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ASSESSMENT OF INNOVATIVE SMALL SCALE LNG CARRIER CONCEPTS

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Bureau Veritas Marine & Offshore

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INTRODUCTION/BACKGROUND

Sophisticated liquefied natural gas (LNG) carriers for break bulk distribution commonly known as small scale LNG carriers have been developed for many years already. The first modern designs are in service for more than one decade. Although this market segment represent less than one per cent of the total shipping capacity, it is still a high value fleet taking into account the unitary cost of small scale carriers.

The concept of small scale LNG carrier has further developed in the past few years due to new developments linked to the distribution of LNG as a marine bunker fuel.

LNG as a marine fuel is step by step taking a relevant position as one of the most interesting solution to comply with stringent environmental regulations for shipping. The global cap of 0,5% of sulphur content in marine fuels established by the International Maritime Organization (IMO) will possibly drive shipowners to consider clean fuels instead of exhaust gas abatement systems in the horizon of 2020.

As a consequence additional LNG bunker supply capacity is required to satisfy the demand and it is expected that new small scale carriers dedicated to deliver this bunker fuel will be deployed in the most important bunkering hubs all over the world. In fact several small scale LNG ships below 10,000 cubic meters have recently entered into service with LNG bunkering ability. These ships are more innovative than standard small LNG carriers and have been designed and built to perform break bulk LNG distribution but mainly distribution of LNG as a bunker fuel.

Specific issues have to be considered during the assessment and validation of the ship's design and during the construction or conversion process at the shipyard. Among others, the transfer system and the issues in relation with the boil off gas management are the most important aspects to be considered.

On this respect, Bureau Veritas (BV) certification and ship classification body was first involved in the classification of small scale LNG carriers more than ten years ago and has become a reliable partner these days in the certification of LNG bunkering vessels, holding over 50% of the market share. Furthermore, BV developed in 2015 specific regulations for the assessment of LNG bunker ships. The so called regulation NR.620 covers safety issues and is currently the instrument to grant the service notation LNG bunkering vessel.

Other innovative breakbulk LNG projects commonly known as virtual LNG pipelines have been developed in the last years in various locations responding to a growing demand of LNG as fuel for power, industrial, domestic and transport applications.

OBJECTIVES

The presentation will address specific technical aspects of the small scale LNG carrier fleet which are also considered during the design phase of LNG bunkering vessels. In addition, we will address some interesting case studies of new buildings and conversions developed with BV class and relevant specific challenges encountered in the frame of the assessment of small scale LNG carriers specially designed for delivering LNG as a bunker fuel.

In addition, the way to assess new breakbulk solutions for the marine distribution of LNG in ISO containers will be presented.

<u>THE MODERN SHIP DESIGNS</u>

<u>Ships size</u>

The LNG bunkering industry for the time being seems to follow the path of the heavy fuel oil (HFO) bunker maritime industry.

A typical size for an oil bunkering tanker is in the range of 5.000 dwt representing approximately a cargo volume of 5.000 m^3. In case we switch into LNG as fuel we will need approximately to double this cargo volume to provide the same autonomy.

However, for some large gas fuelled ships presently on order increased capacities over 10.000 m^3 will be designed even if ports and terminals of operation may have some restrictions related to manoeuvrability for instance and the risk of operating larger ships in commercial ports would be increased.

Ship's dimensions are also linked to the type of Cargo Containment System (CCS) selected as we will describe in detail in the following paragraph.

Containment system

There is a variety of LNG containment systems that can be used in accordance to the main international regulation, the IMO International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code). The Classification societies have their own regulations for the assessment of CCS where safety aspects are also based on the IMO IGC Code.

Type C tanks have been widely used used in small scale LNG carriers followed by membrane systems. However only two units in the range of 20.000 m^3 have been built with Type B Moss type as described in the figure 1 below.

