LNG as Marine fuel : The Marine engineer's perspective.

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Abstract : LNG as marine fuel is gaining a lot of attention in recent years. Conventional LNG vessels have for many years used this as fuel in their propulsion boilers. LNG as a fuel in compression ignition engines is altogether a different matter. The paper addresses some of the issues involved such as safety, bunkering and fuel handling, combustion aspects of natural gas in engines as compared to HFO.

Key words: ***Fire safety, lean burning, knocking, emission control, methane number, methane slip***.

Introduction:

As the saying goes "Necessity is the mother of invention". The present focus on LNG as an alternative marine fuel has been due to two driving influences. One has been the ever rising cost of HFO and MGO and the near certainty that this will only go higher in the years to come. The other is the unrelenting pressure to reduce the environmental footprint our industry is leaving on the world. Stricter air pollution targets that loom in the horizon, have triggered the need to search for alternatives. Especially the need to reduce SOx emissions limits choices to either use a low sulphur fuel or a scrubber system. This paper covers some of the aspects of using Liquefied Natural Gas as fuel on board vessels, from the view point of the Engineers on board.

Historical Background:

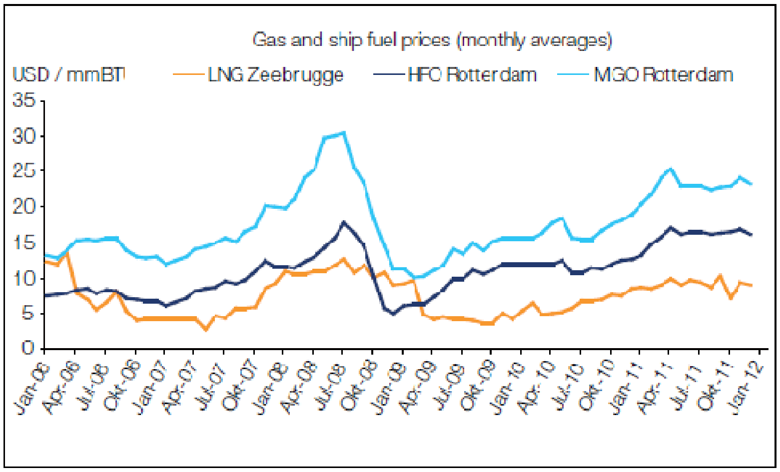
The "natural" version of LNG, i.e. Natural Gas has been used as a fuel from many years back. The ancient Chinese and Persians are said to have used it a few thousands of years ago. In the later years of the 18th century "Manufactured natural gas" from coal was used as fuel for streetlights, in England. In 1885 Robert Bunsen invented the "Bunsen Burner " , which many of us will recall from our science laboratories in school. In India, "Gobar Gas" plants have come up in rural areas to supply natural gas from a proficient gas producer, the cow!!!.

LNG is not a novel fuel for marine applications. Conventional LNG vessels have been using the Boil Off Gas (BOG) from cargo as fuel in propulsion boilers. Combustion of natural gas in a boiler is quite simple once basic safety issues are taken care of. However the poor thermal efficiency of steam cycle when compared to the Diesel engine, resulted in the development of gas burning diesel engines for use onboard LNG vessels. Quite a few vessels are in service where the BOG is used as a bunker fuel in propulsion engines. The technology for the gas burning engine developed for this reason.

Now the focus is on the feasibility of using LNG as fuel on other types of ships such as ferries, container vessels, tankers etc. Vessels (such as ***Bit Viking***, a product tanker) have been converted to LNG fuel. Many new buildings have also been delivered including a high speed RO-RO Ferry.

The Reasons for Using LNG:

The economics of LNG as an alternative to HFO seem to be strong as the present price of LNG is lower compared to HFO and while oil reserves are depleting worldwide, there are many natural gas deposits being discovered. Recent developments include the discovery of large amounts of natural gas in ***Shale*** formations. One important issue will be availability in ports around the world. At least in most major ports, LNG as bunker fuel could become a reality in the near future. Vessels operating in fixed costal routes, or in liner mode between major ports can be assured of reliable supply.



