Tomasz ABRAMOWSKI, Monika BORTNOWSKA
Szczecin University of Technology

ANALYSIS OF DESIGN SOLUTIONS AND OPERATIONAL FEATURES OF NATURAL GAS CARRIERS

Key words

LNG carrier, natural gas, cargo tanks, LNG safety, propulsion system, CNG carriers.

Summary

In the last few years, there has been a dynamic increase in orders for ships transporting natural gas. It results from the fact that natural gas has become third source of energy in the world, after oil and carbon. The article presents a general characterisation of newly built ships for LNG transport, including the design of the hull shape, the design of loading space, the construction of tanks, and the design of the main propulsion system. The forefront technology of gas transportation with the use of CNG ships is presented as well.

Introduction

The natural gas industry is becoming an important part of the world economy with political impact. Each year, the demand for this resource increases by 2%. Natural gas is presently the most desired energy carrier and the development of LNG technology results in the global dimension of the gas trade. Moreover, many countries aim at the diversification of natural gas supplies. Today, natural gas production is strongly concentrated in the Persian Gulf area (41 % of reserves) and in Russia (32%) [1]. This results in increasing gas import (Fig.1).

Fig. 1. Natural gas in the world [1]

In relation to the above it is obvious that the number of orders for gas carriers is growing. At the same time, there are attempts to increase their cargo loading capability which now reaches over 220 000 m^3. The boom for gas carriers results in decreasing prices, due to competition. However, the fact that gas carriers are very expensive remains unchanged due to their difficult construction and operation. Until now, there are only a few countries in the world which construct gas carriers, i.e. France, Norway, Japan, South Korea, the Netherlands, Italy, Spain, USA, and Finland.

It is possible that Poland will also join these countries because of the planned gas terminal in Świnoujście. Natural gas may be transported by sea in liquid phase, compressed, or, due to the newest technology, as a hydrate. Its phase influences the type of ship, its construction, and the equipment of gas terminal. The most popular form of transport is in the liquid phase by LNG ships at a temperature of $-163^{o}C$ and slightly increased pressure of 0.17 MPa.

CNG ships transport gas compressed under high-pressure (about 250 atmospheres) in cylinders. This kind of transport is most economically viable at a short distance up to 3000 nautical miles [2].

This paper, based on a prepared database, contains the characteristics of newly built ships for natural gas in the liquid phase and compares them to CNG ships representing newer and more competitive technology for transporting natural gas.

1. Characteristics of natural gas

Natural gas is a colourless, odourless mixture of many compounds in which methane constitutes 86-96% of the mixture. There are also small amounts of ethane, propane, butane and other mineral and organic compounds [3]. Natural gas in its natural phase as gas is found at normal temperature and atmospheric pressure. In order to change its phase to liquid, it must be compressed and/or cooled down [4].

Natural gas is compressed by being cooled down to the temperature of about –163^{o}C and at a pressure slightly higher than atmospheric (0.035-0.17MPa). After compression, its original volume is decreased by about 600 times, which is a great advantage in transport and storage. Before the compression, all pollutants are removed, such as CO_2, hydrogen sulphide, nitrogen, steam, etc., because they cause corrosion in containers and pipes. After the removal, the obtained LNG's density is half of the density of water.

LNG safety

The threat to LNG safety may be caused by its three main properties [5]:

- cryogenic temperature,
- dispersion,
- flammability.

During its transport, LNG is non-flammable. Potential leaks in a carrier will not cause explosion due to the slightly increased atmospheric pressure and very low temperature of the gas. In the case of a spill, LNG evaporates to the atmosphere and causes *white cloud*. LNG's vapours may ignite if their concentration in the air is 5-15% and in direct contact with the source of ignition (ignition takes place at the temperature of 540^{o}C). In such conditions the explosion may have a powerful effect. However, the possibility of favourable conditions for explosion is slight. Methane may undergo a dangerous reaction with chlorine. The spill may also cause serious frostbites.

The only real danger in today's world would be using gas carriers in terrorist attacks. Therefore, LNG ships are subject to very restrictive legal regulations, etc.

2. Technical and operational parameters of LNG carriers

According to the statistical data taken at the end of 2007, the world fleet of gas carriers contains 246 ships most of which have a cargo loading capability exceeding 100 000 m^3 [6]. Table 1 presents a division of gas containers in respect to the number and capacity of loading containers.

LNG carriers are highly specialised ships, mainly due to the applied transport technology. Providing continuous cooling of the cargo and avoiding its evaporation into the atmosphere have been given high priority. Therefore, the transport of LNG requires very good thermal insulation of tanks from the outer environment. In comparison with crude oil carriers, LNG carriers are medium sized ships. Their dead-weights reach 85 000 t.

Table 1. The world fleet of LNG carriers [6]

Size range of LNG carriers	Number of carriers
Small carriers of loading capability < than 50 000 m^3	18
Medium carriers of loading capability 50 000 ÷ 100 000 m^3	17
Large carriers of loading capability > 100 000 m^3	208
Very large carriers of loading capability > 200 000 m^3	3

They are among the fastest merchant ships. Their average speed is usually 19-20 knots. The loss of cargo, unique in gas transport, has forced the time of voyage to its minimum. Daily loss of cargo caused by its evaporation is 0.15–0.2% of gas volume on average – it depends mainly on the insulation [7]. This is why LNG carriers must have high-power propulsion systems providing great speed - the shorter voyage the smaller loss.

