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Study of New Generation LNG Duel Fuel Marine Propulsion Green Technologies

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ABSTRACT: Nowadays, most merchant vessels use Heavy Fuel Oils (HFOs) for the ship propulsion. These fuels are cost effective but they produce significant amounts of noxious emissions. To comply with IMO & MARPOL environmental regulations, Liquefied Natural Gas (LNG) is becoming an interesting option for the merchant ships. The purpose and scope of this paper is to describe the factors to consider when determining LNG & duel fuel new generation marine propulsion technologies implemented in the shipping industry to promote green ships concept and change the view of sea transportation to a more ecological and environment-friendly system. The aim of the research presented in this paper is to analyse the economic upturn that can result from the use of LNG as fuel for merchant ships and to assess the effects of its utilization in terms of environmental impact.

1 INTRODUCTION

When studying, professional publications concerning LNG marine propulsion green ships technology (i.e. [1], [3], [6], [10]) and after analysing some environmental aspects regarding marine transport efficiency ([2], [4]) we can draw the following conclusions:

- Currently we have wide range of modern marine green ships technologies available on the market used to enhance performance and sustainability for oceangoing vessels. These technologies range from simple with low capability such as traditional sails or small scale renewables wind power plants or solar modules to very capable and highly complex systems such as hybrid diesel-electric, waste heat recovery, variable speed generators or LNG & dual fuel power plants.
- Today, most merchant ships are using Heavy Fuel Oil (HFO), Marine Gas Oil (MGO) or Marine Diesel Oil (MDO) as a main fuel for ship propulsion system. These fuels are cost effective but unfortunately they produce significant amounts of noxious emissions such as CO2, NOX, SOX & PM (Particulates Matter). The largest amount of noxious emissions is observed especially in the costal and harbour areas where the marine traffic density is also much higher compare with traffic density observed at open ocean [2], [6].
- On the other hand, it must be also noted that the sea transportation is one of the most environment-friendly means when we compare transporting the same cargo on the same distance by using different means of transportation such as rail, road and marine [2].
- To comply with IMO and MARPOL environmental regulations, Liquefied Natural Gas (LNG) is becoming an interesting option for shipping industry. The use of LNG as fuel allows reducing emissions, complying emissions rules and reducing operating cost [6]. Several energy

recovery solutions have been considered on a LNG tanker [3] to improve efficiency (+15%) and reduce costs (−20%). Some economic incentives have been shown also to be advantageous to running an LNG propulsion system on other ships than LNG tankers. The best candidates for LNG use are small and medium product tankers, LNG & LPG carriers, cruise vessels, ferries, offshore vessels, roll on roll off, feeder containers and tugboats [6], [10].

- Since it is established that LNG for ship propulsion reduces CO2 and other pollutants compared to common heavy fuel oils, LNG implementation depends on the following key factors: gas availability, demand for ships, emission limits in ECA (emission controlled areas), LNG tank installation and safety requirements.
- Another challenge is hazards associated with the LNG being stored at very low temperatures. Insulation of the tank is critical, and structural brittleness and personnel frostbite injuries are very likely to happen. In additions, the challenges such as the lack of infrastructure in most commercial ports, crew's limited experience running engines with gas fuels, the future price of gas, the required safety measures etc. There are all critical points to be considered when we want to use LNG in shipping industry.
- Regarding natural gas, it must be also noted that there is an environmental issue called methane slip. Methane slip happens when gas leaks unburned through the engine. Methane has a GWP100 (100-year global warming potential), which is 25x higher than CO2. If the methane slip isn't controlled, environmental benefits to using natural gas are reduced [6].

The purpose and scope of this paper is to describe factors to consider when determining LNG & duel fuel new generation marine propulsion technologies implemented in shipping industry to promote green ships concept and change the view of sea transportation to more ecological and environmental friendly system. The aim of the research presented in this paper is to analyse the economic upturn that can result from the use of LNG as fuel for merchant ships and to assess the effects of its utilization in terms of safety issues and environmental impact.

2 MARINE LNG DUEL FUEL ENGINE

A marine LNG (Liquefied Natural Gas) engine is a dual fuel engine that uses natural gas (NG) and liquid bunker fuel (HFO, MGO, MDO) to convert chemical energy into mechanical energy.

