ASPECTS OF USING LNG AS A MARINE FUEL

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Abstract

The paper presents a probe of LNG usage analysis as a marine fuel. The restrictions of harmful substances emission to atmosphere from marine engines, especially in controlled emission areas (ECA and SECA areas) of nitrogen oxides and sulfur oxides, forces the engine makers to use additional installations, which operation may fulfill the cleanness requirements of exhaust gases. The option is a usage such marine fuels which fulfill the requirements without any cleaning processes. Such fuels are gaseous fuels, especially liquid natural gas (LNG) or compressed natural gas (CNG). It was undertaken many tests for determination the conditions of safety bunkering, storage on board, preparation and supplying the fuel to the engine and realization of working process. About dozens merchant ships were applied LNG as a fuel. There is enough experience for spreading the LNG usage. The basic problem is still the limited network of LNG distribution in ports. The next one is the conviction of ship-owners that is no return from transition to the LNG or CNG fuelling. In the end it may occurred to the double beneficial situation that the fuel costs would be decreasing and simultaneously the improvement of exhaust gases quality (the restriction of negative effects for the natural environment).

Keywords: *marine fuel, ships propulsion, LNG, liquid natural gas, atmosphere protection*

1. Introduction

The typical composition of LNG is: 91-97% of methane, 1-5% of ethane, about 1% of propane and about 1% other gases like: butane, nitrogen. LNG burns more clearly than other fossil fuels. The important difference between natural gas and LNG is specific volume, for gas is about 600 times more than for liquid. The bunker volume of MDO and LNG was presented in Tab. 1. The MDO/LNG energy density ratio (as the same volume) is about 1.6. Taking into account needed thermal isolation of the LNG tanks, the volume of tanks ought to be 2-3 times more.

Tab. 1. The bunker volume between marine diesel oil and liquid natural gas.

Fuel	LHV [MJ/kg]	Fuel density [kg/m^3]	Energy density [MJ/m^3]
MDO	42.7	900	38.430
LNG	54.7	442	24.177

The advantage of use LNG as a marine fuel is reduced emissions of harmful substances like: NO_x, SO_x, CO_2 and particles. Moreover it leads for decreasing other costs like [2,8]:
- reduced maintenance costs and higher time between overhauls (TBO),
- reduced ship-owners tax costs due to reduced emissions,
- reduced lubricating oil consumption,
- reduced fuel consumption due to higher efficiency of engine fuelled LNG,
- the LNG is cheaper than fuel oils taking into account LHV (lower heat value) as total cost energy,
- there is no need heavy fuel installations for cleaning, heating and other treatment.

The interest in LNG use will be raise. It needs a small revolution in technology, in people thinking and it will change the marine fuel market.

2. Legislation and regulation - time for change – solution propositions

According to IMO regulation (annex VI of MARPOL Convention) from January 1st, 2012 the sulfur content in HFO ought to be less than 3.5% and will decrease in the next years up to below 0.5%. On the SECA areas from January 1st, 2015 the sulfur content in marine fuels would be less 0.1%. If the bunker fuel has over 0.1% the scrubbers will be used. From January 1st, 2016 the Tier III demand will be in force, it means reduction of NO_x approximately 75% below the Tier II level [3]. On Fig. 1. it was presented the ECAs areas in 2012.

Fig. 1. IMO and EPA emission controlled areas [1]

The regulations for the ship design and construction were prepared by classification societies [7, 8] and national authorities. The IMO prepared INTERIM guidelines, by 2014 will be ready new IGF code.

It was proposed new engines fuelled LNG which they fulfill the Tier III requirements. The engines may be dual fuel or single fuel (only gas). In that case there is no purification system for HFO, less waste oil and without problem with switching among fuels. The fuel consumption system (supplying installation) was presented on Fig. 2.

