LNG as a Fuel for Vessels – Some Design Notes

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This article discusses some operational design considerations for LNG fueled vessels.

While LNG has been the fuel of LNG carriers for decades, it is gaining interest as a possible fuel for all manner of marine craft.

The reasons for the interest in LNG as a fuel are presented as well as operational considerations affecting the design of a LNG fueled vessel.

1. Introduction

Industrial emissions have increased substantially in the last 100 years, releasing undesirable byproducts into the atmosphere. Particularly detrimental byproducts include nitrous oxides (NO_X), sulfurous oxides (SO_X), and carbon dioxide (CO_2).

Today, vehicles on land, sea, and air are still large sources of emissions. Data from the year 2000 indicate that the US transportation industry alone accounted for 55% of the total man-made sources of NO_X,. At least 30% of the national fossil fuel-related CO_2 emissions in 1999 were attributed to the transportation industry.

The International Convention for the Prevention of Pollution from Ships (MARPOL) was revised in 2008 to set stricter standards for the emissions from ships. Globally, sulfur content in fuels will be limited to 0.5% from 2020 and on (vs. 4.5% now). New limitations will also be imposed on NOx emissions. The timing and amounts of sulfur in fuel for global and ECA zones (defined below) requirements are shown in Figure 1; requirements for NOX are shown in Figure 2.

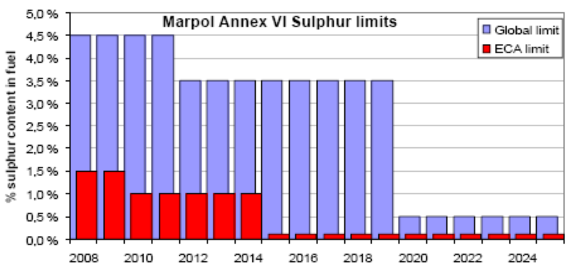

Figure 1: MARPOL Limits on Fuel Sulfur Content

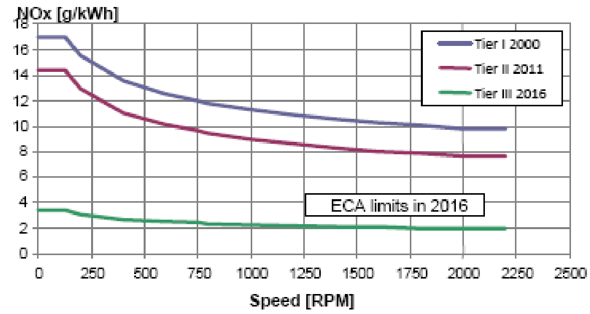

Figure 2: NOx Emission Limits, MARPOL Annex VI

In addition to these limits, the US-based Marine Environmental Protection Committee has also given approval for plans to declare certain areas of the US and Canada's coastal waters as an Emission Control Area (ECA).The MEPC is a committee of IMO that develops international conventions relating to the marine environment.

The North and Baltic Seas are already ECA's and the initial US /Canadian ECA is likely to become effective in August of 2012. While the initial area will be restrictive, it is expected that nearly the entire US coast line could become an ECA within the next 10 years. Depending on how far out this ECA extends (possibly 200 miles), coastal US shipping may eventually operate entirely within the ECA. Vessels coming in and out of the ECA from foreign voyages would have to comply with ECA requirements while within the ECA.

In order to meet future limitations within ECA's, much cleaner fuels will be required, in addition to exhaust treatment.

2. LNG as a fuel

The proposed future regulations for controlling emissions and the pending ECA zones in the US will require that diesel propelled vessels burn Ultra Low Sulfur Diesel Oil (ULSD) which is made in short supply today and which requires much more extensive refining than conventional diesel oil. Aside from the general rise in oil prices, it is expected, as new facilities will have to be constructed to produce ULSD, that the cost of ULSD will be very high, perhaps 70% higher than DO, at the time.

LNG (liquefied natural gas) has been proposed as an alternative, less costly, solution to the challenge of cleaner shipping fuels, for scheduled trades in Northern Europe, and particularly those within the ECA. The environmental qualities of LNG are superior to those of any liquid petroleum fuel. The technical and operational viability of LNG as a fuel for ships has already been demonstrated in Norway, where a number of coastal ferries and other ships have operated on LNG for several years, with more under way. The use of LNG effectively eliminates the need for exhaust treatment, due to very low NOx formation in the engines, as well as the absence of sulfur. Table 1 demonstrates the differences in emissions among LNG and other liquid petroleum fuels.

