LNG AS SHIP FUEL: THE REASONS OF A CHOICE

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ABSTRACT

The consciousness on environmental issue, the stricter emission requirements and the flotation of fuel price are pushing owners to consider alternative solutions to conventional oil fuel. In Northern Europe, where air emission regulations are already effective, a large amount of new building gas fuelled ships have been delivered over the last decade and some ships have been also refitted, considering that Marpol regulation apply for both new and existing ships.

Taking into account the expected enlargement of emission control areas, the social pressure for environmental preservation and the perspective of large amount of methane availability, the paper resumes the reasons for the use of gas as fuel for ships.

According to IMO draft 2014 at moment available and rules/guidelines of some classification societies, a case study is also presented, where particular attention is dedicated to LNG tank dimensions and location, being one of the major impact design factor concerning simultaneously safety, range and ship stability.

1. INTRODUCTION

The quickly evolving requirements for reduced emissions from ships sailing in the costal waters of North America and Northern Europe, together with the probable enlargement of Emission Control Areas, has lead maritime industries to search new design solutions and LNG seems to be the best choice to meet ECA requirements. In fact, there are almost three aspects which make liquefied natural gas one of the most promising new technologies for shipping: first, LNG is clean burning, so it reduces sulphur oxide (SOx) and (NOx) emissions to comply with IMO Tier III limits and it offers much reduced particulate matter emissions as compared to most oil fuels; second, the low carbon content in the natural gas leads to a reduction of carbon dioxide (CO2) emissions by 20 to 25 per cent, compared to conventional fuels; third, current LNG prices are lower in cost than low sulphur diesel oil or other alternate fuels under consideration.

But the change of the propulsion plant from oil to gas requires a more deep analysis, considering also that ships designed today will be in operation for the next 25-30 years and decisions made today will determine the commercial successful of the ship in the years to come. It is evidently difficult to imagine the challenges in the long term, but the short one seems also a bet. Market uncertainties, oil price variation, progressive environmental legislation, pull designers towards a prudent strategy, where flexibility can be the answer in a world of uncertainties. Fortunately, concept and design development is just the last of the three phases composing the whole design process, being business case with market analysis the two initial steps.

From a design point of view, flexibility is many times the opposite of optimization. Looking to design speed, for example, it is simple to demonstrate that a lower speed is the best way of reducing the operational costs and the environmental impact. But, a lower speed is also less attractive when the market conditions improve. Anyway, the ability to link two different speed values can be obtained by newer technologies without redesigning the plant or new power production plant using alternatively energy sources. Therefore, in this case also the use of LNG as fuel seems to be the best practical solution of the problem.

Now, although LNG has been for long time used as fuel on LNG carriers (where the boil off gas evaporating from cargo tanks is burned in the engines or boilers), the adoption of gas as fuel has significant impacts both on ship design and operation, more than just it did when going from coal to distillate and heavy fuel over the past 100 years. In fact, storage and handling issues of LNG are complex, due to flammability and GHG effect in its gaseous state and to cryogenic temperature in its liquid state.

In the following paragraphs, main problems, aspects and case study are outlined, showing alternative design solutions.

2. THE REASONS OF EMISSION REGULATIONS

Climate scientist have concluded that in the next 30-50 years significant and disturbing effects will be unavoidable and some changes are already observable. The primary example are loss of polar sea ice cover and net melting of Greenland and Antarctic land ice, whose effects - when extrapolated linearly - show catastrophic scenarios. Fortunately, climate scientist say also that the mechanism and processes responsible for long term climate change are relatively well understood, so reliable climate models will be available to evaluate the effects of measures to adopt for mitigating climate change. These news have an high social impact, particularly in Europe and western countries, so that a social pressure for regulating the matter has rapidly risen.

Although the weight on global emission of air pollution from ships is about 3% (as for Imo studies), there are some geographical areas where diesel marine engines represent an increasing large air pollution. (Generally speaking, any geographical area where maritime traffic is particularly concentrated, becomes environmental dangerous; harbours hosting passenger vessels and located nearby city centre are the higher expression of this factor). Forecast studies have demonstrate that, without an appropriate regulation, shipping emission could be become the most environmental problem in the next future, comparing to land emissions.

As consequence, in 1997 MARPOL annex VI on air emission regulation has been issued, fixing progressive and stricter emission requirements in order to reduce significantly Nitrogen and Sulphur oxides, unburned hydrocarbons and particulate matter.