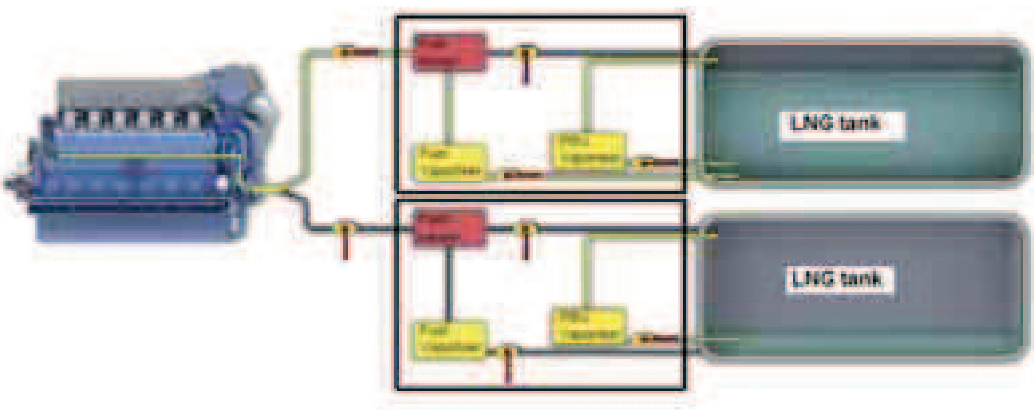

Fig. 2. The LNG fuel supplying installation (tank room arrangement) [1]

The system is very simple in operation, fully automatic and without pumps in it. The idea is that the Pressure Build Up (PBU) Vaporizer regulates the pressure in the LNG tanks which is driving the LNG to the fuel vaporizer. Liquid gas vaporizes to natural gas which goes to the fuel heater. It is a necessary because the temperature of fuel in the LNG tank is about –160ºC. The heater takes the natural gas to the temperature level required before entering the gas regulating unit (GRU) just in the front of the engine. The safety and operation automatic system was presented on Fig. 3. The Bergen is spark engine fuelled LNG through fuel gas module. The heated natural gas is mixing with air making the fuel-air mixture ignited in the combustion chamber by spark.

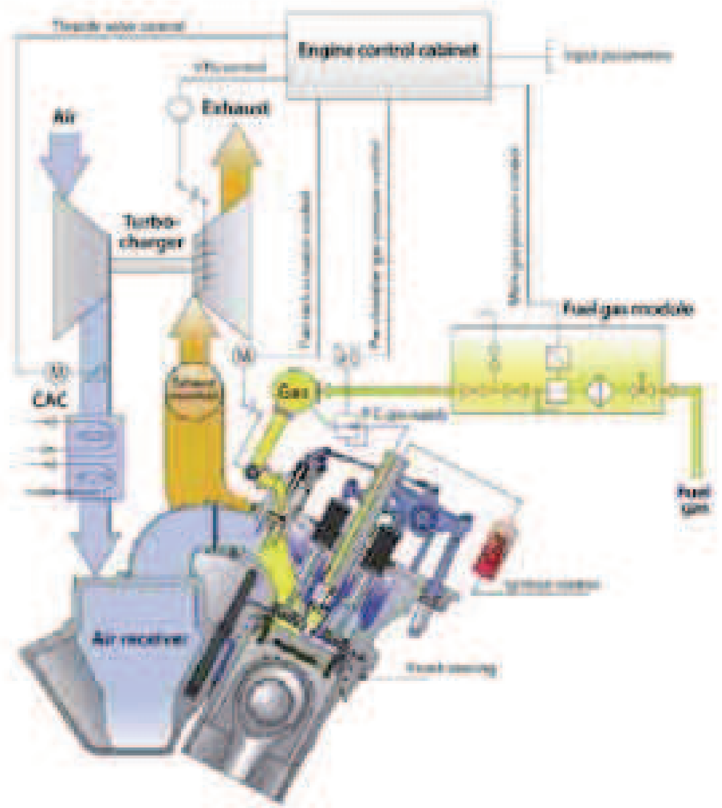

Fig. 3. Supplying fuel system of Bergen gas engine [1]

The engine efficiency is about 3.6% better when fuelled by LNG. The heat consumption is 7500 kJ/kWh on LNG and 7770 kJ/kWh on MDO.