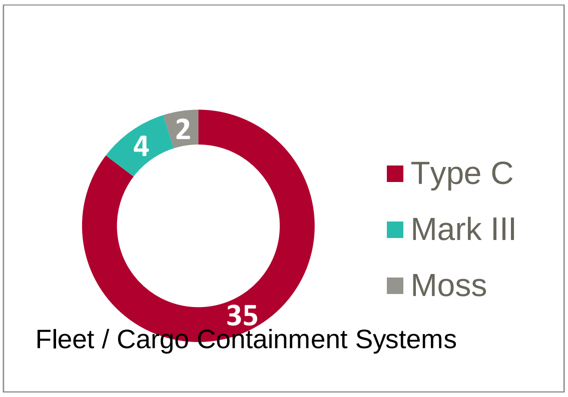

Fig 1.

Prismatic tanks (independent or membrane) are preferred to optimize the cargo capacity or in other words, the ship's dimensions, because the tanks are adjusted to the ship's hull in such a way that void spaces surrounding the tanks are reduced significantly (see figure 2).

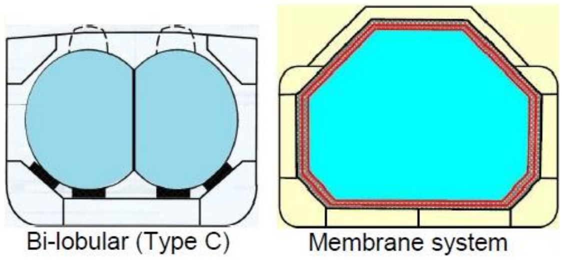

Fig 2.

It has to be noted anyway that following the IGC Code, CCS which require a secondary membrane need to be insulated from machinery spaces by means of a cofferdam. In addition, a cofferdam with heating is usually considered in membrane ships as a transversal division between tanks to optimize the steel grade of the structure. This additional isolation spaces slightly reduce the cargo hold volume available to install the CCS.

Having said the above, the main conclusion is that the volume optimization provided by the membrane and prismatic CCS has further advantage for applications on board of large ships (i.e ships over 10,000 m^3).

On the other hand, most of the LNG bunkering vessels designers prefers type C tanks because of the ability to withstand pressure inside the tank, generally up to 5 barg. As the LNG is boiling and the insulation is not perfect, the heat ingress the tank and vapours are generated leading to a pressure rise. One of the ways to handle the boil off gas (BOG) is by pressure accumulation in the tank. This will be described in more detail in a dedicated part of this document below describing the challenges encountered. However, a pressurized CCS implies reinforcement in the tank structure that gives additional weight.

Consequently another positive aspect for membrane tanks may be the weight of the tank as compared to a pressurized type C. Membrane CCS are designed in accordance to the IGC Code to withstand a maximum pressure of 0,7 barg. The reduction of tank weight may lead to a reduced lightship, very convenient for shallow draft designs or to an increase of cargo capacity for the same draft and dimensions.

In addition to the conventional systems already described, other innovative systems have been recently developed. As commonly requested by the designers, a two tier approval process is offered for the new systems to facilitate marketing the products. In any event classification society and IMO IGC code regulations will apply as a minimum set of requirements to approve the system.

On this respect, the level of approval in principle (AIP) is proposed in the first instance in order to ascertain that there are no showstoppers to implement the CCS on board of a ship. The scope of an AIP is not pre-determined and can easily be developed with a limited amount of documents to be mutually agreed between the classification society and the client.

A more detailed level of assessment called design assessment (DA) or general approval for ship application (GASA) may be performed later when all necessary detailed information is available to assess the CCS in compliance with the class and IMO IGC code regulations. A DA approved containment system can be finally installed on board of the LNG carrier whenever the final investment decision takes place (FID).

Among the systems recently developed new membrane, prismatic type B and A CCS have been recently introduced to the industry and passed different level of assessment.

Another interesting application had been developed by the membrane designer Gaztransport & Technigaz (GTT) with the aim to cope with pressure rise in the tank for LNG bunkering applications. It is the membrane Mark III system with 2 barg maximum allowable relief valve setting (MARVS) which is giving additional flexibility for LNG bunkering vessel applications. An AIP has been granted based on paragraph “Equivalents” of IGC Code chapter 1, but this CCS evolution has not yet implemented in any LNG bunkering vessel.

