MAN B&W low speed two-stroke diesel engines, in combination with reliquefaction and MAN GenSets.

Not only has MAN Diesel & Turbo played a very active role in the development, design and configuration of the propulsion arrangement for the new generation of LNG vessels, but maintenance has also been taken into consideration.

Accordingly, MAN Diesel & Turbo is currently building a service centre in Ras Lafan where experienced service engineers will be available on a 24-hour basis. Key spare part components will be on stock to ensure a high reliability and availability at all times for these LNG carriers. The service centre will be located in the region close to the loading terminals for these LNG carriers, in support of the operation and maintenance of the engine arrangements for vessels.

This service model can also be offered to new LNG carrier trains and other gas-fuelled ships that intend to use the ME-GI as propulsion for their ship.

Also with the new ME-GI engine components, operation and maintenance is a straightforward process for the skilled and experienced engine crew, at least if the maintenance jobs are planned, prepared and controlled. In general, superintendents and engine crews are well educated, skilled, and dedicated professionals. MAN Diesel & Turbo offers education programmes to marine engineers to keep them updated with the newest information about maintenance and technology.

Engine operating modes

One of the advantages of the ME-GI engine is its fuel flexibility, which is a major benefit especially for operators of LNG carriers. Burning the boil-off gas with a variation in the heat value is perfect for the diesel working principle. At the start of a laden voyage, the natural boil-off gas holds a large amount of nitrogen, and the heat value is low. If boil-off gas is forced, it can consist of both ethane and propane, and the heat value could be high. A two-stroke, high-pressure gas injection engine can burn those different fuels without seeing a drop in the thermal efficiency of the engine. The control concept comprises three different fuel modes see Fig. 12:

- fuel-oil-only mode

Gas modes:

- minimum pilot oil
- specified dual fuel operation

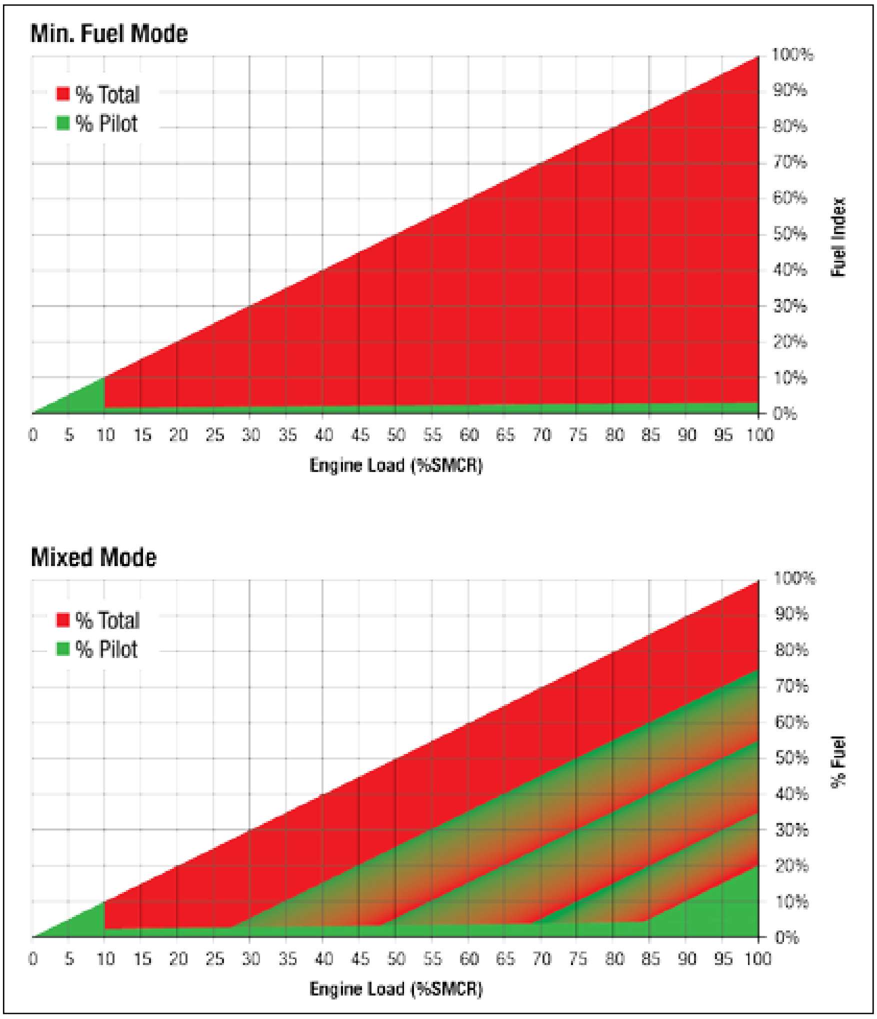


Fig. 12: Fuel type modes for the ME-GI engines for LNG carriers

The fuel-oil-only mode is well known from the ME engine. Operating the engine in this mode can only be done on fuel oil. In this mode, the engine is considered “gas safe”.

The pilot oill mode is developed for gas operation, and it can only be started manually by an operator on the Gas Main Operating Panel (GMOP) 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. If a failure in the gas system occurs, this will result in a gas shutdown and a return to the fuel-oil-only mode

The preset minimum amount of fuel oil (pilot oil) to be used is max. 3% at 100% engine load. At lower engine loads, the pilot fuel amount is reduced to approx. 1.5% at 10% engine load. Both heavy fuel oil, marine diesel oil and marine gas oil can be used as pilot oil. When the operator has started gas mode operation, the engine will stay in gas mode until the operator decides to stop gas operation. Tests have shown that a pilot oil amount down to 1.5% is possible, however, the engine will then have some load limitation in the fuel oil mode.

The specified dual fuel operation mode is offered to give the operator full fuel flexibility and 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.

Gas fuels correspond to low-sulphur fuels, and for this type of fuel we recommend the cylinder lube oil TBN40 to be used. Excellent cylinder condition with this lube oil was achieved from the gas engine on the Chiba power plant.

A heavy fuel oil with a high sulphur content requires the cylinder lube oil TBN 70. Shipowners intending to run their engine on high-sulphur fuels for longer periods of time are recommended to install two lube oil tanks. When changing to minimum-fuel mode, the lube oil should be changed as well.

Emission control – ME-GI engines

Compared with HFO operation, gas gives a cleaner exhaust. Having very low or no sulphur, SO_x sulphur oxides are negligible in the exhaust gas. Particulates will be reduced considerably as well as the emission of NO_x and CO_2.

Fig. 13 lists an arbitrary comparison of emissions from an HFO burning and a gas burning 70-bore ME-GI engine.

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

If the EGR system is combined with gas operation, the engine can easily fulfil Tier III. The NO_x level when operating on gas is 20-30% lower compared with HFO operation, and only around 30% of the exhaust gas needs to be bypassed across the EGR, this will lead to a higher efficiency on gas compared with HFO operation in Tier III zones. Cleaning of the EGR scrubber water is another issue that becomes a lot easier when operating the engine on gas, because exhaust from gas contains limited particulate matter and no SO_x.

On 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 NO_x by 94-98%.