Table 1. LNG Emission Comparison

Fuel type	SOx (g/kWh)	NOx (g/kWh)	PM (g/kWh)	CO2 (g/kWh)
Residual oil 3.5% sulphur	13	9-12	1,5	580-630
Marine diesel oil, 0,5%S	2	8-11	0,25-0,5	580-630
Gasoil, 0.1% sulphur	0,4	8-11	0,15-0,25	580-630
Natural gas (LNG)	0	2	~0	430-480

Notably, LNG as a fuel emits no SOx, very little NOx, and no particulate matter, but it does emit CO_2, albeit 20-25% less than liquid fuels.

The use of LNG as a fuel in Norway is somewhat underwritten by carbon credits, paid to the operator of the vessel for reducing the vessel's carbon footprint. No such carbon credits exist in the US.

Some of these LNG fueled vessels use engines with spark ignition. Other LNG-fueled ships are powered by engines that use ignition by a small diesel portion in the fuel, and can alternatively run on diesel oil alone.

A number of established diesel engine manufacturers have developed, or are developing, gas versions of their engines.

3. The supply of LNG

The logistics of LNG fueling is often cited as a reason why LNG-fueled ships will be difficult to implement. The implication is that a special LNG bunkering port would have to be constructed for LNG fueling. There are four existing East Coast LNG terminals: Nova Scotia, Boston, Maryland, and Savannah and one Gulf coast LNG terminal in Lake Charles. All of these facilities are intended as receiving terminals for LNG carriers and none could provide LNG to a vessel for fuel as they are presently configured. The practicality of fueling a vessel at an existing LNG facility is low as the amount of LNG to be backed filled would be incredibly small for the investment required and the interference of fueling operations with the main business of LNG import, would seem to be not worth the effort. However, most of these existing terminals have tanker truck loading capability.

Since LNG is 1/600th of its gaseous volume and has a specific gravity of 0.44, it occupies little volume and has a weight less than liquid fuel. It is estimated that a coastal vessel would only need a few hundred cubic meters of LNG to complete a voyage. As an LNG tanker truck carries about 55 M3, only a few truck loads would be required to bunker the vessel for a round trip. Barges are also possible for fueling, either carrying tank trucks on deck, or fitted with permanently mounted deck tanks.

When ports handle a sufficient number of LNG fueled vessels, permanent, peak shaving type LNG storage can be set up in the port.

In the case of a RO/RO, one could also consider LNG tanker trucks staying on board, in the cargo area, and not installing fuel tanks in the vessel.

The logistics of LNG fueling and the final cost of the LNG delivered to the vessel has been the major factor killing a number of proposed European LNG fueled vessel studies. It is thus suggested that the logistics and cost of LNG be determined before substantial engineering is started.

3.1. Peak Shaving Plants

Many gas distribution utilities rely on "peak shaving" LNG plants to supplement pipe line gas supplies during periods of peak demand during winter cold snaps. The LNG is stored in large refrigerated tanks integrated with the local gas pipeline network. The largest facilities usually liquefy natural gas drawn directly from the interstate pipeline grid, although many smaller facilities without such liquefaction capabilities receive LNG by truck. LNG peak shaving plants are often located near the populations they serve, although many are in remote areas away from people.

According to the Energy Information Administration (EIA) there are 96 active LNG storage facilities in the United States distributed among approximately 55 utilities.

Of these facilities, 32 are in the Northeast where pipeline capacity and underground gas storage have historically been constrained. Figure 3 shows the locations of U.S. LNG storage facilities within utilities and marine terminals.

Figure 3 LNG Peak Shaving and terminals in the US

4.0 The cost of LNG as a Fuel

There are more projections of the relative cost of LNG and ULSD than there are LNG facilities in the US and,

as the numbers change daily, there is no set formula that will provide a potential owner with the projected cost of LNG as a fuel.

Table 2 shows one projection for ULSD and LNG in 5-year increments. It can be seen that these projections have already been exceeded with current price of standard DO.

Table 2 : Projected Fuel Prices

Year	Cost ($/gal)	
	LNG	ULSD
2014	1.36	3.44
2019	1.46	3.57
2024	1.55	3.68
2029	1.74	3.91

Additionally, the general cost of LNG will not be the cost of LNG at every US location. Thus designers will have to obtain LNG costs from specific sites within the area of the proposed vessel's operation. Historically, LNG costs were fixed within long term contracts, but that is no longer the case.

When comparing LNG and MDO, or ULSD, it is important to note that the btu content per unit is not equivalent. While there is a btu content variance in both LNG and MDO, based upon source, as a rule of thumb, LNG has about 65% of the btu content of an equivalent volume of MDO.

5.0 Designing the LNG Fueled Vessel

5.1 LNG Consultants

LNG has been around for decades so it is not unusual to find LNG consultants with 40 years of experience. The LNG industry, like many other industries, has many facets, a number of which are not related to the marine environment. To say that one was involved with the XYZ LNG project may mean they were involved in the vaporization and distribution from the shore tank systems. Someone versed in all tank containment systems may have never worked with these systems in other than in a land, static environment. The designer needs to make sure that the consultant selected has experience in his application.