Propulsion system

LNG carriers have been traditionally built to use the cargo vapours as fuel. The first application being turbines driven by steam produced in dual fuel (DF) boilers. Later on combustion engines burning these LNG cargo vapours were introduced for marine application.

In this last development of the LNG carrier industry basically dual fuel (DF) or gas engines have been proposed for the LNG bunkering vessels to produce energy onboard for propulsion and electricity generation.

The technology is widely available nowadays and different types of engines have been approved such as 4-stroke DF, 4-stroke spark ignited (gas engines) and lately 2-stroke DF.

Different combinations of propulsion can be also used by means of mechanically or electrically driven propellers. Diesel Electric (DE) installations can be also considered giving additional flexibility to the system in combination with azimuthal propellers for instance.

The most popular system for small ships is based on 4-stroke propulsion DF engine(s) coupled to propeller(s) via reduction gear and several DF generator sets connected to a main electrical distribution switchboard. A shaft generator could be also an option to produce electricity during navigation.

An alternative that gives flexibility is a DE plant based on several DF generator sets all connected to the main electrical distribution switchboard and two electrical motors driving azimuthal propellers. The advantages of the system might be the increased manoeuvrability due to this type of propellers, flexibility and reduction of overall running hours for the engines meaning also less maintenance cost. Anyhow, from the CAPEX point of view this solution may be expensive.

A new solution has been proposed already by means of 2-stroke DF engines that will normally drive at low speed the propeller without the need of a reduction gear in between. The BOG consumers in this case will be completed by the necessary 4-stroke DF generator sets to produce the necessary electricity onboard. Nevertheless, this alternative seems to be less appropriate for small ships because of the engine size.

The operational profile of the ship and the area where the ship is to perform bunkering activities are key points for the selection of the propulsion system. A highly variable work load of the engines may be a reason to consider eventually an electric hybrid system to store the electricity produced when burning BOG in batteries and use the energy during peak consumption periods.

Cooling or re-liquefaction systems

Sub-cooling of cargo or re-liquefaction of BOG may be a good method to keep the cargo cool and reduce the pressure in the tank.

Full re-liquefaction systems on board of standard LNG carriers were designed and installed in the Qatar fleet of Q-Max and Q-Flex ships for instance and in other standard LNG carriers. Some of these ships have a very specific requirement to liquefy all the amount of BOG to save the cargo and keep it cool at any time so do not use the cargo vapours as a fuel.

However, re-liquefaction systems are general challenging. The design of this equipment has to take into consideration motions, such as rolling, pitching, etc which have never been design considerations for LNG plant on shore which are not subject to such conditions. In addition, re-liquefaction systems are complex and expensive systems usually based on cryogenic moving components such as piston, screw or centrifugal compressors.

Re-liquefaction systems are based on the principle of a circuit where nitrogen (or mixed refrigerant) as a cooling media is compressed, then expanded and finally circulated through a heat exchanger where compressed BOG is circulated through another circuit. The BOG is condensed when passing through the refrigerant heat exchanger and finally sent back to the cargo tank.

Sub-cooling of cargo is another method used to reduce temperature and therefore the pressure inside the tank. In this case the liquid cargo is pumped to a heat exchanger where the nitrogen loop cools down the cargo.

A recently implemented sub-cooling system proposes to extract the BOG and circulate into the heat exchanger as compared to the standard re-liquefaction systems where the BOG is first of all compressed before being sent for condensation to the heat exchanger.

Transfer systems

The world's first commercial ship to ship (STS) transfer of LNG was performed in the Gulf of Mexico by Exmar and Excelerate in 2005. Nowadays this type of transfer system is certified in accordance to international standards for the transfer of LNG and approved by Class societies. Specific LNG STS transfer procedures were developed by the shipping companies involved and reviewed by the class societies.