Comparison of prices different fuels [1]

The reduction in air pollution also will be substantial as there is no sulphur in this fuel. Since gas burns cleanly, particulate matter and visible smoke will be absent. Lower combustion temperatures result in lower NOx emissions (reduction of about 90 %) . As the proportion of Hydrogen with respect to Carbon is highest in methane when compared with other HC fuels,CO_2 emission is also reduced by 20 to 25 %. There are concerns about un burnt Methane in the exhaust gas contributing to Green House Gas emission.

Even if other arguments are not considered, our stock of oil will run out sooner than later and fuels other than oil have to be used. For all the above reasons one can assume that natural gas is a likely choice as marine fuel in the days to come.

For the Engineer on board:

Commercial factors notwithstanding, for the Engineer onboard the issues will relate to safety and reliable engine operation. While it means - no sludge to dispose off, clean engine rooms and boiler suits –nice thoughts these- doubts will arise. Is this fuel really safe? Will we be handling an explosive fuel? How does one bunker this? How will leaks be detected though? Will it be an invisible danger in the Engine Room? How will the engine handle this fuel?

Properties of Natural Gas and Fire safety

Commercial LNG is not a pure substance; it is about 85 to 90 % methane. Ethane, propane and nitrogen make up the rest. The physical properties of Methane are very different from HFO. Its density is much lower, nearly half; Its critical temperature is - 82.5 deg C. Which means it cannot be a liquid at ambient temperature. In fact, even at -82.5 deg C, a pressure of about 44 bar is needed to keep it liquid. Its atmospheric boiling point is -161.5 deg C. Even such a low temperature does not guarantee fire safety as its flash point is -175 deg C. [2] As it is extremely volatile, even small liquid spills can produce large vapour clouds, which on mixing with air can result in flammable mixtures in huge quantities. Gas cloud can travel. Even if the area in the immediate vicinity of the leak is free from ignition sources, the gas cloud can ignite from a far off ignition source and possibly, the flame can flash back to the source of leak. Clearly there are serious fire safety issues which the engineer needs to be aware of.

How does one handle such a flammable gas then? The answer lies in the volatility, which in one way is the problem. Every day in many millions of kitchens LPG is used for cooking, by untrained people, with absolute safety. The safety lies in the fact that the cylinder contains no air and a flammable mixture cannot form inside the cylinder. It is only in the burner, that the gas and air mix to create the fire. There is absolutely no danger of the flame travelling through the hose to ignite the fuel in the cylinder. The same safety is assured in the LNG stored for bunker onboard. The volatility of the cargo will ensure that as the fuel is consumed, more vapour will generate and ensure positive pressure in the tank and prevent air ingress. There is no need to introduce inert gas in to the tank to maintain pressure. However, if the gas leaks into the atmosphere, the story will take an unsavoury turn!

Rules and Guidelines

The current legislative frame work such as the IGC code is for Liquefied Gas Carriers which carry LNG as cargo. The code for gas as fuel (***IGF code***) from IMO is presently under development and will probably become applicable from 2015.

MSC resolution 285(86): Interim guidelines on safety for Natural Gas fuelled Engine Installations in Ships, (adopted on 1 June 2009) is the current relevant IMO instrument. IACS Unified Requirement M59: Control and Safety Systems for Dual Fuel Diesel Engines is another documents with relevance. From the MSC guidelines a few key points are listed below.

Two alternative system configurations are possible

1. Gas safe machinery spaces: Arrangements in machinery spaces are such that the spaces are considered gas safe under all conditions, normal as well as abnormal conditions, i.e. inherently gas safe.

For Gas safe machinery spaces the following requirements will apply.

All gas supply piping within machinery space boundaries, will be in a double walled piping or ducting.

The space between the concentric pipes should be filled with inert gas at a pressure greater than the natural gas, or it should be ventilated with its own ventilation system.

In case of leakage in a gas supply pipe making shutdown of the gas supply necessary, a secondary independent fuel supply should be available. Alternatively, in the case of multi-engine installations, independent and separate gas supply systems for each engine or group of engines may be accepted.