3. THE REASON OF AN ALTERNATIVE ENERGY SOURCE

According to MARPOL Code, from 1st January 2015 it is operative 0.1 % SOx limit emission in ECA zone, for all ship systems (main and auxiliary engines, boiler and so on). In the same time, additional emission control areas are expected to be introduced at other coastlines worldwide and some local administrations already apply new rules for ships at berth. These limitation limit values can be only reached by using a more refined fuels with low percentage of sulphur, but the actual desulfuration technique is too expansive and then liquid fuel will not be commercialized. Alternatively, the conventional liquid fuel can also be used, by retrofitting the plant with emission reduction equipments: catalyser for NOx and scrubber for SOx.

One possible approach to meet these emission requirements is based on a changeover of the energy source, adopting NG as fuel for both propulsion and electric power generation. Looking to the history, it is clear that in the past the high availability at adequate cost of oil fuel address designer towards this kind of energy source. In the same time, due to lack of sufficient rules for supply, bunkering and ship design, NG has never been considered a serious alternative to traditional marine fuel. And it is also known that, due to problems always connected to storage, in the past, NG represented a by-product of oil production and generally it was burned off at the well site or pumped back into the oil substrates.

Today, the usage of natural gas is noticeably increased and become more popular, due to industrial and residential applications. Gas reservoir are relatively abundant compared to other fossil fuels and almost worldwide available (more than oil), considering also the availability of Shale gas that represents new chance of gas reservoir.

It is also important to examine regulatory pressure, which may drive the use of NG, considering for example the adoption of the Energy Efficiency Design Index for new ships entered into force since 2013. In fact, EEDI expresses the impact to environment from shipping, according the ratio: impact environment/benefit to society. Due to lower emission of NG compared to oil fuels, there is an immediate advantage in EEDI value and this is an effective cost reduction in some countries like port fees and so on.

4. THE REASON OF SAFETY RULES

All the advantages mentioned above, it must be compared to disadvantages in connection to LNG using. In fact, it needs to take into account as first that natural gas, though found in abundance, is not renewable and hence is not a long term solution to the energy problems and secondly its cost can be affected according the low of supply and demand.

As safety concerns, the main aim is to achieve the same degree of reliability as a ship using oil fuel, but gas release or leakage of liquefied natural gas can have serious consequences:

- even if natural gas is cleaner than oil or coal, methane is in fact a GHG that causes global warming and climate change;
- due to high expansion ratio (1:600) and extreme cold temperature (-161°), during spillage LNG can cause a double risk: frostbite to personnel and brittleness to the closing structures;
- due to wide flammability range, in case of gas release it is present a risk of explosion or fire;
- due to gas toxicity, it is dangerous for human health when inhaled.

Actually, these problems are properly evaluated by IMO guidelines "Interim Gas fuelled code", pending a mandatory code to be included inside SOLAS rules. In addition to the IMO Interim Guidelines, several classification societies have published rules or guides for gas-fuelled ships whose standards are closely aligned with the IMO Guidelines and in some cases provide more comprehensive requirements.

Any kind of hazard is taken into account by the rules, but all the measures considered cannot solve fully the problems related to gas adoption; it could be explanatory the example as follows. In order to mitigate the risks connected to LNG, two basic design concepts for engineering plant arrangements are considered by rules: the inherently gas safe concept and the emergency shutdown (ESD) concept.

For the former, machinery spaces are considered gas safe under all conditions, requiring for example gas fuel piping within engine room boundaries to be fitted in a gastight enclosure (double-barrier for gas), being pressurized with inert gas or ventilated the space between inner and outer pipe or duct.

For ESD concept, machinery spaces are considered gas safe under normal conditions, but have the potential to become gas-dangerous spaces under certain abnormal conditions. In this case, it is allowed single-walled piping inside the engine room but, in the event of gas release within the space, all electrical equipment is automatically shut down.

Both the concepts represent an effective measure for safety, but involve in different manner methane gas release into the atmosphere (by means a vent mast), that is harmful to the environment.

5. THE REASON OF NEW DESIGN

The choice of LNG as fuel has a great impact on ship design and often a dual solution can be adopted, as shown below:

- as main engine concerns, Dual fuel versus Gas only;
- as storage tank concerns, membrane or IMO type "C" tank.
- as propulsion concerns, direct drive versus diesel electric;

- as engineering plant arrangement concerns, inherently safe engine room versus ESD concept.