The STS operation may be carried out in protected or open waters and has been proven in a wide range of meteocean conditions. Nowadays STS with flexible hoses is widely accepted in the LNG industry and over fifteen hundred STS have been already performed.

Basically two different bunkering systems have been developed. The first solution is based on flexible hoses combined with other systems, such as cranes, davits or tailor made structures to handle the hoses and connections. This is typically the system used in the marine bunker industry. Alternatively rigid transfer systems similar to the already proven terminal loading arms have been also designed and installed in at least one bunkering vessel. The system may be less flexible than the flexible hose solution but may be more reliable.

In any event, the safety of the system must be kept and necessary assessment, including tests will have to be properly done.

Based on all the above accumulated experience Bureau Veritas developed in October of 2015 the Rule Note NR.620. The requirements set out in the regulation cover special arrangements for ships carrying LNG which will transfer that LNG to ships using LNG as fuel.

In particular, this regulation covers the design and installation of the LNG transfer systems within Section 4 from the bunkering vessel to the receiving ship and the vapour transfer system from the receiving ship to bunkering vessel, including LNG hoses, transfer arms and auxiliary systems for handling the LNG system. Another important aspect of the NR.620 is the requirement to perform a risk assessment of the design and the installation of the LNG transfer system.

The purpose of the risk analysis is to assess the consequences of a failure affecting the concerned systems, an LNG leakage, a tank over-pressurization or any other risk leading to safety issues. The required analysis can be a HAZOP analysis or another type of analysis providing equivalent information for the LNG transfer system.

The required analysis is to be based on the single failure concept, which means that only one failure needs to be considered at the same time. Both detectable and non-detectable failures are to be considered. Consequences failures, i.e. failures of any component directly caused by a single failure of another component, are also to be considered.

THE CHALLENGES

Handling of BOG

Vapours resulting from the evaporation of the LNG cargo will harm the atmosphere because of the green-house gas properties of this gas, 25 times more than CO_2. IMO IGC Code does not allow venting of cargo vapours because of this reason and the risk to have a flammable atmosphere.

As mentioned in the IGC Code there are different methods to be used in a gas carrier in order to keep the pressure and temperature in the tank below the setting of the MARVS. The different ways described are as follows:

- Re-liquefaction of cargo vapours;
- thermal oxidation of vapours;
- pressure accumulation; and
- liquid cargo cooling.

The key issue when dealing with the BOG on LNG bunkering vessels is the quite different profile of operation as compared to a small scale LNG carrier.

First of all we have to consider that an LNG carrier, no matter the size, is designed to load the cargo in a terminal, transport the LNG at a normal sailing speed and finally discharge the cargo in another terminal. During the transportation, BOG generated is burnt in the engines on board and used mainly to propel the vessel and for the electrical consumers. Depending on the required power during this phase a part of all BOG is consumed.

Small scale LNG carriers specifically designed for bunkering will normally have less BOG consumption in the DF or gas engines onboard due to the specific operational profile. The way these ships may be operated as longer stand-by periods are foreseen for this type of ships is something to be considered to optimize the BOG management. In addition, LNG transfer to gas fuelled ships may lead to an increased amount of cargo vapours and there might be a vapour return connection to the LNG bunkering vessel to reduce the bunkering time so increased amount of vapours are expected as compared to an LNG carrier. Consequently BOG to be taken into consideration is much more that the amount considered in a small scale ship purely designed for LNG transportation.

As already mentioned new small scale units for re-liquefaction or cargo sub-cooling have been recently developed. These systems have been installed already in big LNG carriers but the technology is evolving and some LNG bunkering vessels have also installed these systems already. Nevertheless the efficiency and reliability of small scale installations remain to be seen as it is a very new technology.

As mentioned in the IGC Code, thermal oxidation method means a system where the boil-off vapours are utilized as fuel for shipboard use or as a waste heat system, the so called gas combustion unit (GCU). Anyhow, for designs equipped with gas engines and type C tanks it is expected that GCU will not be installed.