3. LNG market in Europe ports

Only a little over 20 ports in Europe (Fig. 4.) there is possible to get the LNG, but still there is a problem to bunker this type of marine fuel. The LNG market [4] of LNG fuel is theoretical ready but often there is no barges for bunkering, no places in ports prepared to do it. The reason of course is a lack of ships fuelled LNG. The fuel is still not so popular because only about 30 ships on all the world have the possibility to be fuelled LNG. This is a circle of impossibility. In the ports of Baltic Sea there is only two with LNG terminal, the third will be in Poland in Świnoujście. It is a need minimum 20 ports around the Baltic Sea when the distance between arbitrary ports where the LNG bunkering is possible would be less than 50 Nm (about 100 km). The ship's fuel tanks have limited total volume especially for LNG so it is a necessity to meet on the ship's route the port or the LNG barge in the roads to bunker needed fuel. This is impossible to sail on that route with return to the initial port during maximum 30 days because this time period is ship's independence.

An example of existing LNG terminal for ship bunkering is presented on Fig. 5. The possibility is for one ship m/v Bergensford or for other small ferries so we must remember that one swallow doesn't make a summer.

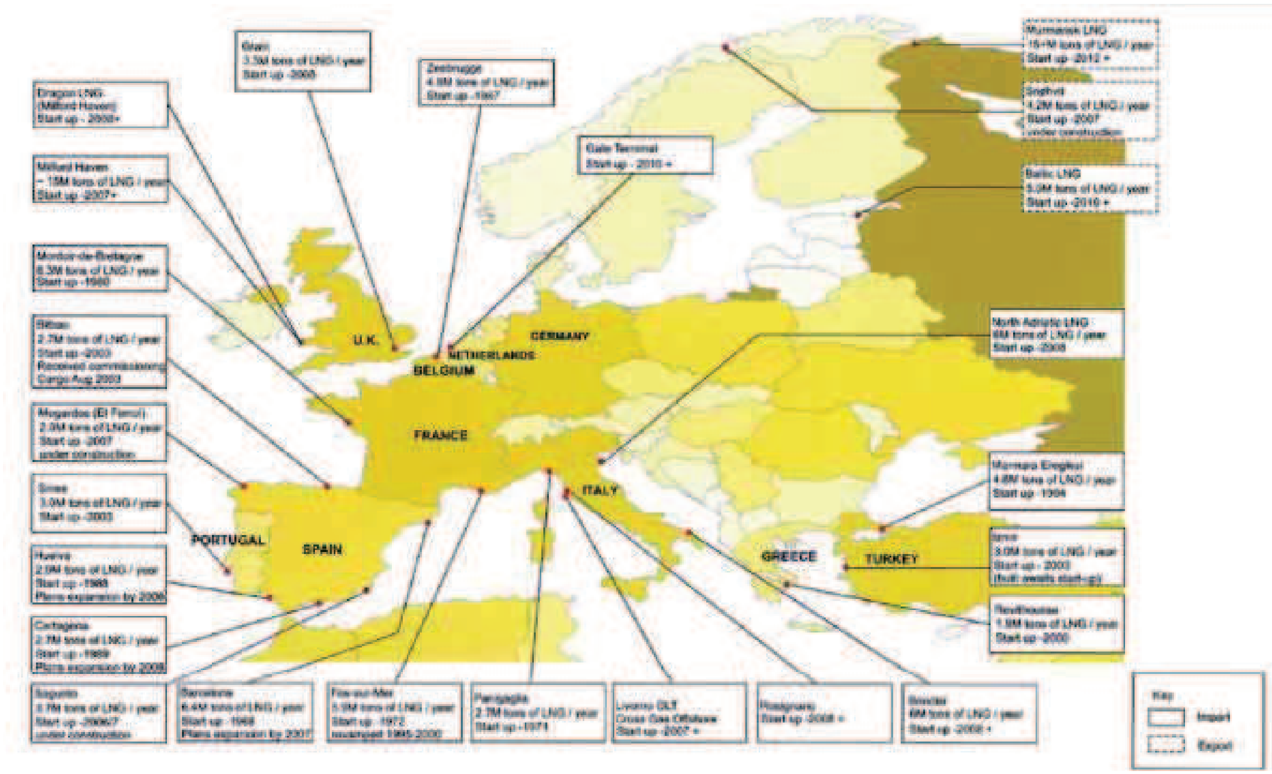

Fig. 4. LNG terminals in Europe [source: world lng map 2006], [5]

Fig. 5. LNG bunkering station at ferry berth for m/v Bergensfjord [10]

The number of ships with possibility of LNG use is still not many. On the Fig. 6 it was presented 26 ships fuelled LNG (but not only LNG) and on the Fig. 7. there was presented 17 ships in order so in that moment (March 2012) probably 30 ships has the possibility of fuelled by LNG.