The advantage of transporting LNG is clear: a defined volume of LNG contains approximately 600 times more energy than the same volume of natural gas (NG). The natural gas NG that fuels dual fuel engines is carried on ships as a boiling liquid, and transported at slightly higher than atmospheric pressure in heavily insulated tanks to keep the LNG in liquid state at around -160 °C where from the boil-off gas (BOG) is routed to and burned in dual fuel engines. When tank insulation is penetrated by any influx in heat, it will cause the temperature of the liquefied natural gas to rise, which allows for vaporization from liquid to gas. When heat penetrates the tank, the tank's pressure increases due to boil-off gas (BOG) effect.

The insulation of the tanks is designed with the most advanced technology. However even now, on LNG carrier the insulation of the tanks is still penetrated by heat and the boil-off process occurs during the ships voyages. During a storm for the example, the LNG cargo moves and sloshes around in the tanks. The boil-off gas represents 0.1% to 0.25% of the ships capacity per day. Tanks need to be maintained at a steady pressure. If the pressure in tanks is not controlled relief or safety valves are forced to open, venting the boil-off into the atmosphere until pressure is relieved. At this point, it has been proven that on-board LNG reliquefication is uneconomical for most ships ([3], [6]). Instead, the gas produced by this boil-off effect is routed to the ship's propulsion system and used as fuel for power plants such as steam boilers or i.e. dual fuel marine diesel engines ([5], [8], [10]). This reduces the use of bunker fuel, reducing fuel costs and equipment maintenance costs. In addition, when natural gas cleaner burning properties are compared to HFO, MDO or MGO burning properties, the use of LNG technology in the shipping industry is becoming an interesting option to comply with IMO and MARPOL international rules & regulations [6], [10].

Nowadays in shipping industry we can find wide range of different propulsion system such as dual-fuel steam turbine mechanical (DFSM), dual-fuel diesel electric (DFDE), dual-fuel gas turbine electric (DFGE), dual-fuel diesel mechanical (DFDM) or i.e. diesel mechanical propulsion with reliquefication (SFDM+R) ([4], [5], [6], [10]).

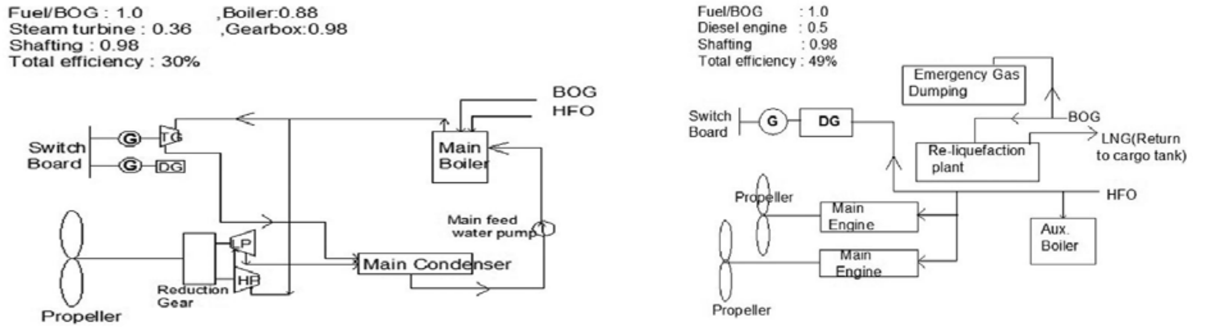

Figure 1. Comparison of steam plant (on the left) with slow speed diesel engine with a re-liquefaction plant (on the right) as example of typical propulsion plant used on LNG carrier of 150,000m3. Source: adapted from [4]. Nov.2016.