Comparison of emissions from an HFO burning and a gas burning 70ME type engine

Estimated emissions 6S70ME-C		Estimated emissions 6S70ME-GI	
Load 100%	g/kWh	Load 100%	g/kWh
CO_2	577	CO_2	446
O2 (%)	1359	O2 (%)	1340
CO	0.64	CO	0.79
NO_x	11.58	NO_x	8.76
HC	0.19	HC	0.39
SO_x	10.96	SO_x	0.88
PM (mg/m^3)	0.54	PM (mg/m3)	0.34

Fig. 13

Efficiency improvement measures during gas operation

Instead of offering 20-30% lower NO$_x$ emissions, MDT have found that a benefit in engine effficiency is to be preferred by owners. Scavenging at lower load operation is increaced by adjusting the closing time on the exhaust valve. It was found that an up to 3.5% gain in effciency can be achieved. With the results in our hands, we have introduced the NO$_x$ tuning mode on a majority of our gas-fuelled engines, see Fig. 14.

Gas Supply Systems

Recent developments in LNG carrier propulsion and cargo handling include dual fuel diesel-electric systems (capable of burning BOG, MDO and HFO), low speed diesel engines (burning HFO) linked to reliquefaction plants and, more recently, the direct gas injection engines (ME-GI), pioneered by MAN Diesel & Turbo. The ME-GI type engines require fuel gas supplied at a pressure of 300 bar.

Overall vessel configuration

Irrespective of the type of propulsion, a primary requirement on board any LNG carrier is the tank pressure control. For vessels with membrane type containment systems, the tolerances are relatively small to ensure a safe operation of the tanks.

Cryostar's solution for ME-GI engines

Cryostar performed a study of the alternatives to ME-GI engine applications, based on a 170,000 m3 LNGC hull configuration.

The study took account of the thermal power required to operate the system. It was noted that most vessels are designed to suit the conditions for 100% MCR operation. It is clear that if the vessel is operated at low load, the power consumption drops significantly. With the ME-GI engines being more fuel efficient than both steam and DFDE propulsion, the issue of surplus BOG becomes significant.

With the 300-bar fuel gas supply pressure, a centrifugal compressor is uneconomical. It makes sense to use a positive displacement pump to increase the pressure to 300 bar. By comparison, the power required in liquid state is almost negligible (less than 1/6th). This led Cryostar to offer a high-pressure liquid pump solution, which is then fed by condensate from a reliquefaction plant, returning any surplus condensate to the cargo tanks.

Cryostar's EcoRel reliquefaction plant, together with its HP pump and vaporizer system, provides a well-balanced solution.

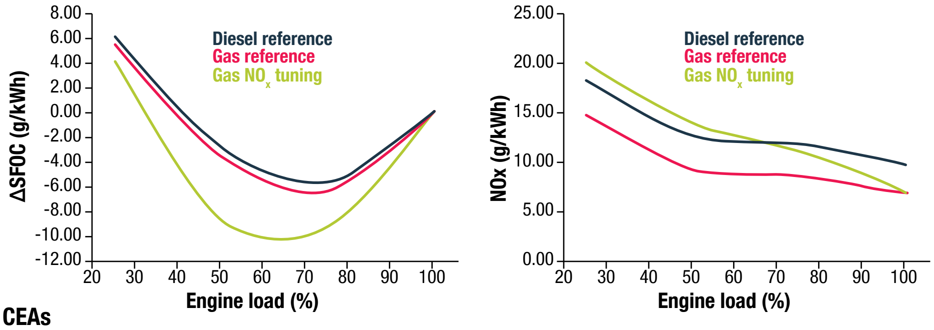
EcoRel reliquefaction plant configuration

Cryostar's proven EcoRel reliquefaction plant consists of a nitrogen-filled refrigeration loop with a compander as the main component. This machine combines three compressor stages and a single expander stage on a common gearbox. This configuration was a Cryostar world-first, and it was utilised on

Improving efficienc in gas mode:

SFOC/NO$_x$ tuning
- NO$_x$ margin in gas mode
- SFOC reduction potential
- Design limits maintained

Results
- SFOC reduces 1-3%
- NO$_x$ margin is still available



Released in ingeine programme and CEAs

Fig. 14: SFOC/NO$_x$ tuning

a machine delivered as early as 1996. The nitrogen loop also incorporates a counter-current heat exchanger, which improves the efficiency of the N2 loop.

After leaving the expander, the cold nitrogen enters the BOG condenser, where the BOG is condensed.

The BOG loop receives gas from the tanks, compresses it in a BOG compressor with intercooling, and passes it through a desuperheater that precedes the BOG condenser.

This de-superheater is a key component in the EcoRel system. It protects the delicate plate-fin construction of the BOG condenser from damage due to rapid temperature changes. This unit is also a major contributor to the fast start-up times achieved by the system. See also Fig. 15.

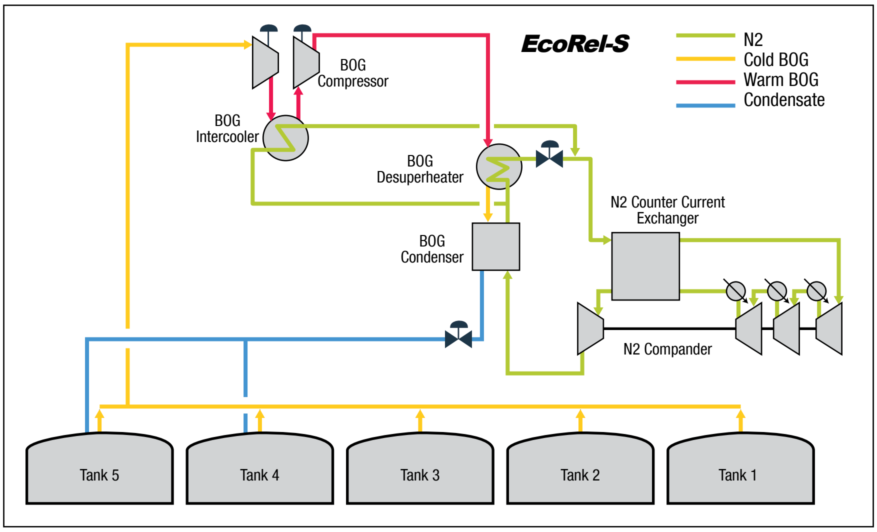


Fig. 15: Simplified process flow diagram

The high-pressure pump and vaporizer system

The skid-mounted HP pump is driven by either a gearbox or a simple belt-drive. The low-friction crank drive is connected to one or more pumping chambers where multiple seals ensure efficient pumping of the cryogenic liquid to these high-pressures. Pressures of over 400 bar are common for this pump design, see Fig. 16. The pumping chamber is vacuum insulated to reduce the heat inleak and promote constant priming. Vapour return lines allow simple return of any vapour to the supply vessel. Starting is simple, with protection interlocks to ensure safe operation. A wide flow range is possible by use of a variable speed drive and pressure is achieved promptly, allowing the system to easily follow engine load requirements.

Fig. 16: EcoRel–S high-pressure HP pump

A typical skid is fitted with three pumping chambers to smooth out the flow. In addition, a pulsation damper is fitted to avoid any issues with downstream pulsation in the fuel gas lines. Simple control loops are used to maintain a constant fuel gas pressure irrespective of the flow.