Any item requires a specific analysis and a multi-attribute approach considering all design data can be useful in this phase, but actually a common solution for all ship types cannot be found. So, it is obvious that different ship types will need different solutions (as shown in the statistical data reported in the follow).

From a design point of view, LNG storage and location is one of the most problem. In order to achieve a better value of gas density, it is convenient to store NG according two different ways: at a very low temperature (-182°C) and atmospheric pressure as liquefied gas (LNG) or at a pressure between 100 to 275 bar as compressed gas (CNG).

The latter is very unlikely to be adopted as a fuel on board because of its very high working pressure and relative safety aspects. Therefore, more frequently gas for propulsion is stored in tanks at atmospheric pressure or below 10 bar, according IMO Type A, B, C tanks, membrane tanks and portable containerized tanks.

Although IMO Type A and B or membrane tanks are more efficient in term of volume space ratio and lower cost per cubic meter, they require a secondary barrier in order to prevent leakage of liquefied gas and present a more evident problem of boil off gas.

As consequence, portable containerized tanks and cylindrical IMO type C tanks are the most practicable tank types for LNG storage, because they do not present problems already shown for the previous tank types and have the advantages as follows: they are built off site and are easy and fast to drop in place; present high volume flexibility for any need and have reduced time of bunkering.

Moreover, the major engine producers for ocean-going ships, are supporting the use of these tank types with their LNG engines, offering packaged system where all of the auxiliary equipment is combined in a tank room at the end of the tank.

Anyway, LNG storage remains not space efficient. It requires more volumes than oil because its density is about the half; this means that to grant the same range of oil fuelled ship, it is required 3 to 4 times more volume for LNG storage.

Moreover, gas tanks must be opportunely insulated and spaced from hull bottom and side shell to limit the risk of external fire load and to prevent damage impact from collisions and groundings. This means that gas tanks should be placed as close to centreline as possible, reducing pay load volumes.

Considering also an adequate redundancy level or backup power, fuel storage should be divided between two or more tanks located in separate compartments, so increasing the volume onboard dedicated to fuel storage.

Finally, the real range of the vessel must be evaluated considering an usable capacity of LNG in a Type C tank of about 85% of its geometrical volume, in order to take into account LNG expansion and residual LNG in the empty tank to keep it cold.

The last ring of the propulsion system is represented by the main propulsion engine, capable of gas burning and the engine types actually available (4-stroke and 2- stroke), cover a great power range (up to 35.000 kW), useful to satisfy the requiring power of any ship.

In the range of the lower power, the choice is between Full gas or Dual fuel engine: full gas engines are four strokes medium or high speed engines that operate on gas only, according Otto cycle, while Dual fuel engines are four stroke medium speed able to operate on both gas and oil fuels. In particular, when it operates on gas, the engine works according Otto cycle, while when it utilizes oil fuel as its source of energy, the engine works as a conventional diesel cycle. The choice depends on many aspects: power plant, space volume available on board and so on. Here, it is only remarked the design impact of both systems:

- Full gas engine optimizes the source of energy, but it requires alternatively two independent gas plants or an oil fuelled back up power in case of emergency and for bunkering operations
- Dual fuel engine has an inherent redundancy as source of energy, but it needs double auxiliary components and fuel tanks; moreover, its ability to burn two fuels with distinct ignition temperature and different physical states, requires a special injection system and an accurate monitoring and electronic control.

The examined design problems show that for many ship types, a new building is often required in respect of a refitting approach.

6. THE REASON OF ACTUAL GAS FUELLED SHIPS

As consequences of technical limitations discussed above, LNG is actually only economically viable for use on ferry, coast guard vessels, offshore supply vessels and, generally, cargo ships engaged in short sea trade.

A total number of 62 gas fuelled ships have been delivered over the last 14 years, 40% of these are Car/Passenger Ferry, 23% are PSV and 5% are RoPax. Figure 1 and 2 show graphically ship types built up until today.