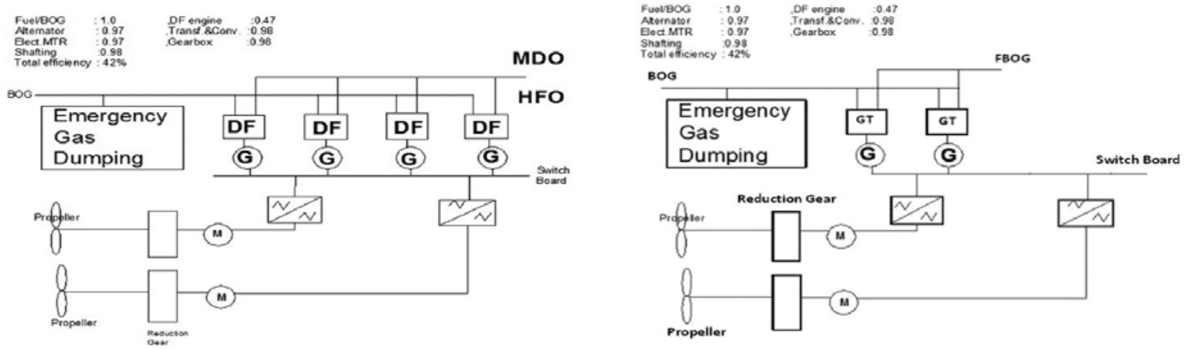

Figure 2. Comparison of dual fuel diesel engine plant (on the left) with advanced cycle marine gas turbine (on the right) as example of propulsion plant for LNG carriers. Source: adapted from [4]. Nov.2016.

Today steam turbine (ST) installation has dominated in LNG shipping so far. This is because it can easily handle the evaporated BOG, in addition to its high reliability and maintainability. Although, this installation has successfully met market requirements, the total plant efficiency is very low (based on [4] it has been calculated and found to be 30%), which led to high running costs. Another disadvantage of ST is the shortage of qualified crew and low system redundancy.

Another solution is slow speed diesel engine, which has been dominated the propulsion and electric power generation in all segments of merchant shipping, except LNG carriers. Experience gained from thousands of diesel engine installations in service [6] has resulted in the development of high efficiency (about 50%), reliable and safe operation. It commonly burns liquid fuel as HFO. However, BOG in such case must be re-liquefied onboard by re-liquefaction plant and fed back to the cargo tank. In case of re-liquefaction plant failure, a gas combustion unit (GCU) must be also installed. These re-liquefaction plants require a substantial amount of electric power (≈3600 kW) to operate, representing a considerable added cost for installation (based on [4] it can be about 6 million US$ extra cost) and weight. However, this installation can give us opportunity to deliver more cargo to LNG terminal due to saving the BOG.

Another solution is to use dual fuel power plant, which can work as mechanical or electrical drive. Using electric drive arrangement, the engines can be installed on a higher deck and hence, a great reduction in engine room could be provided. The dual fuel engines utilize natural boil-off gas (N-BOG) in addition to the MDO for their pilot injection. In case of no NG available the engine will burn HFO, MDO or MGO. The main disadvantage of this system is the slightly higher cost for alternators and transformers, the low thermal efficiency of the plant, (based on [4] the calculated efficiency was reduced to 42%) and the incompatibility of lube oil when shifting between gas and liquid mode.

Another feasible alternative option for LNG carriers is gas turbine propulsion systems presented on Figure 2 on the right [2]. The advanced marine gas turbine cycle suggested i.e. by Daewoo Shipbuilding & Marine Engineering (DSME) and Gaztransport & Technigaz (GTT) is employed in two gas turbine/electric generators in father and son arrangement. The larger generator is based on the converted simple cycle and provides all power needed for sea going service. The small unit provides power of 5000 kW, for cargo pumping and port duty. Additionally, the small unit provides get-home service in case of non-availability of the large unit. The primary fuel used for gas turbines is natural boil-off gas (N-BOG) and forced boil-off gas (F-BOG). Marine diesel oil (MDO) is carried only to provide an emergency secondary fuel source to/from dry dock when gas is not available. The suggested plant efficiency has been calculated by [4] and recognized as approximately 40%.

Nowadays commercial ship propulsion system manufacturers such as Finland's Wärtsilä [10], Germany's MAN Diesel & Turbo [5] or Siemens [9], Japan's Mitsubishi [7] or British's Roll Royce [8], produce large bore dual-fuel diesel engines that comply with all modern emission legislation when sailing in environmentally sensitive areas and which meet the strict safety requirements that LNG carriers operate under. All above manufacturers can deliver LNG systems for propulsion and power generation for any applicable types of ship or engine [6].

Whether newbuilt or retrofitted, LNG ships are clearly the way of the future. Per MAN Diesel & Turbo [5] website's subfolder dated December 2014 the MAN B&W Dual Fuel Engines starting a new era in shipping industry having a total of 116 ordered LNG engine projects. On top of this, more and more new-buildings has been constructed as LNG-ready, which means that they can relatively easy be retrofitted with dual fuel engines at a later point. The MAN B&W ME-GI Engines [5] offer extremely flexible fuel modes that range from 95% natural gas to 100% HFO and anywhere in between. A minimum of 5% HFO for pilot oil is required as these are compression ignition engines and natural gas is not self-combustible.