The control of temperature and pressure by accumulation of pressure is basically related to the selection of CCS. As described above a pressure of 5 barg can be typically considered for type C tanks so additional amount of BOG can be stored for a period of time that is to be calculated and justified by the CCS designer. As an example of holding time please see figure 3 where depending on the cargo tank construction material a duration of 49 days is calculated until the tank reaches 3,5 barg pressure.

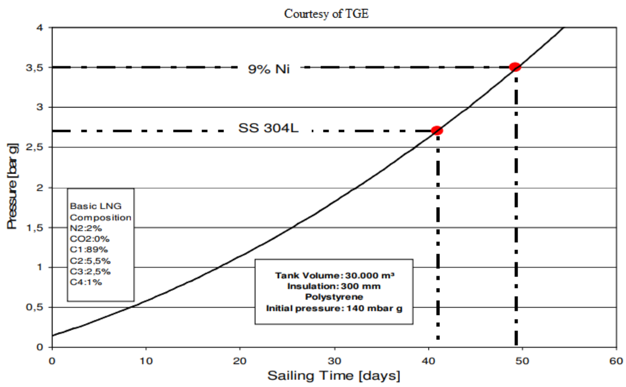

Fig 3 – Holding time for a 30,000 m^3 tank.

As a consequence, pressurized tanks will give additional flexibility to the ship BOG handling onboard. However, having a warm LNG inside the cargo tank does not necessarily help for the typical operations to be carried out by a bunkering vessel. In figure 4 it is shown the relation between pressure and temperature for LNG. As pressure increases, the LNG becomes warmer, as a consequence the density of the LNG decreases and the calorific content of the fuel per volume unit is reduced. Warm LNG as a fuel will not contain the same energy than a cool fuel and increased BOG amount will be generated during the bunkering operations.

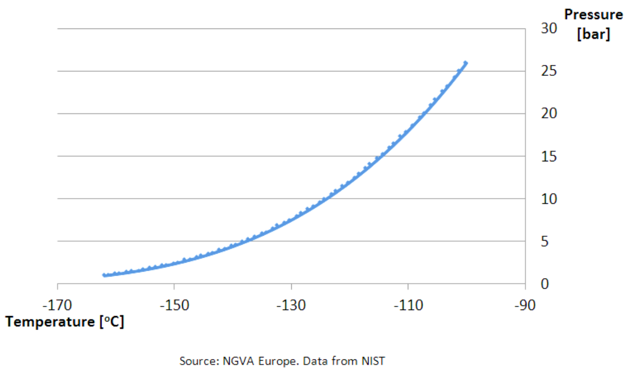

Fig 4 – Temperature vs. Pressure for LNG.

Assessment of the transfer system

LNG is transported at temperature of around -160 Celsius at atmospheric pressure and at around -150 Celsius in pressurized type C tanks whenever there is a pressure rise. As a cryogenic liquid, an LNG spill will cause brittle fractures in the carbon steel leading to cracks which may affect the overall strength of the ship. See figure 5.

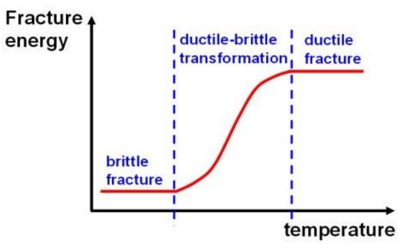

Fig 5 – Energy needed to fracture the material related to temperature.

In addition, once evaporated, the vapours become a low flash point gas flammable in a composition of between 5 and 15 percent in air at atmospheric conditions and with consequential risk of fire if an ignition source is nearby. See figure 6.

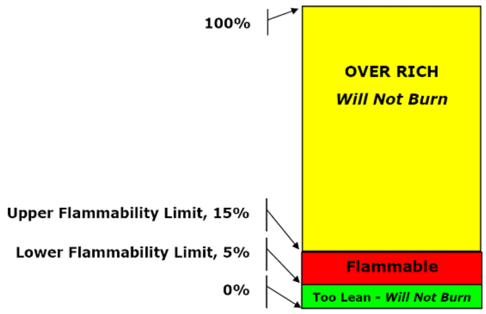

Fig 6 – Flammability range of methane in air.