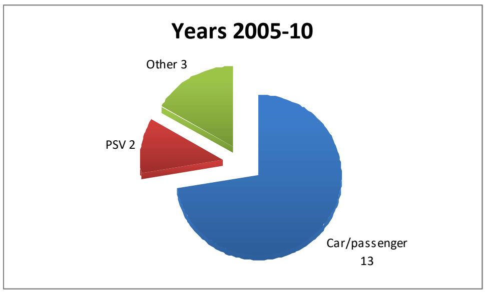

Fig 1. Gas Fuelled Ships in operation until 2010

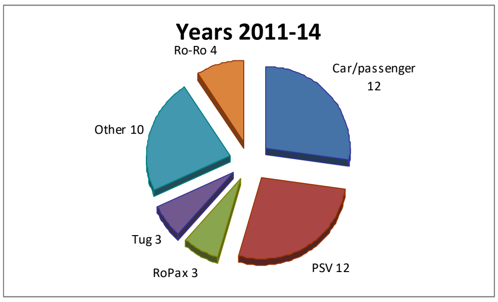

Fig 2. G.F. Ships in operation until 2014

This trend is confirmed by order-book updated on 2014 (Wursig, DNV) as shown in figure 3, where it appears a steady market for Car/passenger ferry and PSV, but it is also evident the growth of gas fuelled Container Ships (+ 25%), that can represent a significant improvement in the field of vessels engaged in unrestricted navigation.

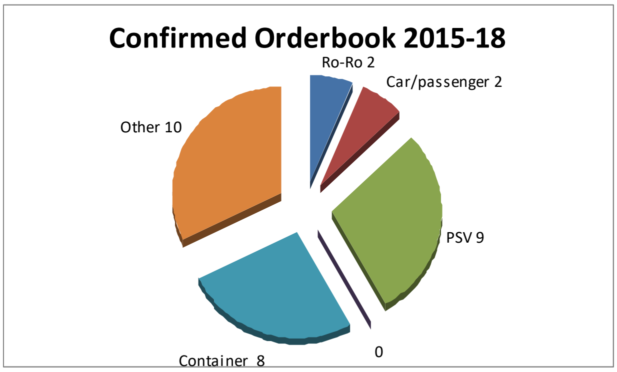

Fig. 3 Confirmed order book 2015-2018

But the fully introduction of LNG in ships depends on factors other than technical ones. It is no accident that most of the gas fuelled ships in operation has been designed, built and classified in Norway and operates in the North Sea.

- Norway has created a reliable natural gas distribution system
- Norway taxes NOx and CO2 emissions and so owners who use NG are taxed less
- Norway has issued safety rules for gas managing and bunkering
- Northern Sea has been classified ECA zone from the beginning

All of the above aspects can contribute to favourite the change of energy source. Therefore, when a technical solution for ship design is found, it begins a socio-political-economical problem.

7. EXAMINED CASE

A preliminary design of a gas fuelled RoRo Pax has been developed, starting from a conventional oil fuelled sister ship of the Owner fleet, in order to compare the obtained results in term of commercial aspect. As referred ship, a Car-Passenger ferry gas fuelled ship Viking Line has been considered. Main dimensions and characteristics of the three ships are reported in table 1 .

Table 1. Main characteristics of the considered ships

	Proposed GF Ship	Fleet Sister Ship	Referred GF Ship
L_{OA} (m)	200	214	218
L_{BP} (m)	180	192	-
B (m)	24,7	26,4	31,8
D (m)	9,3	10	-
T (m)	6,8	7,3	6,8
Δ (T)	17880	18930	-
P (kW)	34200	51360	30400
V (kN)	22	30	22
Pass. N	2500	2900	2890
Cabin N.	350	320	880
Cars N.	819	1085	500

The ship general arrangement of the proposed ship has been designed in order to accommodate both main engine and tank rooms below main deck. At this end, a diesel-electric integrated plan (with 4 main diesel generators to supply both propulsion and ship systems) has been considered for its greater flexibility and operational advantages. In fact, it has been optimized space volume eliminating the gen-set space and adopting a POD system (no shaft propeller, no engine-propeller alignment, no gear reductions).

The specified power plant consists in four Wartsila 9L50 Dual fuel IMO Tier III engines 950 kW/cyl. instead of four Wartsila 12V46 IMO Tier II engine 1000 kW/cyl. for propulsion and a total of about 4000 kW for power generation.