For single fuel installations (gas only), the fuel storage should be divided between two or more tanks of approximately equal size. The tanks should be located in separate compartments.

.2. ESD-protected machinery spaces: Arrangements in machinery spaces are such that the spaces are considered non-hazardous under normal conditions, but under certain abnormal conditions may have the potential to become hazardous. In the event of abnormal conditions involving gas hazards, emergency shutdown (ESD) of non-safe equipment (ignition sources) and machinery is to be automatically executed while equipment or machinery in use or active during these conditions are to be of a certified safe type.

Gas supply piping within machinery spaces may be accepted without a gastight external enclosure on the following conditions:

Engines for generating propulsion power and electric power should be located in two or more machinery spaces not having any common boundaries unless it can be documented that the common boundary can withstand an explosion in one of the rooms. Pressure in gas supply lines within machinery spaces should be less than 10 bar, e.g., this concept can only be used for low pressure systems. A gas detection system arranged to automatically shutdown the gas supply (also oil fuel supply if dual fuel) and disconnect all non-explosion protected equipment or installations should be fitted.

For single fuel installations (gas only), the fuel storage should be divided between two or more tanks of approximately equal size. The tanks should be located in separate compartments.

Requirements dual fuel engines

Start and normal stop should be on oil fuel only. Gas injection should not be possible without a corresponding pilot oil injection. The amount of pilot fuel fed to each cylinder should be sufficient to ensure a positive ignition of the gas mixture. In case of shut-off of the gas fuel supply, the engines should be capable of continuous operation by oil fuel only. Changeover to and from gas fuel operation should only be possible at a power level and under conditions where it can be done with acceptable reliability as demonstrated through testing. On power reduction the changeover to oil fuel is to be automatic. The changeover process itself from and to gas operation should be automatic. Manual interruption should be possible in all cases.

On normal stop as well as emergency shutdown, gas fuel supply should be shut off not later than simultaneously with the oil fuel. It should not be possible to shut off the supply pilot fuel without first or simultaneously closing the gas supply to each cylinder or to the complete engine

Requirements for gas-only engines

The starting sequence should be such that fuel gas is not admitted to the cylinders until ignition is activated and the engine has reached an engine and application specific minimum rotational speed.

If ignition has not been detected by the engine monitoring system within an engine specific time after opening of the gas supply valve the gas supply valve should be automatically shut off and the starting sequence terminated. It should be ensured by any mean that any unburned gas mixture is flushed away from the exhaust system.

On normal stop as well as emergency shutdown, gas fuel supply should be shut off not later than simultaneously with the ignition. It should not be possible to shut off the ignition without first or simultaneously closing the gas supply to each cylinder or to the complete engine.

For constant speed engines the shut down sequence should be such that the engine gas supply valve closes at idle speed and that the ignition system is kept active until the engine is down to standstill. [3]

Bunkering:

LNG bunker vessels will be small LNG carriers which will comply with IGC code requirements. The IGF code and other such regulations will cover the vessel which taking the LNG on as fuel. The present storage arrangements are type Independent C tanks (pressure vessels) with a maximum design pressure of 10 bar, made of stainless steel which are heavily insulated. LNG bunkering will not be similar to oil bunkering as it will be a closed operation. The bunker volume required will be nearly double as the density of liquid methane is only about 420 kg /cbm. Additional fire safety systems including water spray and a fixed DCP system, similar to what is provided on Liquefied gas carriers, is required for the bunkering arrangement.

Combustion of Natural Gas as fuel in engines

The issues related to combustion of natural gas in internal combustion engines are many. Though the flashpoint of methane is only -175 deg C, its auto ignition temperature is very high, 596 deg C.

Achieving reliable ignition, has also to be balanced by the need to avoid knocking, which is highly likely in a premixed combustion process as seen in gas burning engines.

Methane Slip: This refers to the presence of unburnt methane in the exhaust gas from the engine. Apart from safety implications, release of methane has serious pollution potential. As mentioned earlier natural gas has a high proportion of Hydrogen with respect to Carbon and thus CO_2 emissions can be brought down significantly. However since the global warming potential of methane is 23 times that of CO_2 , even a small presence of Methane in the exhaust can seriously undermine this claim.