Integration of reliquefaction and fuel gas supply

Cryostar has designed a simple interface between the two systems to allow simple operation of the fuel gas supply, either by reliquefaction or independently if required. The liquid supply to the HP pump is from the flash drum where the condensate is separated after the BOG condenser. This vessel acts as a holding vessel, which allows condensate to be led to the engines or returned to the tank. In addition, if the reliquefaction plant is not operating, then liquid may be pumped from the cargo tanks to provide LNG for fuel. In this way, complete versatility is maintained.

The fuel gas supply system consists of the high-pressure liquid pump together with a vaporizer system to ensure that the gas enters the engines at an acceptable temperature, see Fig. 17.

Experience base

Cryostar has over 30 years of experience with reciprocating pumps, and the reference list comprises many thousands in daily operation worldwide. The vast majority of these cryogenic pumps operate in conjunction with vaporizers for high-pressure gas filling operations. This experience with the supply and control of high-pressure gas means that the technology is well established and suitable for this application.

In addition, Cryostar EcoRel reliquefaction plants were specified by Qatargas for the entire fleet of Q-Max vessels.

Special benefits

Below are listed special cases where HP pump and EcoRel reliquefaction plants offer significant benefits thanks to their ability to adequately handle surplus BOG without burning it in the GCU (gas combustion unit):

- Vessels likely to be laden and idle for any length of time (such as lying in wait before a Suez canal transit)
- Long periods of low speed operation
- Spot trading if cargo is to be maintained for extended periods
- Very long trading routes, where max. cargo delivery is paramount
- Either BOG or liquid fuel can be used whenever economically advantageous
- Thermal power consumption is lower for a combination of HP pump and EcoRel
- The system offers full fuel flexibility to use the cheapest fuel available – either gas or HFO.

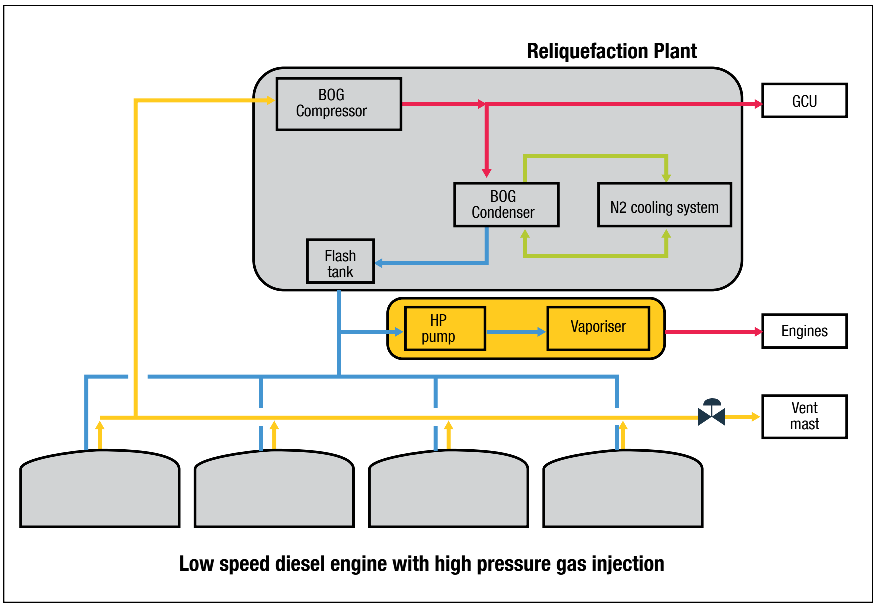


Fig. 17: Combined reliquefaction plant and HP LNP pump supply system delivering high pressure fuel gas to the ME-GI engine.

Cryostar system philosophy

Recent developments in LNG carrier propulsion and cargo handling include low speed diesel engines (burning HFO) linked to reliquefaction plants and, more recently, the direct gas injection engines (ME-GI), pioneered by MAN Diesel & Turbo. The ME-GI type engines require fuel gas supplied at a pressure of 300 bar.

Overall vessel configuration

The typical LNG carrier with ME-GI propulsion can be fitted with a reliquefaction plant to:

- control the tank pressure on short or long voyages
- control the tank pressure during idling if spot trading

The reliquefaction plant converts BOG into a liquid condensate, which can either be returned to the tank or consumed as fuel in gaseous form.

To be able to burn the condensate as fuel on an ME-GI engine, the pressure must be increased considerably, and the temperature must be controlled within a certain range.

A typical equipment arrangement is shown in Fig. 17. As it is more efficient to increase the pressure by use of a positive displacement pump, rather than vaporize the LNG and compress the gas in a multi-stage compressor, Cryostar proposes a high-pressure pump followed by a vaporizer to convert the liquid to a supercritical fluid suitable for injection into the engine. This system of liquid compression and vaporization has been used for decades in the industrial gas sector with colder and more volatile compounds than LNG. Typically, oxygen cylinders for oxy-acetylene cutting and medical gases are filled using identical technology. Thousands of operating references exist with Cryostar cryogenic pumps.

The application of this technology for fuel gas supply is not more stringent than any of these other uses.

Fuel gas pressure control

Suitable measures are required to keep the pressure within tight limits so as to avoid undesirable pulsation. As the pump is a reciprocating unit, there are unavoidable pulsations due to each delivery stroke. In order to smoothen (and almost eliminate) these pulsations, a damper is fitted to each pump skid to absorb these fluctuations. This, together with the gas volume downstream the vaporizer, results in almost negligible changes to the pressure in steady-state operations.

The pressure in the system is a function of the liquid flow at the pump discharge and the consumption by the engine/-s. Therefore, the primary pressure control is done by adjusting the pump speed to meet the consumption of the engines. Since the engine cannot operate with pressures below 150 bar, the initial fuel gas pressure should be attained before changing over to gas.

Because the pump is controlled by a variable frequency drive and the action of the pump is immediate, it will take very short time to pressurise the system by filling the downstream volume with fuel gas at the correct pressure. If this pressure is achieved and if engine consumption is low, excess fuel gas will be returned to the tank by a pressure control valve

The drawing in Fig. 18 shows the liquid feed from the flash drum of the reliquefaction plant. Surplus condensate is returned to the tanks and any shortfall of liquid can be made-up using an intermittent supply from the spray pumps to maintain the necessary buffer level in the flash drum.

System safety

Sequences already exist for the cool down, degassing and starting of the reciprocating pump. Likewise for shutdown, depressurisation sequences are also required. These can be automated, as is done on some land-based applications.

According to the pipework layout, purging sequences will be required before maintenance. These will be developed according to the actual installation.