5.2 Regulatory

LNG fueled vessels are an emerging technology and currently, there is no regulatory review process in place in the US. Existing projects have been summarized in a "Regulatory Review of Concept" report where the design had been carried to the point of identifying sizes of equipment, the preparation of piping diagrammatics and the arrangements in the areas of LNG storage and processing. To aid in review, this report should contain a matrix of the relevant rules of the regulatory body to which it is addressed together with action items, or questions, relating to each of those rules.

The only classification society that has presently classed non LNG carriers using LNG as a fuel is DNV. ABS has just published (May 2011) their "Guide for Propulsion and Auxiliary Systems for Gas Fueled Ships".

The role of the USCG in the design of LNG carriers in the last few years has been minimal, however, in the US, the role of the USCG in the operation of all LNG carriers entering US ports, is considerable. Each US port has COTP LNG operational rules that have been in place for many years. The outstanding safety record of the LNG fleet, overall, and of cargo operations in US ports indicates how well these regulations have worked.

The USCG, under Annex ll of Resolution MSC.285(86), adopted on June 1 2009, published "Interim Guidelines on Safety for Natural Gas Fueled Engine Installations in ships".

The purpose of these design notes is not to chronicle all aspects of these guidelines, but to use the LNG carrier COTP regulations to show how operational aspects of fueling a vessel with LNG may affect the design.

5.3 The properties of LNG as they relate to design

- **Sloshing**

LNG is carried at cryogenic temperatures and any spillage onto steel structure will fracture the structure.

As an illustration, a foreign LNG carrier, discharging in the US, had previous problems with low spots in LNG piping and condensation. To make sure the lines were dry; the crew would open small ¾ inch drain lines in the LNG transfer piping, prior to entering the discharge terminal, and blow nitrogen through the empty lines.

In order to maximize LNG tank capacity, while keeping the deck height low, the vessel was constructed with the deck plating against the LNG tank insulation with the transverse and longitudinal stiffeners above the deck plating, forming an egg crate structure.

One drain was inadvertently left open and upon the start of discharge, the ¾ inch stream spewed out for about 3 minutes, before it could be secured. For a 30 foot radius from the drain, the deck plating and stiffeners were fractured, requiring replacement of all of the affected deck structure.

LNG is carried in single or double walled cryogenic tanks and as a light liquid (S.G = 0.44), it's density and viscosity properties make it susceptible to sloshing.

All liquids slosh in tanks at sea to some extent, however, the degree of slosh in LNG tanks is greater than most other liquids in that baffles are not installed in LNG tanks. Sloshing imparts energy to the stored LNG. Imparting energy to any liquid may cause a slight rise in liquid temperature; however, in LNG such a rise can lead to the formation of more gas from the stored LNG than might be desired.

A poorly configured rectangular storage tank, mounted well above the roll and pitch center of a research vessel, could provide more gas than the vessel can use if the research vessel is towing an array, at slow speeds, in heavy weather. The excess gas can be vented at sea, however, in the age of saving every btu possible, venting non- usable gas is not economic. Excess gas can be reliquified, however, in small quantities the energy expended approaches the energy saved. Small reliquifaction plants exist, but they are quite expensive (20 tpd unit costs about $2m).

- **Mission Profile**

The time a vessel spends at sea and in port is important in any design, however it takes on an added dimension in the LNG fueled vessel.

USCG LNG carrier COTP regulations do not allow LNG carriers to vent in port, so it is presumed LNG fueled vessels will also not be allowed to vent in port.

There are many different configurations of LNG containment tanks, some with much better insulation properties than others. Claims from the manufacturer of those tank structures must be carefully reviewed to make sure the designer and manufacturer are speaking on the same terms.

All containment systems have some “boil off” where increased temperature of the stored LNG causes some vaporization of the stored liquid. This starts as a very cold gas layer just above the stored liquid LNG, however, very small temperature increases can raise the pressure in this gas layer to the point the gas must be removed for use, or automatically vented. Containment systems vary considerably with regard to the internal pressure the tank can accommodate.

When a manufacturer indicates his tank will hold LNG, without venting, for 2 weeks at moderate ambient temperatures, the manufacturer assumes the tank is at atmospheric pressure when the period starts. If your vessel has just returned from a rough crossing the LNG tanks might not be at ambient pressure on arrival, unless they are vented, releasing gas you have paid for.

If the LNG tanks are low on arrival and are filled during port time, the filling operation will add some energy to the LNG, forming gas. Unless the filling tank (truck, barge or shore tank) can take back all of the gas formed in fueling, the internal pressure in the vessel’s LNG storage tank will rise.

5.4 LNG Consumers in the Machinery Spaces

Recognizing that any assumed mission profile can change and that LNG storage tank pressure may force venting, the design of machinery should be such that there is always an LNG gas consumer available to reduce LNG storage tank pressure or that reliquifaction can take place as explained above.