Looking for the lists it may be said that there are only European ship-owners, mainly from Norway. From here has come the main idea for the changes in ship's fuelling. Here it was prepared the solutions of LNG use. As the firsts it was prepared the regulations by Det Norske Veritas (DNV) and American Bureau of Shipping (ABS) as the „Guide for propulsion and auxiliary systems for gas fuelled ships" [6-8]. The marine fuel market ought to belong to the LNG and it will happen in the future. Now there is the first steps for achieving it.

Year	Type of ship	Ship name	Owner	Engine
2000	Car/Passenger ferry	Glutra	Fjord1	Mitsubishi
2003	Offshore vessel	Viking Energy	Eidesvik	Wärtsilä DF
2003	Offshore vessel	Stril Pioner	Simon Møkster	Wärtsilä DF
2004	LNG tanker	Pioner Knutsen	Knutsen OAS	Mitsubishi
2006	Car/Passenger ferry	Bergensfjord	Fjord1	Rolls Royce
2007	Car/Passenger ferry	Stavangerfjord	Fjord1	Rolls Royce
2007	Car/Passenger ferry	Raunefjord	Fjord1	Rolls Royce
2007	Car/Passenger ferry	Mastrafjord	Fjord1	Rolls Royce
2007	Car/Passenger ferry	Fanafjord	Fjord1	Rolls Royce
2008	Offshore vessel	Viking Queen	Eidesvik	Wärtsilä DF
2009	Car/Passenger ferry	Moldefjord	Fjord1	Mitsubishi
2009	Car/Passenger ferry	Tideprinsen	Tide Sjø	Mitsubishi
2009	Car/Passenger ferry	Tidekongen	Tide Sjø	Mitsubishi
2009	Car/Passenger ferry	Tidedronningen	Tide Sjø	Mitsubishi
2009	LNG tanker	Coral Methane	Anthony Veder	Rolls Royce
2009	Offshore vessel	Viking Lady	Eidesvik	Wärtsilä DF
2009	Patrol vessel	Barentshav	REM	Mitsubishi
2010	Car/Passenger ferry	Fannefjord	Fjord1	Mitsubishi
2010	Car/Passenger ferry	Romsdalsfjord	Fjord1	Mitsubishi
2010	Car/Passenger ferry	Korsfjord	Fjord1	Mitsubishi
2010	Car/Passenger ferry	Tresfjord	Fjord1	Rolls Royce
2010	Car/Passenger ferry	Selbjørnsfjord	FosenNamsos	Mitsubishi
2010	Patrol vessel	Bergen	REM	Mitsubishi
2010	Patrol vessel	Sortland	REM	Mitsubishi
2011	Product tanker	Bit Viking	Tarbit Shipping	Wärtsilä DF
2011	Car/Passenger ferry	Boknafjord	Fjord1	Rolls Royce

Fig. 6. Ships in operation fuelled LNG (26 ships in February 2011) [10]

Year	Type of ship	Ship name	Owner	Engine
2011	Offshore vessel	TBD	DOF	Wärtsilä DF
2011	Offshore vessel	TBD	Solstad	Wärtsilä DF
2011	RoRo ship	TBD	Seacargo	Rolls Royce
2012	Bulk ship	TBD	NSK Shipping	Rolls Royce
2012	Car/Passenger ferry	TBD	Torghatten Nord	Rolls Royce
2012	Car/Passenger ferry	TBD	Torghatten Nord	Rolls Royce
2012	Car/Passenger ferry	TBD	Torghatten Nord	Rolls Royce
2012	Car/Passenger ferry	TBD	Torghatten Nord	Rolls Royce
2012	Offshore vessel	TBD	Eidesvik	Wärtsilä DF
2012	Offshore vessel	TBD	Eidesvik	Wärtsilä DF
2012	Offshore vessel	TBD	Olympic Shipping	Wärtsilä DF
2012	Offshore vessel	TBD	Island Offshore	Rolls Royce
2012	Offshore vessel	TBD	Island Offshore	Rolls Royce
2012	RoRo ship	TBD	Seacargo	Rolls Royce
2013	RoPax	TBD	Viking Line	Wärtsilä DF
2013	RoRo ship	TBD	Norlines	Rolls Royce
2013	RoRo ship	TBD	Norlines	Rolls Royce

Fig. 7. Ships in order (17 in February 2011) [10]

4. Small scale LNG and CNG

How to increase the LNG availability in ports? There are some possibilities of solving that problem [5]:

- distribution from European main import terminals to smaller regional and local regassification terminals,
- smaller vessels or trucks can supply to small markets not connected to the gas network,
- create the supply chain for marine bunkering,
- increase the demand for LNG or CNG as a fuel for heavy transport (rail, trucks, buses etc.).