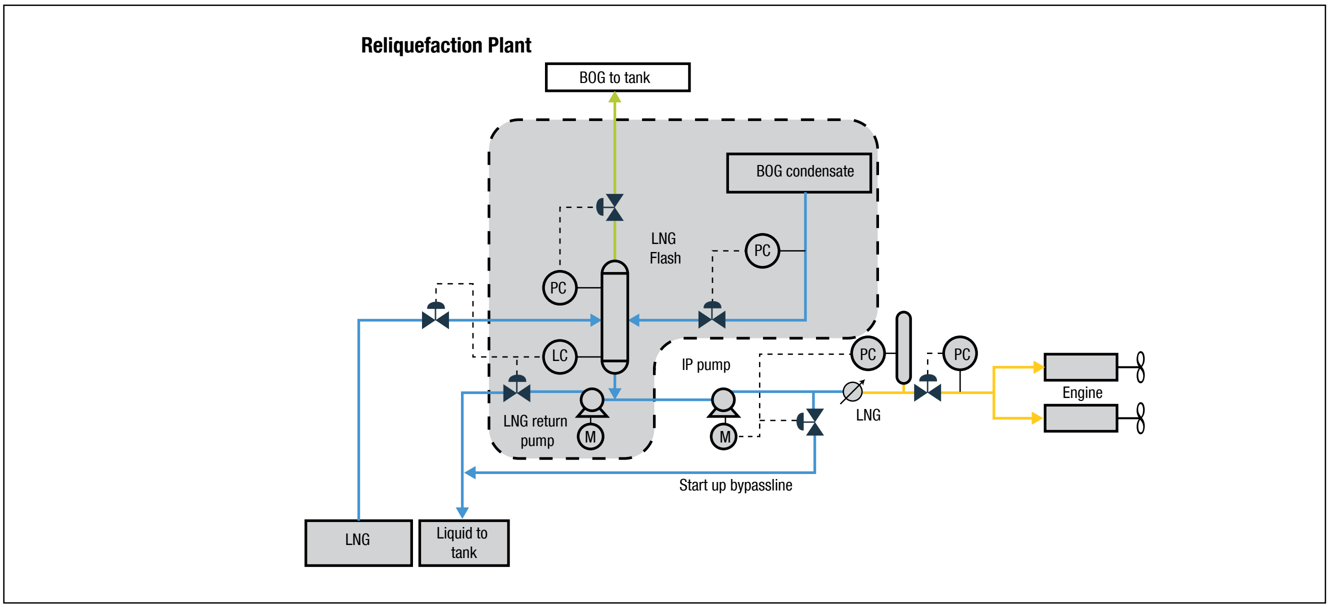


Fig. 18: Liquid feed from LNG flash drum

BOG Reliquefaction System from Hamworthy

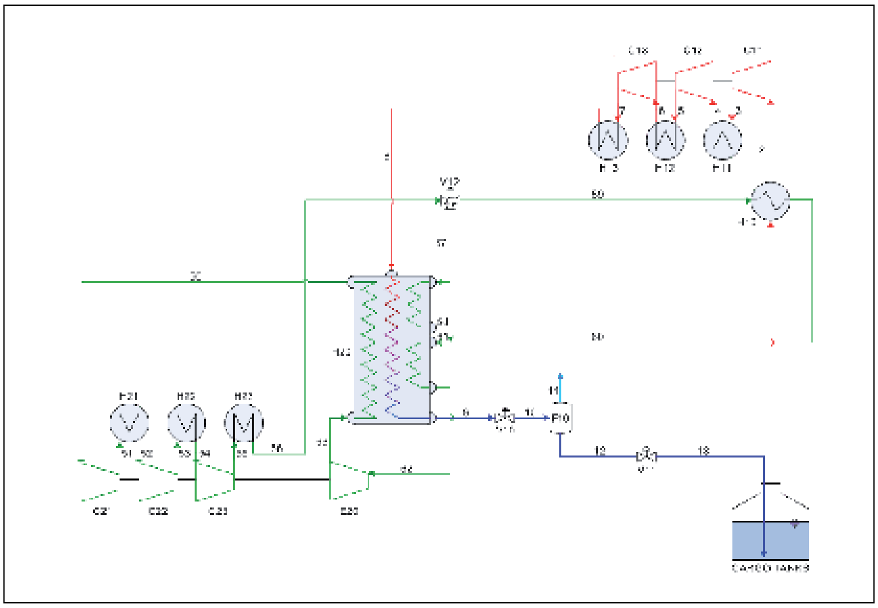


Fig. 19: Process description of LNG reliquefaction system (Mark III, 3rd generation)

In the Mark III version, the principle of the boil-off gas compression is different compared with previous generations of LNG reliquefaction systems. The boil-off gas (BOG) is evacuated from the LNG tanks by a three-stage centrifugal type BOG compressor with subsequent cooling after each stage, see Fig. 19.

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 because 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 aftercoolers. 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 preheater and ambient temperature BOG compression.

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

A special feature of the Hamworthy reliquefaction process is the fact 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 comprising a 3-stage centrifugal compressor and a single expander on a common gearbox.

After the third-stage cooler, the stream is split in two different streams. One stream is used to preheat the BOG in a separate heat exchanger (preheater), 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 Figs. 19 and 20.

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 vaporiser) to the temperature required. The high-pressure gas is then fed to the dual fuel engine, see Fig. 21.

The discharge pressure of the high-pressure pump is 300 bar at 100% engine load.

The system is based on an evaporation of LNG at high-pressure with heat

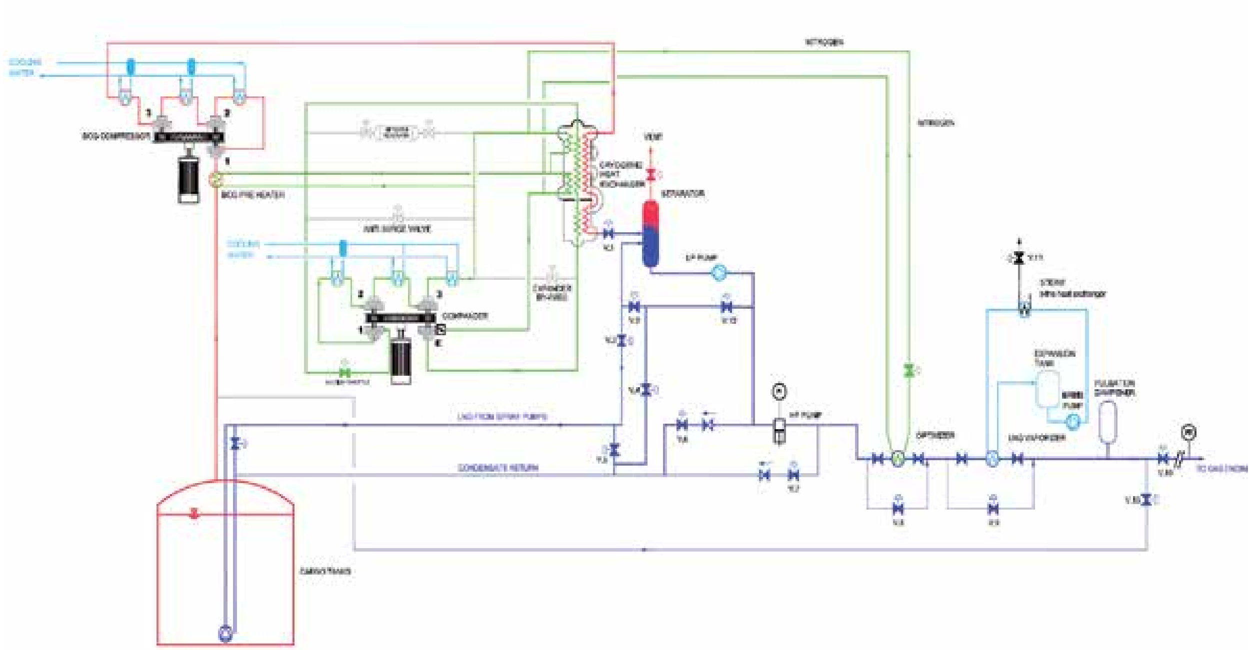


Fig. 20: Process integration between the LNG reliquefaction system and fuel gas supply system for dual fuel ME-GI engine

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 vaporiser. The intermediate media is a "brine" mixture. If process water from the BOG compressors or compander is considered, direct heating should be considered to reduce the energy loss in the system. In that case, the process water loop will be considered an intermediate loop.