The Genova – PortoTorres round trip voyage (about 240 NM at a speed of 22 knots) has been considered using all engines at 80% of MCR. In order to fix ship range and tank volumes, it could be need to take into account both technical and managerial aspects. In particular:

Bunkering time : It depends on gas quantity
Bunkering metodology : Ship to Ship – Track to ship – Shore to ship
Bunkering operation : During loading/unloading of cargo/passengers or separately
Bunker payment : In full or deferred
Regulatory requirements : Tank segregation

The managerial aspects will not be analysed depending on different factors and border conditions; while as regulatory requirements, IMO Draft 2014 has been applied establishing fuel tank location in such a way that the probability for the tanks to be damaged as consequence of external impact is reduced to a minimum taking into account the safe operation of the ship and other relevant hazards. According these rules, fuel tank location has to respect:

- transversally, minimum distances from ship sides and bottom plating according limit values reported in figure 4
- longitudinally, fuel tank length shall not exceed limit value reported in figure 5, considering also that tanks have to be located B/10 forward aft terminal of the ship and 0,8% L from collision bulkhead

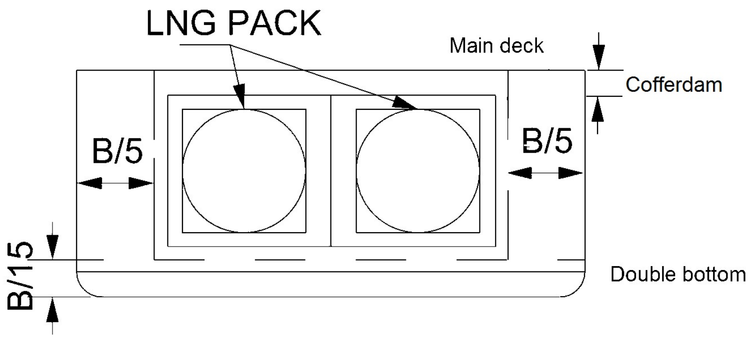

Fig. 4 Tank room arrangement (transversal view)

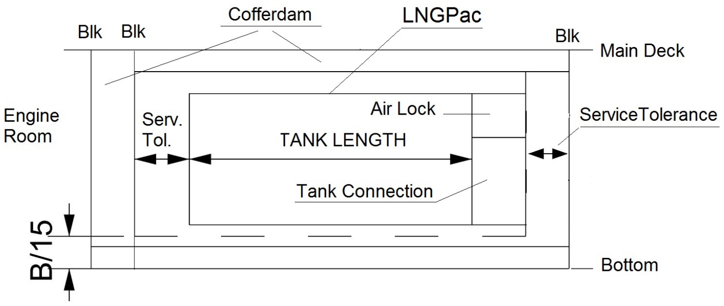

Fig. 5 Tank room arrangement (longitudinal view)

IMO Tank C tanks have been choose, as best compromise between space required on board and respectively: low risk of leakages, easy and fast installation, modular structure. Moreover, using the appropriate packages offered by many engine manufacturers, it is possible to know in advance the effective space/volume/weight of the whole complex: tank + facilities. Finally, two LNGPac 280 Wartsila having a net volume of about 250 m3 each one, have been installed, assuring a range that corresponds to four trips. In such a way, just one bunker operation is need at the departure port, limiting bunkering impacts.

Anyway, two bunker stations have been provided at each side of main deck (3 deck), whose piping is arranged opportunely to fill both the LNG tanks by each station.

Two Main engine rooms and one gas tank room are located below main deck, taking into account the presence of Gas valve unit and cold box, cofferdam length and service tolerances for maintenance, in addition to rules. Figure 6 shows a detail of aft part ship layout.