Wärtsilä [10] is also recognized as a leader in propulsion solutions for gas fuelled vessels, and has led the way in developing a complete value chain of systems, solutions and bunkering arrangements, both on-board and shore-based, to accelerate the use of environmentally sustainable and economically competitive LNG fuel. Since 2000, Wärtsilä engines have been selected for more than 200 LNG fuelled vessels either in operation or under construction. In addition, at the end of 2014, Wärtsilä had performed 14 LNGPac installations and the oldest of which had been operating successfully for more than three years without any problem [10].

The LNGPac system has been specified with various types of ships. These include product tankers, cruise vessels, offshore vessels, roll and roll off, feeder container vessels, LPG and ethylene carriers and, obviously, ferries, such as the 'Viking Grace' operating between Turku, Finland and Stockholm, Sweden [10]. This is the largest passenger vessel in the world today equipped with two 200 m3 Wärtsilä LNGPacs, including a Wärtsilä patented system utilising the latent heat from the LNG evaporation process for the vessel's heating, ventilation and air conditioning system (HVAC). In the new cold recovery system Wärtsilä can directly connect the ship's HVAC (or other refrigeration systems) to the tank connection space and thus remove a complete heating media circuit consisting of heat exchangers, valves and pumps. This system provides significant energy savings for the whole ship by increasing its total efficiency.

There is also possibility of improving energy efficiency on board by considering that combustion gases, produced by LNG, are cleaner, thus simplifying the introduction of exhaust gas heat recovery: simple heat recovery and heat recovery to drive a turbine (ORC). The results show (based on [10]) that it is possible to achieve a reduction in fuel consumption of up to 15%.

In addition, when certain systems such as waste heat recovery WHR [5], [9] (using waste heat to do work rather than dissipate) are added to the power plant, significant savings can be observed. One study [3] shows that an LNG engine with a WHR system saves money compared to a diesel engine with WHR. There is a higher initial investment cost but it is a cost-efficient method and environmentally sound one [6].

The Wärtsilä LNGPac system is based on IMO type C LNG storage tank with design pressure 6-9 bar and either double walled vacuum or single walled polyurethane insulation. Bunkering takes place from the bunkering station to the LNG tank via an insulated pipe. All necessary process equipment, the heating media skid, and the control and monitoring system are installed in a separate unit which can be either mounted directly to the LNG tank or placed remotely from the LNG tank. The main process equipment ensures correct gas temperature and pressure for the engines and other gas consumers. The LNGPac system can be customised to the needs of each project on a case to case basis. Dedicated engineering is conducted from the beginning of the project to match the specific operational requirements, safety and classification society requirements. The LNG fuel system can be offered as a standalone product, as well as a part of a complete propulsion system [10]. By upgrading the system into a more compact and technically advanced version, safety and reliability will be enhanced, while the capital and operating expenditures (CAPEX & OPEX) will be reduced. The new system has fewer moving parts and therefore less maintenance is required. Furthermore, the compact design and increased integration of components makes installation at the shipyard faster and easier [10].

The Wärtsilä gas valve unit (GVU) is a module located between the LNG storage system and the dual-fuel (DF) engine. It is used to regulate the gas pressure and ensure a safe disconnect of the gas system should that be necessary. By combining the LNGPac and the GVU into a single, fully integrated system, considerable space can be saved and a relatively simple 'plug and play' solution will save installation time and costs for the yard.

In addition, the airlock and control cabinet has been integrated into the tank connection space. This innovation results in a dramatic reduction of interfaces since the amount of electrical cabling from the tank connection space to the external switchboards can be significantly reduced.

Development of the LNGPac is the result of Wärtsilä's extensive experience and technical leadership in gas propulsion, as well as its comprehensive in-house know-how concerning all aspects of the vessel's machinery, fuel gas handling system, and ship design. By removing the intermediate heating media skid and its pumps, and by directly utilising the engine's cooling water, less interfaces and installation work is required. With less electrical consumers they are making the ship even more environmentally friendly.