In the LNG vaporiser, the cold duty is removed from the LNG while it is heated to engine requirement. The cold duty is removed by a heating source and is not utilised. For this reason, Hamworthy

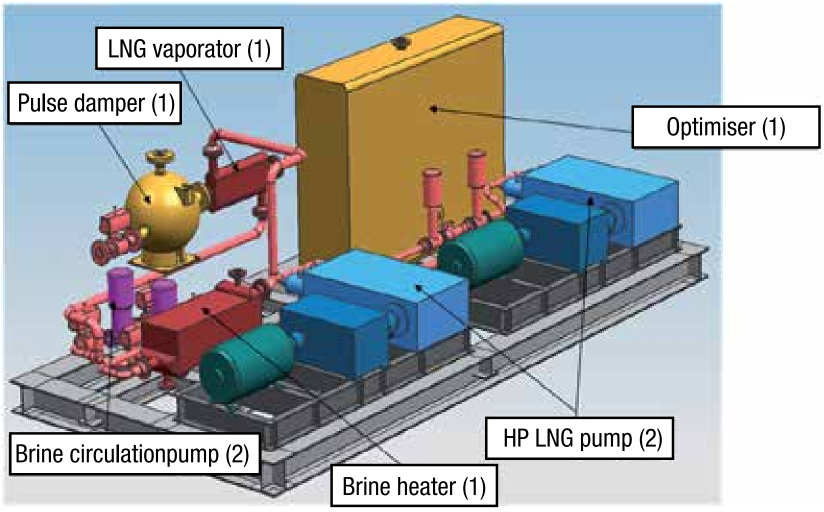


Fig. 21: High-pressure gas supply system from Hamworthy, including 2 x LNG pumps and a vaporiser (size 7 x 3 x 2 m)

has optimised the complete process of the BOG reliquefaction system and the gas supply system so as to reduce the overall power consumption.

The main objective is to utilise the cold duty taken out, before the LNG reaches the evaporator, and use it to cool the BOG reliquefaction system. This heat exchange is performed in a unit referred to as the optimiser, which operates in parallel to the cold box. This has the effect that part of the nitrogen, from the nitrogen cycle and at ambient condition, is cooled by heat exchanging with the pressurised LNG. This is all done in the optimiser. The nitrogen stream is cooled to about the inlet expander temperature, and is mixed with nitrogen from the cold box.

The optimiser can only be in operation when the BOG reliquefaction system is working and the engine is being fuelled with LNG. If the reliquefaction system is stopped or the optimiser is not heating the LNG sufficiently, the standalone vaporisation system will heat the gas sufficiently before it enters the engine.

By installing the gas supply system in the cargo compressor room together with the BOG reliquefaction plant, a very compact installation is achieved.

Laby®-GI Compressor from Burckhardt Compression

Combined with a compressor gas supply system, The ME-GI propulsion engine will utilise the BOG (boil-off gas) coming from the ship storage tanks. 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 & Turbo.

Design concept

Various design options have been evaluated during the last four years of compressor and system development. 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. Thereby, the diesel engines themselves will consume 50% each of the compressed gas. The main compressor will be operating continuously to ensure full redundancy and the second unit can be started manually in case of a malfunction. We will focus on this design in the following description. Other design options are explained in a later chapter.

There are many parameters influencing the design of an efficient fuel gas supply system. For example, the total amount of BOG is highly dependent on the ship operation cycle (laden or ballast voyage) and the tank pressure level. This may result in extreme operating conditions for the fuel gas compressor, from ultra cold to warm start-up temperatures. Other factors can be the gas composition, handling of forced or natural BOG (fBOG or nBOG), the simultaneous delivery of low-pressure gas to the gas combustion unit (GCU), dual fuel gensets, parallel reliquefaction of BOG and many more.

Laby®-GI key components

Handling of cryogenic natural gas with suction temperatures below –160°C in the pressure range of 10 to 50 barg (1.0 to 5.0 MPa g) is a common application in many on- and offshore LNG or LPG facilities worldwide. With its unique labyrinth sealing technology, the Laby-GI compressor design has demonstrated a performance that is second to none in this field.

The Laby-GI fuel gas compressor is designed for the same low suction temperatures as the Laby-GI. The only difference is the extension of the pressure range up to 300 bar. Therefore, the three oil-free labyrinth-sealed, low-pressure stages are complemented with two stages of piston ring sealing systems, comparable to the proven API 618 design. All five stages are combined in a vertical crank gear and form the six-crank Laby-GI fuel gas compressor. As a result of mass balancing, the compressor will be free from vibrations and moments, see Fig. 22.

The optimised piston sealing technology – a combination of labyrinth sealing and piston ring sealing of the five-stage compressor, results in ultralong lifetime of the sealing elements. Careful thermal design and material selection means that it is not necessary to precool the compressor or to heat the gas prior to startup. The combination of a rugged design and well-proven equipment ensures the longest mean time between overhaul (MTBO) for this and related applications.