The present day technologies are;

a) low pressure gas mixed with intake air(similar to gasoline engines) and ignited by spark ignition (Rolls-Royce engines and Wartsila). These are single fuel engines.

The lean burn spark ignited gas engines from Rolls Royce are said to meet IMO tier III requirements. High energy efficiency promises a good reduction in CO_2. However Methane slip can dent the performance.

The Wartsila engines (SG models) also incorporate a precombustion chamber in the cylinder head where the spark is initiated. These are lean-burn otto cycle gas engines. During the intake period, gas is also fed into a small prechamber, where the gas mixture is rich compared to the gas in the cylinder. At the end of the compression phase the gas/air mixture in the prechamber is ignited by a spark plug. The flames from the nozzle of the prechamber ignite the gas/air mixture in the whole cylinder. These engines are found more inland based power plants.

b) Low pressure gas injected in intake air and ignited by pilot injection of diesel (Wartsila). These are Dual fuel engines (DF Models) which can run on MGO or Natural Gas. These engines offer considerable reduction of NOx and they meet the IMO tier II requirements. The natural gas fuel can have Methane number 80.[4] The micro pilot injection is by common rail injection system. The main diesel injection is by a conventional jerk type injection system.

However ***Methane slip*** is more pronounced as the fuel is premixed and fuel-air mixture in crevice volumes in the combustion chamber does not burn completely. There is also the possibility of air fuel mixture escaping during valve overlap period.

c) Higher pressure gas (approx 300 bar) injected into the combustion chamber (similar to diesel engines) and ignited by pilot injection of diesel. Wartsila Four stoke engines (GD models) use high pressure gas injection directly in the combustion chamber.

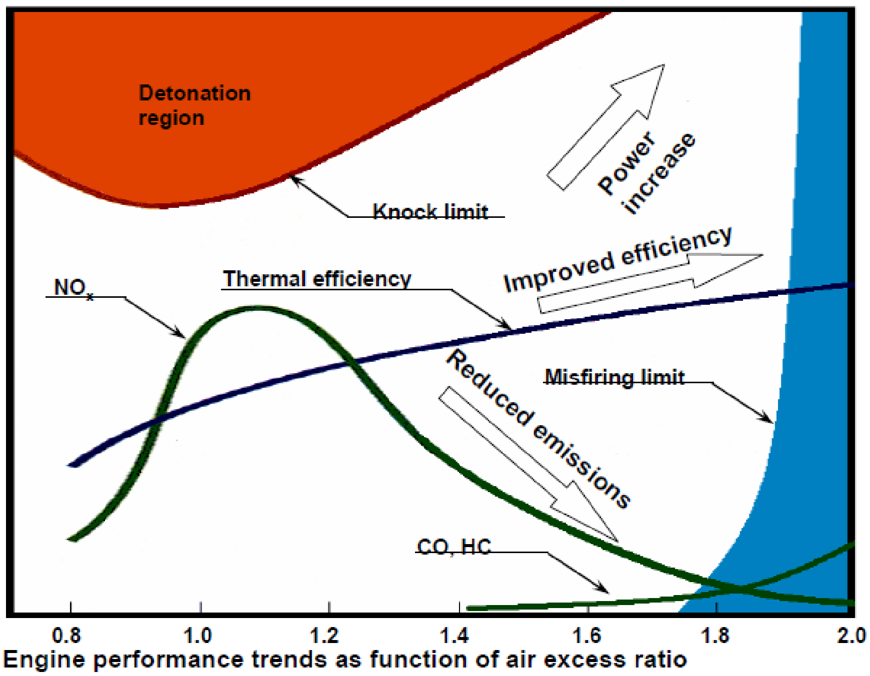
MAN B&W Engines (GI engines) are slow speed two stroke engines with the same direct injection of high pressure gas , ignited by pilot ignition of diesel. These engines need additional measures such as SCR to meet the IMO tier III requirements. Methane slip is considerably less as the combustion is similar to a diesel engine. Green House gas emissions can be brought down by about 30 %.