It's a need for safety regulation for the development of small scale LNG and CNG. It will require a regulatory framework that recognize the gas fuel benefits for promoting and spreading.

The energy equivalence among the diesel oil, LNG and CNG (at 200 bar) is like 1: 1.8: 5. It has an effect on the fuel tank volume taking into account the vehicle range. The volume change between LNG and NG (at normal conditions) was presented on Fig. 8.

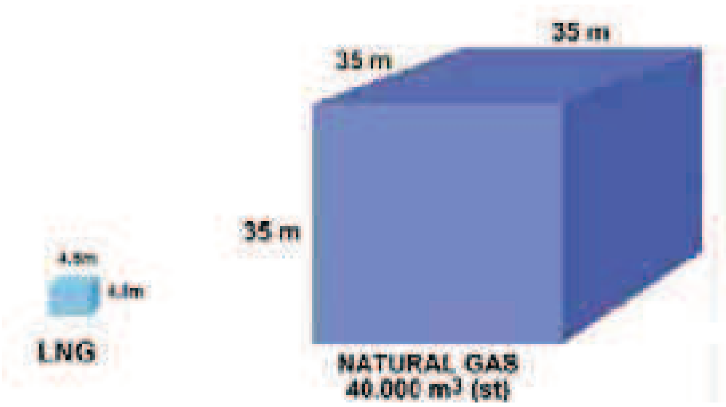

Fig.8. The volume change between LNG and NG (about 660 times) [1]

5. Requirements of gas fuel storage tanks and gas fuel systems [8]

The requirements of gas fuel tank outfit are determined by DNV and ABS classification societies and next by others. All ship's fuel systems, gas storage tanks and associated systems are to be confirmed for satisfactory operation, including associated controls, alarms and shutdowns. The tests are to be conducted in accordance with the classification society approved testing procedure during gas trials. The monitoring and safety system functions for gas fuel storage tanks are presented in Tab. 2, the monitoring and safety system functions for fuel bunkering systems are presented in Tab. 3.

Tab. 2. Monitoring and safety system functions for gas fuel storage tanks and gas fuel storage rooms [8]

Monitored parameters	alarm	automatic shutdown of the main tank valve
High or low liquid level in gas fuel storage tank	X	
High or low pressure in gas fuel storage tank	X	
High or low temperature in gas fuel storage tank	X	
Gas detection in tank connection space above 20% LEL	X	
Gas detection in tank connection space above 40% LEL	X	X
Fire detection in tank connection space	X	X
Bilge well high level in gas fuel storage tank	X	
Bilge well low temperature in gas fuel storage tank	X	X

According to ABS requirements [8], the gas piping is to be a double wall piping system with the gas fuel contained in the inner pipe. The space between the concentric pipes is to be pressurized with inert gas at a pressure greater than the fuel pressure. Suitable alarms are to be provided to indicate a loss of inert gas pressure between the pipes.

The gas fuel piping is to be installed within a ventilated pipe or duct. The air space between the gas fuel piping and the wall of the outer pipe or duct is to be equipped with mechanical under

Tab.3. Monitoring and safety system functions for fuel bunkering systems [8]

Monitored parameters	alarm	automatic shutdown of the manifold ESD valves
Gas detection at enclosed or semi enclosed bunker station above 20% LEL	X	
Gas detection at enclosed or semi enclosed bunker station above 40% LEL	X	X
Fire detection at bunker station	X	X
Fire detection in gas fuel storage room, compressor room or fuel preparation rooms	X	X
Loss of ventilation in ducting around the gas bunkering lines	X	
Gas detection in ducting around the gas bunkering lines above 20% LEL	X	
Gas detection in ducting around the gas bunkering lines above 40% LEL	X	X
High level in gas storage tank	X	X
High pressure in gas storage tank	X	X
Manual ESD shutdowns	X	X
Manual or automatic ESD signal from bunker supplier	X	X
Loss of ESD valve motive power	X	X

pressure ventilation having a capacity of at least 30 air changes per hour. The ventilation outlet is to be covered by a protection screen and placed in a position where no gas-air mixture may be ignited. The ventilation is always to be in operation when there is fuel in the fuel gas supply piping. The applicable master gas valve is to automatically close if the required airflow is not established and maintained by the ventilation system.