The components considered in the LNG transfer systems must be designed and manufacturer to avoid LNG spills which may have dangerous consequences.

Different regulations as the NR.620 described above have been developed to assess the transfer systems. On the other hand, standardization is a key aspect in the industry, since LNG fuel supply will not be regional and standard components will be preferable worldwide. For this reason, industry and standardization bodies have been involved in working groups to elaborate the required standards for the different components of a transfer system.

The International standard organization (ISO) published the ISO/TS 18683:2015 covering "Guidelines for systems and installations for supply of LNG as fuel to ships" which also refers to the EN 1474-3 standard.

In addition, ISO has recently developed the international standard 20519:2017 "Ships and marine technology — Specification for bunkering of liquefied natural gas fuelled vessels" which has been published last February and replaces the TS above described. The working group involved in this ISO standard has included a wide spectrum of specialists from the maritime industry, equipment manufacturers, the Society for Gas as a Marine Fuel (SGMF), trading companies, class societies, international registries and the U.S. Coast Guard. In this document it is stated that all the components of the transfer system shall be fabricated to meet or exceed the applicable sections of the engineering standards, the IGC/IGF Codes, in addition to other requirements listed in this document. In particular, elements such as hoses, swivel joints, flanges, bearings, ERS, breakaway couplings, transfer arms and other transfer system will have to be in compliance with EN, BS, ISO and ASME relevant standards.

One of the standards considered in the above mentioned ISO 20519 is the ISO 16904:2016 which actually addresses several issues related to the transfer arms such as the definition of the length and the configuration of the arms, arms description, design basis, swivel joints, structural bearings, accessories, pipework and fitting, welding, corrosion and embrittlement protection and maintenance.

Last but not least there is a new draft document ISO 21593 - Marine LNG fuel bunkering quick connect/disconnect coupling standard (QCDC) still under discussion by means of which a minimum set of standards for the couplings will be proposed.

Operations

An LNG bunkering vessel under operation in a commercial port involves risks that have to be identified. A leak of LNG or vent of natural gas may lead to an escalation of events which would impair other port operations.

Traditionally LNG carriers operate between terminals specially designed for this type of ships. Otherwise, LNG bunkering vessels will be operated in other type of terminals or ports, including oil, chemical or passenger terminals then involving a more challenging operation profile.

Another important aspect to be taken into consideration is the possibility to perform LNG transfer operations simultaneously with cargo operations (including passenger transit in case of a cruise or ferry ship).

As a consequence, Port and local authorities, supported by experts are developing the necessary HAZID studies to put in place recommendations aiming to eliminate risks during the operations of the ship. Filters will be considered including ship transits and LNG bunkering procedures.

Some of the outcomes of the risk analysis in way of recommendations will have to be incorporated in the ship design as well.

As described above, in particular for the transfer system, a Hazop is requested by Bureau Veritas and the outcomes of the study will have to be considered in the system design.

In addition to the risk identification, port authorities and other industry stakeholders have put in place guidelines for bunkering in order to consider all necessary aspects involving LNG bunkering.

Last but not least, simultaneous operations (SIMOPS) are indeed very relevant to LNG bunkering vessels. From the commercial point of view there is generally a need to perform LNG bunkering simultaneously to other cargo or passenger transfer operations. Anyhow, necessary specific studies will have to be performed in order to assess the SIMOPS as local regulators and ports will be aimed to kept safety to the highest level.