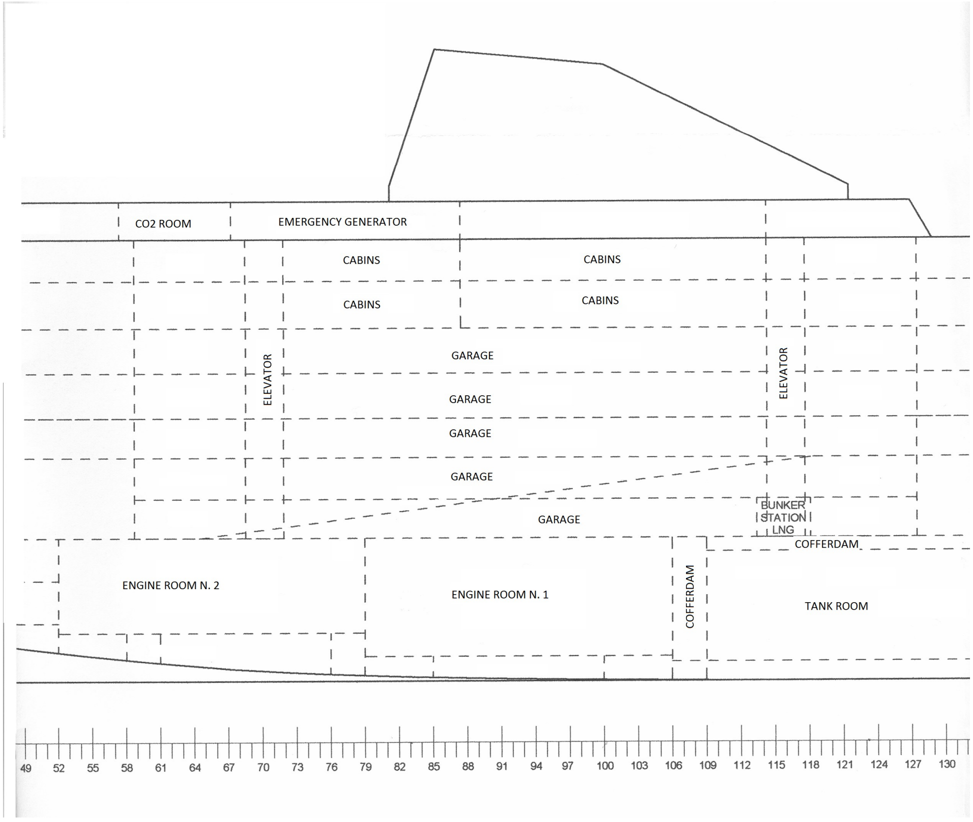

Fig. 6 General plan (detail)

According IMO draft, a venting system is provided connecting each pressure relief valve installed on gas lines; at the end, a vent must is erected on higher deck located at least 10 m. from exhaust outlet of machineries and B/3 (6 m) above walkways.

The evaluation of economic sustainability of LNG respect to oil fuelled ship must consider the different initial investment and operating costs; but, first of all, it is particularly important the ship operations, i.e. if the ship sail in or outside ECA zone and if the ship burns HFO or MDO. These factors affect different ship plant configurations and fuel prices as discussed in Taccani et Alii (2011), Wartsila Technical Megazine (2011) and DNV Technical report (2010) where a more deep economic evaluation has been reported. Limiting the analysis to only fuel price it has been evaluated the cost of one trip for both gas fuelled ship (LNG price 8,95 USD/mmBTU from LNG Journal European Spot and conventional oil fuelled sister ship (HFO low sulphur content with MDO prices) taking into account the values as reported in table 2:

Table 2. Numerical values considered in the case study

	Dim.	Value
Sailing time	[h]	11 h
P (80%MCR)	[kW]	6080
SFGC	[kJ/kW h]	7584
LHV (LNG)	[MJ/m^3]	21328
LNG Price	[$/mmBTU]	8.95

The results show that the advantage of NG is significant when LNG to Oil fuel price ratio is 0.7 (level price in september 2014), saving about 35% for trip. But considering the actual down-turn of the oil market, no significant saving of money is nowadays achievable.

CONCLUSION

To make ships more energy-efficient is today the main challenge of any designers or maritime operators and Natural gas appears to be a real alternative to conventional oil fuel, capable simultaneously to meet environmental requirements and commercial demand.

This work analyzes some general aspects as regards the reasons that can lead to operate a different energy choice on board of ships and technical results can be summarized as follows:

1. Gas impact on ship design is strongly characterized by gas tank segregation as required by rules, that influences ship range and limits actually LNG use for vessel engaged in short sea trade. Most of the ships in operation have gas tanks IMO C type located below deck (horizontal or vertical position) and it is desirable the development of new tanks and relative connections, that can help in the next future to optimize space volume.

2. The required rules for tank protection (active and passive systems) and the measures taken for tank connection and piping, assure an appropriate safety level, while bunkering seems to be the main risk in the LNG fuel operation. This aspect impacts also on general ship operation and therefore it needs more proof studies in order to find a safe way to manage bunkering, possibly even with passengers on board.

3. The switch to the use of LNG as primary energy source on board of ships is already practicable from a technical point of view, but logistical issues can restrain the positive impulse towards green design, depending the final choice on gas availability and diffusion, extension and enlargement of controlled areas, economic incentives and gas price.

ACKNOWLEDGEMENTS

Recognition is given to Dr. Camilla De Rosa and Dr. Riccardo De Luca who provided to develop some calculations and planes in their graduation thesis.

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