Unfortunately, even now, in the marine industry liquefied natural gas (LNG) as a fuel is still sometimes mentioned as a novel technology although platform supply vessels have long been using it. The 'Viking Energy' for the example (IMO 9258442, Length overall 94.90 m, breath 20.4 m, tonnage 5073 GT) was the first new generation PSV LNG-powered vessel, built in Norway in 2003 by Kleven Verft AS for Eidesvik Shipping AS consolidated group as DP class ship for delivering supplies to oil and gas platforms in the North Sea [8]. The 'Viking Energy' was fitted with four 6-cylinder Wärtsilä 32DF dual-fuel engines, each with an output of 2010 kW at 720 rpm, driving the main generating sets. The engines run on liquefied natural gas (LNG) to reduce NOx emissions, but can also run on diesel oil as a backup fuel. This adds fuel flexibility into the mix. The switch between fuels is conducted automatically, without any loss of power.

When running in gas mode, which is the normal operational mode, the Viking Energy's emissions of nitrogen oxides (NOX) are 85% lower than in diesel operation. The dramatic reduction is possible because the Wärtsilä engines operate on the lean burn principle: the mixture of air and gas in the cylinder contains more air than is needed for complete combustion. Lean combustion reduces peak temperatures, so the formation of NOx drops a great deal. Sulphur oxide (SOX) emissions are eliminated because LNG contains no Sulphur. And since natural gas contains less carbon per unit of energy than liquid fuels, emissions of CO2 are also lowered by approximately 30%. Natural gas has no residuals, and the production of particulates is practically zero. Clean combustion has also a positive impact on maintenance of the engine cylinder liners/covers. The maintenance interval can be longer than for liquid fuel operation [6], [10].

In gas mode, Wärtsilä medium-speed DF engines are already compliant with the IMO's Tier III regulations without the need of any secondary exhaust gas purification systems. Furthermore, in liquid fuel oil mode, all Wärtsilä DF engines are fully compliant with the IMO's Tier II exhaust emission regulations set out in Annex VI of the MARPOL 73/78 convention.

The engines perform very well on gas during DP (Dynamic Positioning) operations and severe weather conditions in the North Sea. Diesel mode is only required during LNG refuelling or certain minor preventive maintenance operations. Another strength of the 'Viking Energy' is how smoothly she runs for a completely new system. In 13 years of operation not a single hour of technical off-hire has been caused by the gas system [10].

Looking back at the first LNG decade for shipping industry, one thing that has greatly improved is managing methane slip. In 2003, when the 'Viking Energy' was launched, methane slip was not yet on the agenda. Created by gas engines that allow a small fraction of the fuel to go through unburned, methane slip is a grave concern. Unfortunately, the problem of methane slip is present in all Otto-cycle engines, both dual fuel and spark-ignited. To combat this, Wärtsilä has executed a research and development programme that has shown good results. All the latest dual-fuel engines are now optimized to keep methane slip to an absolute minimum [10].

Other challenges have also been faced and overcome in the past ten years. Initially LNG vessels suffered from close to non-existent LNG bunkering infrastructure. Today we can observe a significant rise in LNG infrastructure. Terminals are being built, and the supply of gas can also be organized with trucks and small-scale storage facilities or LNG bunker barges.

3 CONCLUSION

Whether newbuilt or retrofitted, LNG ships are clearly the way of the future. Short-sea routers, as well as ferries constantly operating between defined ports, are the main applications where a propulsion train based on gas-propulsion offers the biggest advantages. This consideration becomes even stronger when the operation is influenced by sailing periods spent in Emission Control Areas (ECA). Containers, product tankers, cruise vessels, offshore vessels, roll and roll off, LPG, LNG, ethylene carriers and passenger ferries represent typical vessel fleets that could be converted to gas operation. Gas offers a simpler solution for new built ships and for retrofitting vessels for a greener tomorrow. Taking all of this into our consideration today we can predict that during the next ten years, LNG will find its way to a thousand new ships.

Nowadays, when marine LNG DF engines run in natural gas as the primary source of energy, the following targets are achieved:

– CO2 emissions are reduced by approximately 15% to 30%, thanks to a lower carbon content in natural gas compared to liquid fuels [4], [6], [10].
– NOX emissions are reduced by approximately 85%, thanks to the lean burn combustion process implemented in DF engines [6], [10].
– SOX emissions are almost eliminated, since natural gas does not contain any Sulphur [10].
– Particle production is practically non-existent, due to the efficient combustion of natural gas, a fuel with almost no residuals [5], [9], [10].
– The use of LNG as fuel allows reducing emissions, complying emissions rules and reducing operating cost up to 20% (based on [4]) to 35% (based on [10]).

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