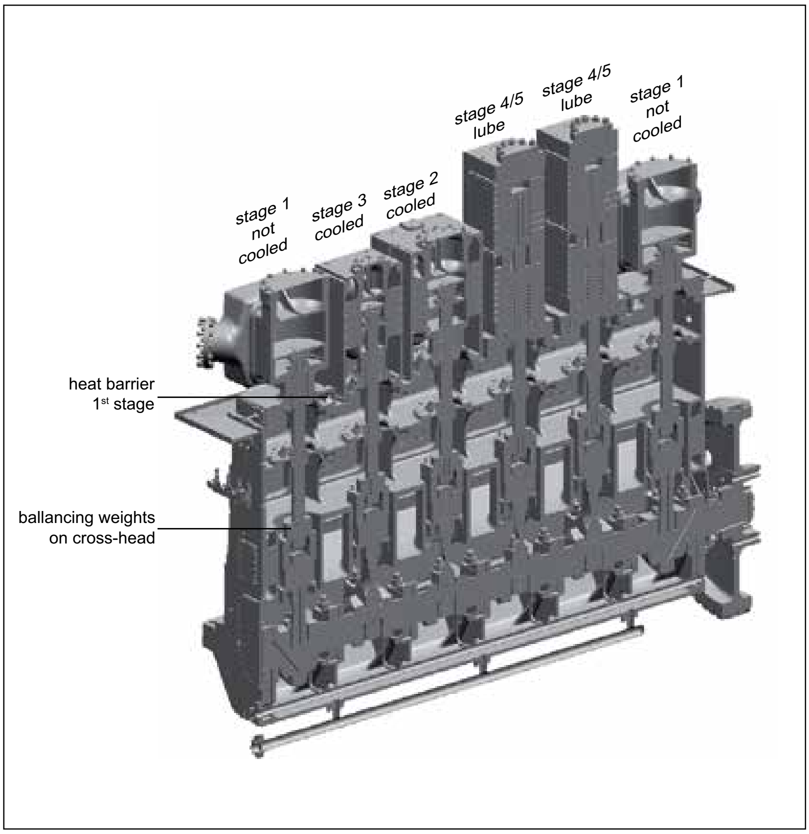
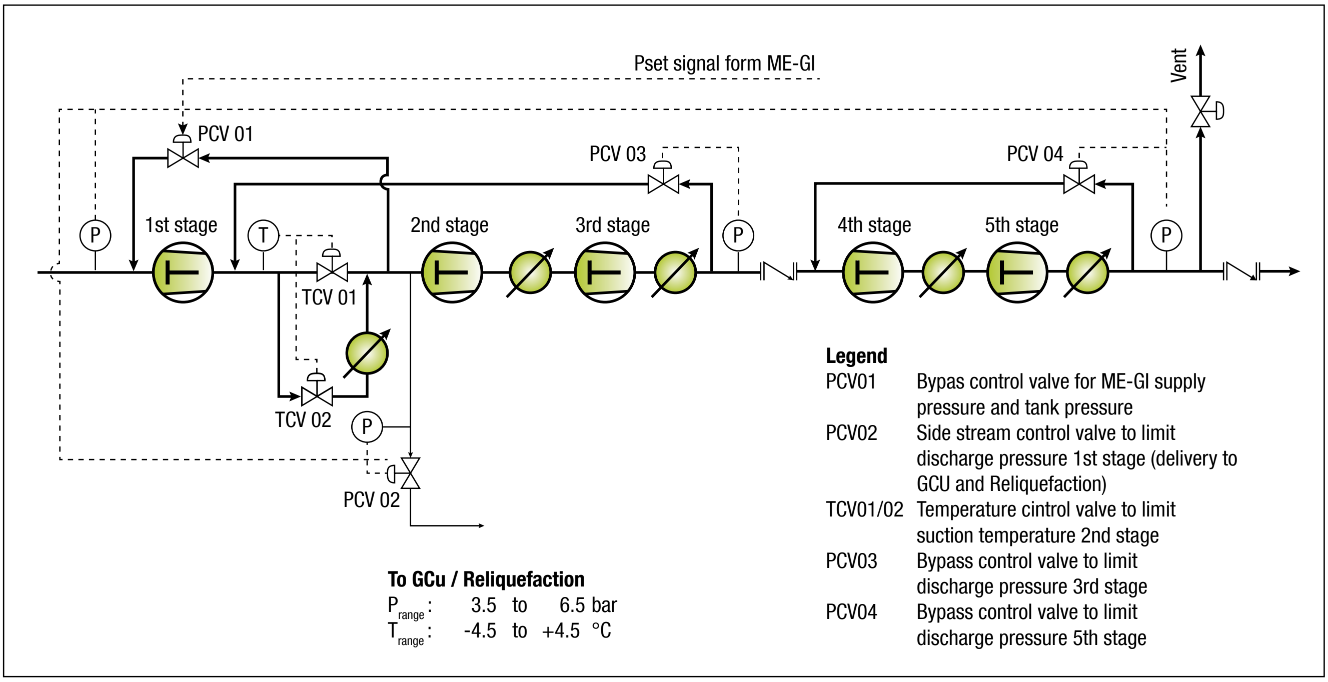


Fig. 22: Compressor cross-section

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 stresses and pulsation and vibration issues of the compressor and its related equipment, e.g. gas piping, pulsation vessels, gas coolers, etc.

Each compressor stage is followed by an intercooler to fully control the inlet temperature of the following stage. Fig. 23 shows a simplified P&I diagram of the compressor. Bypass valves are provided over stage one, stages two and three, and stages four and five. These valves regulate the flow in the compressor according to the engine set pressure within the defined system limits. The entire plant layout is designed according to a zero-vent philosophy. Any BOG in the compressor will be led fully controlled back to the cargo containment system.



To GCu / Reliquefaction

P_{range}: 3.5 to 6.5 bar

T_{range}: -4.5 to +4.5 °C

Legend

PCV01	Bypas control valve for ME-GI supply pressure and tank pressure
PCV02	Side stream control valve to limit discharge pressure 1st stage (delivery to GCU and Reliquefaction)
TCV01/02	Temperature cintrol valve to limit suction temperature 2nd stage
PCV03	Bypass control valve to limit discharge pressure 3rd stage
PCV04	Bypass control valve to limit discharge pressure 5th stage

Fig. 23: Simplified P&F compressor diagram

Compressor safety

Safety relief valves are provided at the discharge of each compression stage to protect the cylinders and gas system against overpressure. Stage differential relief valves, where applicable, are installed to prevent compressor excessive loading.

Pressure and temperature instrumentation for each stage is provided to ensure adequate system monitoring alarm and shutdown. Emergency procedures allow a safe shutdown, isolation and venting of the compressor gas system.

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

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 be able to adequately handle the gas supply variables, such as tank pressure, BOG rate (laden and ballast voyage), gas composition and gas suction temperature.

If the amount of nBOG decreases, the compressor must be operated at part load to ensure a stable tank pressure, or fBOG must be added to the gas supply. If the amount of nBOG increases, resulting in a higher-than-acceptable tank pressure, the control system must act to send excess gas to the gas combustion unit (GCU).

The main control variable for compressor operation is the feed pressure to the ME-GI engine, which may be subject to controlled or instantaneous change. An adequate control system must be able to handle such events as part of the "normal" operating procedure. The required gas delivery pressure varies between 150 and 300 bar, depending on the engine load. The compressor must also be able to operate continuously in full recycle mode with 100% of the delivered gas returned to the suction side of the compressor.

Power saving mode

Economic regulation of a multi-stage compressor is most efficiently executed using a 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 0 to 100%, see Fig. 24.