CASE STUDIES

A significant amount of projects are assessed by BV since 2011. See figure 7

BV class ships & Barges	Shipowner	CCS	Cap. (m3)	Status
CORAL METHANE	Anthony Veder	Type C	7.500	Converted/In service
ENGIE ZEEBRUGGE	Gas4Sea	Type C	5.100	Delivered/In service
CORALIUS	Sirius Veder AB	Type C	5.800	Delivered/In service
OIZMENDI	Itsas Gas Bunker	Type C	660	Converted/In service
BUNKER BREEZE (*)	Suardiaz	Type C	1.200	Delivered/In service
FLEXFUELLER	Titan LNG	Type C	1.480	On order / 2019
FLEXFUELLER II	Titan LNG	Type C	1.480	On order / 2020
LNG London	CFT & Victrol	Type C	3.000	On order / 2020
Hudong-Z.	MOL	GTT – Marl III Flex	18.600	On order / 2020
Damen Yichang	Eesti Gaas	Type C	6.000	On order / 2020
Keppel Nangtong	Shturman Koshelev	Type C	5.800	On order / 2020
Western Marine Shipyard	Jahre Marine AS	Type C	1.200	On order / 2020
Sembacorp	MOL	GTT – Mark III Flex	12.000	On order / 2021

Fig 7 – LNG bunkering vessels assessed by BV

In the frame of the classification society assessment, most of the above technical considerations and challenges have been considered.

Ranking from 660 to 18,600 cubic meters capacity, the ships included in the above table are specially designed to deliver LNG as a marine bunker fuel.

Engie Zeebrugge is the first newbuilt unit in the world tailor made for LNG bunkering operations. She is owned by Engie, NYK, Mitsubishi Corp. and Fluxys and operates in the port of Zeebrugge delivering LNG as fuel to gas fuelled car carriers. A detailed risk analysis involved firstly in 2013 the general operations of the ship in the port of Zeebrugge was performed and lately the ship has been classed by Bureau Veritas and entered in operation in 2017. The necessary risk analysis and assessment has been also carried out for the LNG transfer system.

The second unit to enter into service with BV class is the Coralius to be operated in Sweden by Sirius Shipping and owned by Sirius Veder AB (a joint venture of the operator and the Dutch company Anthony Veder).

Other interesting projects are under development in Spain and The Netherlands covering newbuildings and conversions for different applications including inland navigation. In particular the conversion of a HFO bunker tanker into multipurpose fuel bunker tanker Oizmendi performed during 2017 and Q1 of 2018 is an example of innovative solution which aims to provide bunker on different available fuels to cover the market expectations in Spanish ports from now.

The last case study to be developed covers the largest LNG bunkering vessel ever. The ship will be built with GTT technology Mark III Flex adding the novelty of the membrane to the LNG bunkering vessel industry. The requirement to develop a large bunkering vessel has been led by Total that will provide the bunker fuel to a newly developed fleet of ultra large container ships (22,000 TEU) gas fuelled under construction in China for CMA-CGM. For this purpose MOL has recently contracted the only Chinese shipyard with experience in the field of membrane LNG carriers, Hudong-Zhonghua. Unfortunately by the time of writing this paper, the project has been just confirmed but some other technical details remain undisclosed. More recently a 12,000 m^3 LNG bunkering vessel also equipped with GTT membrane technology has been ordered confirming a new industry trend.

CONCLUSIONS

A careful assessment of all parts of the LNG fuel supply chain is required to avoid accidents including the new comers of the chain.

The LNG bunkering vessels are becoming a key component of the delivery process considering the growing demand of LNG as marine fuel in the coming years. Consequently, necessary regulations have to be in place to insure that no leaks, vents or other issues occur during bunkering operations or ship transits leading to significant accidents.

Classification societies have been deeply involved in the certification of LNG carriers but specific considerations apply to LNG bunkering vessels and in particular to the transfer system and BOG management onboard.

Different technologies are available to insure the compliance with the regulations issued by classification societies and IMO. Commercial considerations will also take place to help the designers to propose a better solution for every specific application.

Standardization of STS transfer systems and in particular couplings for worldwide operation is key together with a proper identification of the risk involving the ship and its operations to prevent accidents from happening.

A new range of marine applications to break the LNG bulk are available or under development. Specific international regulations can be applied but further regulations may be envisaged to cover innovative solutions in the future.