5.5 Shipyard visits and Dry- docking

LNG Carriers, in the US, must arrive at a shipyard for a dry- docking, or major work, in the gas free condition. This requires the LNG carrier to stay at sea for a few days burning up any remaining gas and then inerting the LNG cargo tanks. It would seem reasonable to assume the same criterion would apply to LNG fueled vessels, thus some management of LNG fuel amount is necessary when scheduling out of service time. Additional out of service time has to be factored in to get the LNG fuel tanks in an empty and inerted condition.

6.0 LNG Fuel Tank Location and Bunkering

- **LNG Fuel Tank Location**

Of the two possibilities, above or below deck, the above deck location is less complex and less expensive. The below deck location requires zoned separation from other spaces, explosion proof appliance, dedicated ventilation systems and, in general, more controls. LNG tank storage cannot be placed where MDO can be stored (wing tanks, DB’s) and thus the volume requirements are many times that of storing MDO.

On the other hand, above deck locations, well away from the vessels roll and pitch centers, invite greater sloshing and possibly greater structural weight in the installation.

It is generally thought that LNG fuel tanks should be located inside of B/5 to prevent tank damage in the event of collision.

The location in the length of the vessel could be impacted by cargo considerations as discussed later.

- **Tank fill location**

While somewhat dependent on the tank location, the bottom fill location incurs less energy in filling and has the advantage of cooling the stored LNG with the incoming (probably cooler) filling stream, thereby reducing the amount of gas generated.

The top fill location is preferable if there is any remote chance that the fill line could be impacted by any external force.

The choice in fill location with respect to the bunkering station and the lines in between should be such that there is absolute certainty that the line can be completely drained either back to the bunkering station, or to the LNG storage tank.

Remember that a gallon of trapped liquid LNG will result in 600 gallons of vapor.

- **The Shape of the LNG Fuel Tank**

For reasons of sloshing, the most desirable shape of an LNG tank is a sphere. Next comes a cylinder with semi spherical ends and last, a prismatic shape. Incredible arrays of manufactured LNG fuel tanks exist, and, as with all design, other constraints may force the decision on shape.

- **The orientation of LNG Fuel Tanks**

Again, primarily for sloshing, the LNG Fuel tank should be orientated to minimize sloshing. Cylindrical tanks generally should be orientated fore and aft.

6.1 Bunkering

The bunkering station probably cannot be placed inside of B/5 and may be in violation of existing rules. The station and the filling line to the LNG storage tank must be shown to be free of gas at the completion of bunkering. While Nitrogen and inert gas has been used to “blow out” LNG fill lines, it will not work unless the line is 100% full of liquid and a full piston effect results. The inerting gas can blow by, leaving LNG in the line.

The height of the vessel’s LNG fuel tank, above the fueling truck, may be more than the truck’s pumping capacity can accommodate and thus, an interim pumping station may be required. It is thought that a purpose built LNG bunkering barge or shore facility would have sufficient pump capacity.

The bunkering station must have a sizable drip tray installed beneath the manifold manufactured from a cryogenic material. Additionally, it is recommended that this tray, if filled, drain over the side through a cryogenic line that takes the spilled liquid down to the surface of the water. This line should not be run within the structure of the vessel. To prevent berthing damage, it will be necessary that this line swing out of the way during docking and be adjustable for draft changes.

6.2 Bunkering Operation and Cargo Transfer- LNG Fuel tank location

LNG carriers, under COTP rules, are not allowed to load stores, spares or carry out any other operation once LNG cargo has started to be discharged to the shore facility. The LNG carrier is immediately grounded, after berthing, with a metered reading of the potential between the discharge facility and the LNG carrier established and logged. Only then are the discharge lines hooked up.

It is therefore suggested that USCG will have an interest in bunkering operations with regard to the cargo operations of an LNG fueled vessel. If a Ro/Ro, for instance, has a bunkering and fill line arrangement that passes through the overhead of a Ro/Ro deck, it may be that cargo operations will be prohibited in that area while LNG bunkering is taking place.

If a containership had deck mounted LNG tanks forward of an aft accommodation house, it could be that all cargo operations forward of the house would have to be stopped while LNG bunkering, whereas, if the tanks were deck mounted aft of the house, only aft hatch cargo operations would have to be stopped.

6.3 Venting

Every LNG tank installation must have a ventilation arrangement where the exit of the vent is at least 10M from any possible ignition source. This is usually accomplished by fitting a mast type vent above, or near, the storage tank. Often leads from filling line over pressurization relief valves are led to this mast. Unless the vent mast can drain readily back to the LNG storage tank, the liquid dumped in the base of the mast will vaporize often pistoning remaining liquid to the top.

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