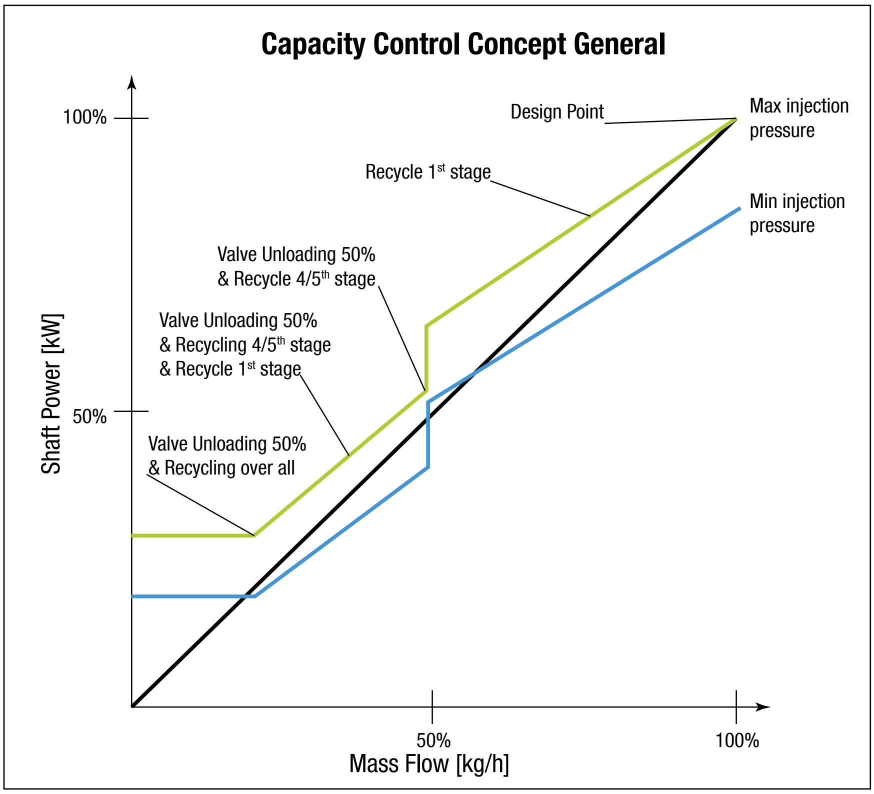


Fig. 24: Capacity control concept

Simulation and test

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

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 Mark III reliquefaction system from Hamworthy Gas Systems (see Fig. 25). The Laby-GI compressor will substitute the normal BOG low-duty compressor upstream the Mark III system. After the first or second stage, at 56 bar, the gas can be partly – or fully – diverted to the reliquefaction system. When the ME-GI engine is running in gas mode, the compressor sends the BOG directly to the engine, thereby bypassing the reliquefaction system. Bypassing of the reliquefaction system can be necessary when operating in ballast condition and the BOG amount is insufficient for fuelling the ME-GI engine.

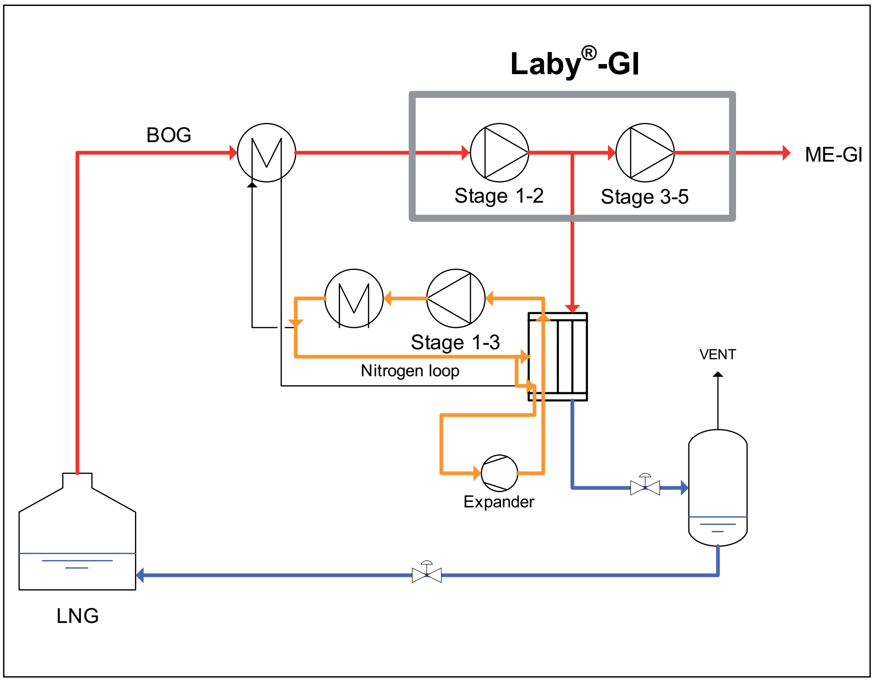


Fig. 25: Integrated compressor and reliquefaction system

TGE's Cascade Reliquefaction System

TGE's cascade type reliquefaction system for LNG BOG on LNG carriers has been developed in cooperation with MAN Diesel & Turbo and Burckhardt with focus on high efficiency and, thereby, low operating costs. The goal is to reliquefy the excess BOG that is not used for propulsion, especially during times of low fuel consumption. Fig. 26 compares the following three system configurations:

- the existing plants with full reliquefaction and a high-pressure pump fuel gas system
- excess gas reliquefaction with a nitrogen cycle
- excess gas reliquefaction combined with the cascade technology.

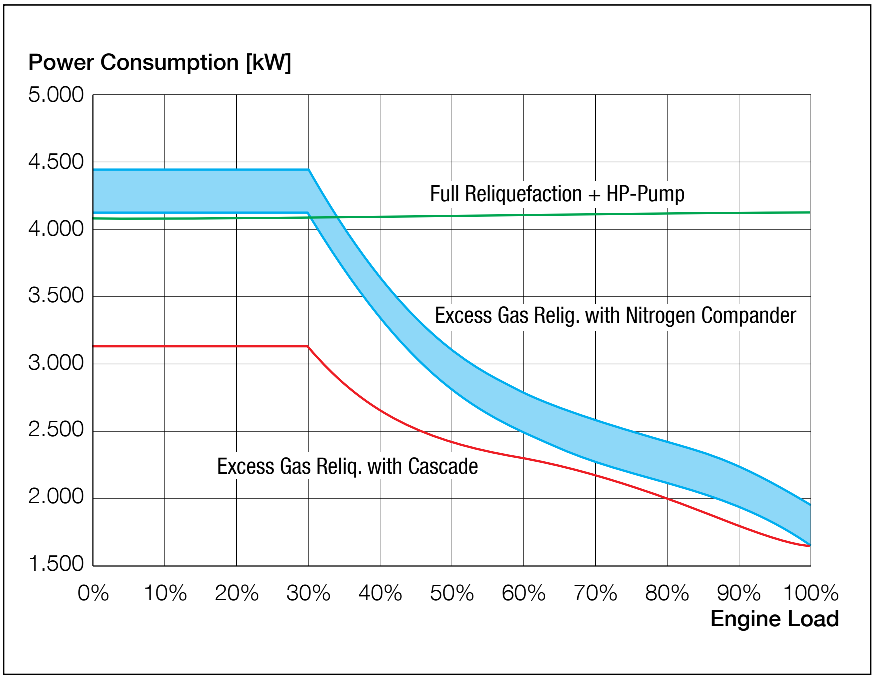


Fig. 26: Comparison between existing plants using full reliquefaction with high-pressure pump fuel gas system, excess gas reliquefaction with a nitrogen cycle, or excess gas reliquefaction by way of the cascade technology.

As described in the previous chapter, the cascade technology is based on two refrigerant cycles. The BOG is liquefied against ethylene, which in turn is liquefied against propylene.

A unique design feature of the system is the integration of the ethylene compression into the BOG compressor. The first and the second stages are used for refrigerant (ethylene) compression, making use of the existing compressor stages.

The energy efficient mass flow control concept of the Laby®-GI has been adapted to the combined duty of ethylene and BOG compression. The balanced frame design guarantees the possibility to operate the compressor in the flow range 0-100%, with any suction condition and supply pressure to consumers. The excellent capacity control of the screw compressors adds further comfort to the operability of the system.

The use of a cold box, combining all streams of the cascade cycle, ensures a high efficiency and a compact design.