Methane Number and Knocking:

The resistance to knocking is also dependant on fuel composition. Methane number is an important indicator for the tendency to knock. It is influenced by different constituent gases within the natural gas, particularly the proportions of methane, ethane, propane and butane. High pressure gas injection engines are more sensitive to this. Methane is quite resistant to knocking and has a Methane number of 100. Hydrogen has a Methane number of 0.

The Composition of LNG available worldwide shows a wide variation and thus the Methane number varies a lot.

	Typical LNG composition in volime %							
LNG export terminals	C1	C2	C3	C4	C5+	N2	LHV[MJ/kg]	MN
Arun (Indonesia)	89,33	7,14	2,22	1,17	0,01	0,08	49,4	70,7
Arzew (Algeria)	87,4	8,6	2,4	0,05	0,02	0,35	49,1	72,3
Badak (Indonesia)	91,09	5,51	2,48	0,88	0	0,03	49,5	72,9
Bintulu (Malaysia)	91,23	4,3	2,95	1,4	0	0,12	49,4	70,4
Bonny (Nigeria)	90,4	5,2	2,8	1,5	0,02	0,07	49,4	69,5
Das Island (Emirates)	84,83	13,39	1,34	0,28	0	0,17	49,3	71,2
Lumut (Brunei)	89,4	6,3	2,8	1,3	0,05	0,05	49,4	69,5
Point Fortin (Trinidad)	96,2	3,26	0,42	0,07	0,01	0,01	49,9	87,4
Ras Laffan (Qatar)	90,1	6,47	2,27	0,6	0,03	0,25	49,3	73,8
Skida (Algeria)	91,5	5,64	1,5	0,5	0,01	0,85	49	77,3
Snøhvit (Norway)	91,9	5,3	1,9	0,2	0	0,6	49,2	78,3
Withnell (Australia)	89,02	7,33	2,56	1,03	0	0,06	49,4	70,6



[5]

The graph illustrates the narrow operating range for proper combustion.

Training of personnel :

Under the MSC resolution 285(86) training requirements are specified. The training on gas-fuelled ships is divided into the following categories:

.*1*. category A: Basic training for the basic safety crew;

.*2*. category B: Supplementary training for deck officers; and

.*3*. category C: Supplementary training for engineer officers.

Category A training

The goal of the category A training should provide the basic safety crew with a basic understanding of the gas in question as a fuel, the technical properties of liquid and compressed gas, explosion limits, ignition sources, risk reducing and consequence reducing measures, and the rules and procedures that must be followed during normal operation and in emergency situations.

The training should consist of both theoretical and practical exercises that involve gas and the relevant systems, as well as personal protection while handling liquid and compressed gas. Practical extinguishing of gas fires should form part of the training, and should take place at an approved safety centre.

Categories B and C training

Deck and engineer officers should have gas training beyond the general basic training. Category B and category C training should be divided technically between deck and engineer officers.

Those ordinary crew members who are to participate in the actual bunkering work, as well as gas purging, or are to perform work on gas engines or gas installations, etc., should participate in all or parts of the training for category B/C. All gas-related systems on board should be reviewed. The ships maintenance manual, gas supply system manual and manual for electrical equipment in explosion hazardous spaces and zones should be used as a basis for this part of the training.

If the ship's own crew will be performing technical maintenance of gas equipment, the training for this type of work should be documented.

The master and the chief engineer officer should give the basic safety crew on board their final clearance prior to the entry into service of the ship. The clearance document should only apply to gas-related training, and it should be signed by both the master/chief engineer officer and the course participant. The clearance document for gas-related training may be integrated in the ships general training programme, but it should be clearly evident what is regarded as gas-related training and what is regarded as other training.

Conclusion

The increasing cost of fuel oils and the need to comply with strict emission control requirements may result in LNG becoming a serious alternative to fuel oils onboard. While the properties of natural gas suggest it is a dangerous fuel, safety can be ensured by proper design. Strict adherence to safe practices will be necessary. Training of Engineers to handle this fuel in the ER will also become necessary.

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