Ducting for high-pressure piping is to be pressure tested to at least 10 bars. It may occur a local instantaneous peak pressure in way of the rupture. This pressure is to be taken as the critical pressure and is given by the following expression [8]:

$$p_k = p_o * [2/(k+1)]^{k/(k-1)},$$

where:

p_o – maximum working pressure of the pipe,

k – c_p/c_v constant pressure specific heat divided by the constant volume specific heat, for LNG=1.31,

p_k – maximum rupture pressure.

The pressure of rupture, when the p_o = 4 bar, will be 2.176 bar in the outlet.

The requirements for monitoring and safety gas functions for fuel gas supply systems are presented in Tab. 4. All requirements presented in Tab. 2-4 are needed for gas fuel systems. This is an additional cost of fulfilment the monitoring and safety functions for gas fuel systems. It is to be performed it for precaution reasons. The next one is cost of cryogenic materials for LNG tanks, tank thermal isolation, additional ventilation systems, double wall pipelines, gas detectors, fire detectors, emergency shutdown valves (ESDV), pressure and temperature gauges and sensors, etc.

6. Final remarks

In a case of LNG carriers parties may agree to allow gas consumption in the engine room during the time between the opening and closing custody transfer surveys. This could be to ensure low air-emission operation in the engine room while ship is at berth or ECA areas but the entire voyage and so may favour the use of boil-off gas perhaps complemented by regasified LNG rather than fuel oils in the engine room [4]. There is no necessity to build special LNG tanks as fuel tanks for

Tab. 4. Monitoring and safety gas system functions for fuel gas supply systems [8]

Monitored parameters	alarm	automatic shutdown of the main tank value	automatic shut-off of the master gas fuel valve and automatic activation of the block and bleed valves
Gas detection in duct between tank and machinery space containing gas fuelled prime movers above 20% LEL	X		
Gas detection in duct between tank and machinery space containing gas fuelled prime movers above 40% LEL	X	X	
Gas detection in compressor, pump or fuel preparation room above 20% LEL	X		
Gas detection in compressor, pump or fuel preparation room above 40% LEL	X	X	
Gas detection in duct inside machinery space containing gas fuelled prime movers above 30% LEL	X		
Gas detection in duct inside machinery space containing gas fuelled prime movers above 40% LEL	X		X
Gas detection in machinery space containing gas fuelled prime movers above 20% LEL	X		
Gas detection in machinery space containing gas fuelled prime movers above 40% LEL	X		X
Loss of ventilation in duct between tank and machinery space containing gas fuelled prime movers	X		X
Loss of ventilation in duct inside machinery space containing gas fuelled prime movers	X		X
Loss of ventilation in machinery space containing gas fuelled prime movers	X		X
Fire detection in machinery space containing gas fuelled prime movers	X		X
Abnormal pressures in the gas fuel supply line	X		X
Failure of valve control actuating medium	X		X
Automatic shutdown of engine (engine failure)	X		X
Emergency shutdown of engine manually released	X		X

engine room. Apart from this particular situation, the use of LNG as a fuel will rapidly increase when the LNG bunkering market is occurred. Many reasons may have an influence on development the LNG network. The spreading of LNG will develop the market of marine gas engines, equipment for LNG, monitoring and safety systems, gas tanks and pipelines system new solutions. The reduction of prices of that installation will cause the development on many fields. It seemed that the fuel of the future would be gas fuels, especially LNG. The main reasons are: low price, green fuel (low emission), rich deposits, accessibility, utilization of onshore networks, new environment protection regulations (tier 2 and tier 3, next tier 4) and in the end – the necessity due to limited stocks of other fuel oils and theirs prices.

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