The main advantages of a cascade liquefaction system are:

- High efficiency of refrigerant due to phase transition
- High liquefaction pressure
- BOG and ethylene compression in one compressor
- Standard oil injected screw compressors for the propylene cycle.

The use of oil-lubricated screw compressors is part of the philosophy to use proven components to the benefit of the owner and operator. Being the world market leader in the supply of cargo plants for ethylene carriers, TGE has vast experience and know-how in the design and application of cascade reliquefaction systems, which have been a standard technology on such carriers for decades, see Fig. 27. It has been a logical step to upgrade this technology for excess BOG reliquefaction of large LNG carriers and provide an efficient and reliable solution.

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 the engine demand in combination with alternative reliquefaction solutions, can easily be integrated into the Laby-GI design. This compressor is therefore the most adaptable solution for the ME-GI propulsion system when it comes to fuel flexibility.

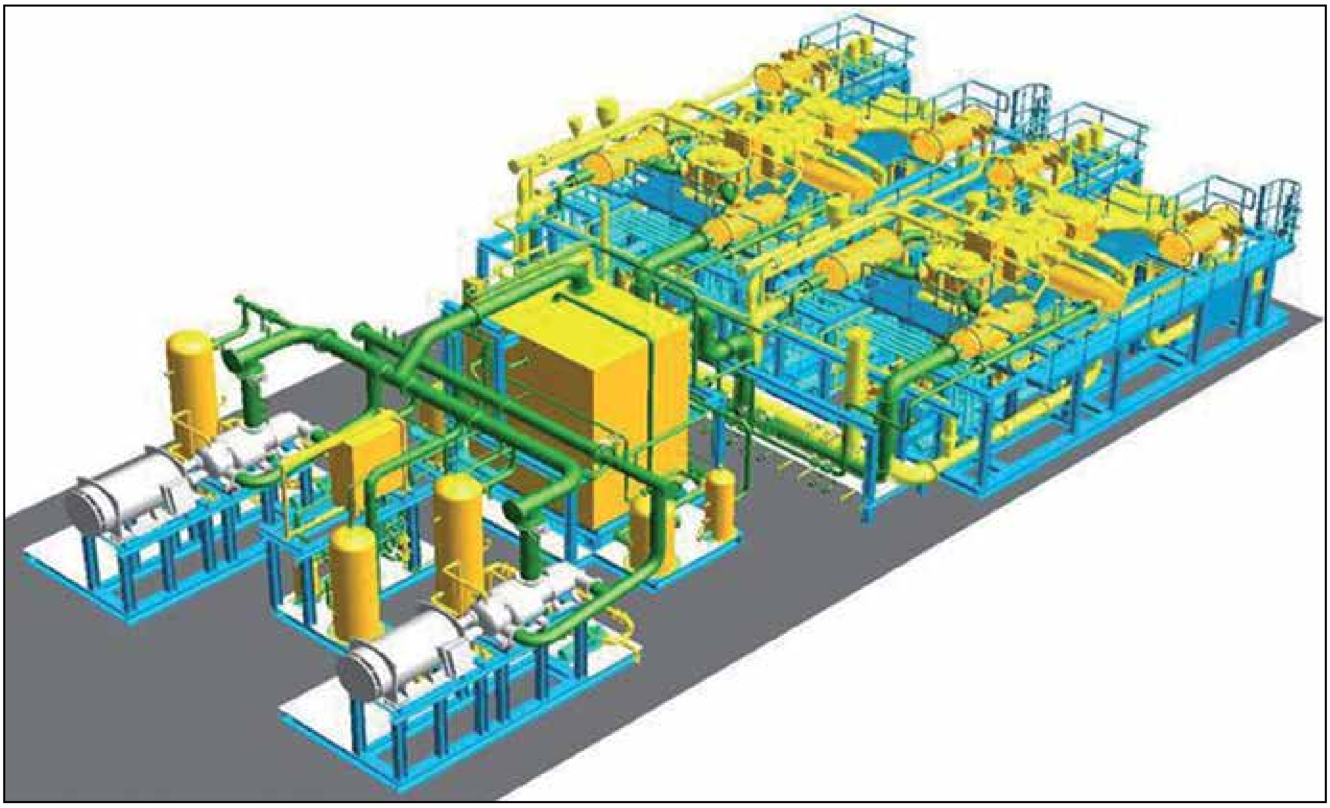


Fig. 27: Cascade reliquefaction plant for LNG carriers developed by TGE and Burckhardt Compression.

High reliability and low maintenance costs add to keep 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 complete system is inhouse engineered and customised to fit the MAN Diesel & Turbo ME-GI propulsion system. It is also the only gastight design on the market that can avoid gas losses and pollution. The possibility to retrofit the Laby®-GI as a fully skid-mounted unit (see Fig. 24) makes the system very interesting not only to newbuilt carriers, but also for the existing fleet. The first Laby-GI compressor was installed on a floating storage and regasification unit (FSRU) in 2009.

ME-GI for Container Ships, Tankers and Bulk Carriers

In recent years, we have seen an increase in fuel prices, and especially in the US we see a situation where it is economically feasible to fuel a merchant vessel with LNG instead of conventional HFO. If the propulsion power of the vessel is delivered by an ME or ME-C type engine, then it is also possible to convert it to run on gas.

A number of studies have already been made by all the major yards and classification societies, and gas fuel designs therefore exist for almost all types of ships. Basically, the space required for the LNG tanks is almost 2.5-3 times the size of an HFO tank system due to the lower LNG density and the heavy insulation required to keep the LNG cold.

The GI engine requires pressurised gas at a max. pressure of 300 bar. The technology to pressurise the LNG and evaporate it at this high pressure is available, and solutions have been developed by HGS, TGE, DSME, Cryostar, HHI and now also MHI.

Common for these system is that they comprise the following:

- Reciprocating LNG pump to generate the high pressure.
- Automatic pump control system to control the pressure according to the engine delivery pressure.
- Heat exchanger to heat LNG according to required engine temperature.
- Buffer volume to dampen out pulstions from the pressure generation.

As an example, the gas supply system utilises a Cryostar LNG pump fed by the LNG fuel 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.

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 to dampen 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, also called the HP vaporizer, requires a heat source to vaporise the LNG, and this can be taken as hot water directly from the cooling system of the ME-GI. Alternatively, steam can be used to heat the LNG. It is also possible incorporate an intermediate heating loop using either brine or glycol water if requested.

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

Concluding Remarks

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

Several fuel gas supply systems are available and have now also been tested and are on order. The first 70-bore ME-GI will go into service in June 2015, and several more will follow soon after. For newbuild LNG carriers, the boil-off rate has been lowered from 0.15%/day to 0.08%/day by increasing the insulation layer on the LNG cargo tanks. This has resulted in that excessive BOG are gone when the two-stroke ME-GI engine is operating at normal ship speed. This makes the basic Laby-GI compressor solution very economically attractive for owners considering use of only gas as fuel on their LNG carriers.

Thus, for LNG carrier owners interested in full fuel flexibility, a gas supply system combined with a full reliquefaction plant is recommended.

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. Therefore, in some parts of the world, e.g. Stockholm and the port of Zeebrygge, LNG is already available. However, the US seems to be showing the way by ordering a large number of gas fuel container ships.

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