The shapes of LNG carriers and constructional solutions have been much the same for years. Compartment arrangement has not been modified significantly and the shape of hull has shown only the attempts of lengthening the cargo compartment in order to increase cargo capability, which has economic dimension (Tab. 2).

Table 2. Main parameters design of the LNG carriers

LNG carrier	Year of construction	Type of tanks	L [m]	B [m]	H [m]	T [m]	Volume of tanks [m^3]	DWT [t]	V [kts]	Propulsion power [kW]	Cost [mln$]
Arctic Princess	2006	spherical	274	49,04	26,8	11,7	147208	84878	19	21400	165
Energy Advance	2005	spherical	277	49	27	11,4	145410	71586	19,5	24200	-
Maersk Qatar	2005	membrane	270	43,4	26	11,4	145000	77803	20,6	29000	-
British Emerald	2007	membrane	288	44,2	26	11,47	155000	76000	20	39900	185
Al Gattara	2007	membrane	315	50	-	12	216200	-	19,5	37300	216

The [6] three largest gas carriers were built at the end of 2007 in Korea. One of them is Al Gattara with a cargo volume over 216 000 m^3, with membrane system and operational speed v =19.5 knots, and total power of over 37 MW. The applied propulsion is DRL type (slow-speed Diesel with reliquefaction). Total cost of its construction was $216 mln.

2.1. Construction of cargo tanks

Today's LNG carriers transport cool natural gas in one of three types of cargo tanks (Fig. 2).

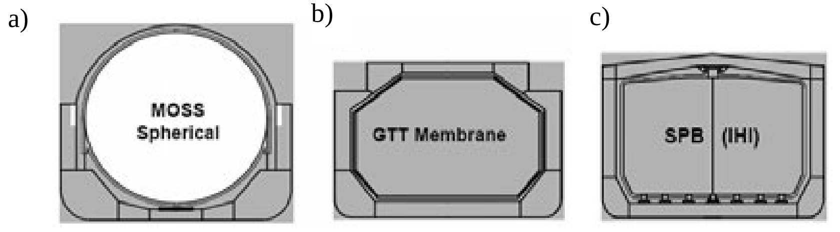

Fig. 2. Types of LNG cargo tanks: a) spherical, b) membrane (for Gas Transport GT No 96, Technigaz TG Mark III and IHI, CS1 systems), c) prismatic in SPB technology [8]

The last type of tank is a new cargo loading system made with SPB technology (self-supporting Prismatic Tank Type B) patented by the Japanese IHI shipyard holding group. This new SPB system was applied for the first time in 1993 and after its modernisation, it will be used in the construction of inventive gas carriers of the M-Flex type by the Korean shipyard Samsung Heavy Industries.

Nowadays, the market is dominated by two types of tanks: spherical and membrane. The percentage of the share of cargo loading solutions in the world is presented in Fig. 3.

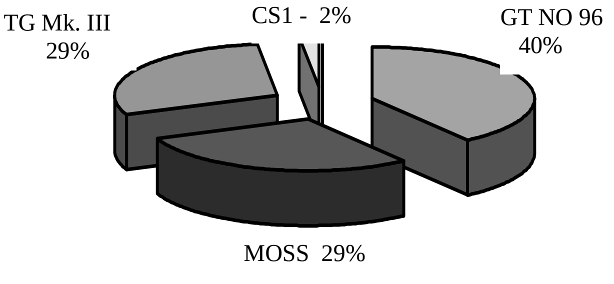

Fig. 3. Percentage share of cargo loading solutions applied in LNG carriers in the world [6]

CS1 (IHI) system is the newest combined membrane system which has the best solutions of Gas Transport and Technigas systems.

Every type of cargo tanks differs, among other things, in construction, kind and the thickness of materials applied in the coating directly touching the cargo, the method of how it was joined with the hull, and in insulation barrier protecting the hull from low temperatures. The main features of the three cargo loading systems are presented in Table 1.

Table 1 Main features of loading tanks of the LNG carriers [8]

Type of tank	Features and properties of tank
SPHERICAL	– independent , self-supporting, – thermally insulated, – made of aluminium alloy, – without internal stiffeners, – with good fatigue properties
MEMBRANE	– non self-supporting, with thin walls, – inbuilt (fits together with the hull into a uniform whole), – internal plating is a secondary protection barrier and hard shell supporting elastically deforming tank
PRISMATIC in SPB technology	– self-supporting, independent – bear loads of cargo, – with thick thermal insulation, – not connected with the hull (do not carry hull loads), – with additional thermal insulation on the internal hull plating, – with tendency to constructional fatigue

The system of membrane tanks shows their advantage over spherical ones, i.e. in their greater safety due to a double hull of the entire ship, good visibility from the navigational bridge because of flat deck structure, better usage of the space within the hull, etc.

The structure of cargo tanks requires special materials in the places they directly touch the cargo. The tanks are made of special steel resistant to brittleness at low temperatures.

2.2. Main propulsion power in LNG carriers

Because of the continuous cargo evaporation during transport, the best propulsion power solution in LNG carriers is steam turbine. The steam turbine and main boilers produce steam using gas or heavy fuel. In spite of poor efficiency of the propelling system, this solution dominates these types of ships and exceeds 94% of all applied propelling solutions.

The advantages of steam turbine include, easy usage of cargo vapours for propelling, readiness of the turbine to move the ship, and the reliability of the turbine (the lowest operating costs comparing to other variants) [7]. Despite these advantages, new solutions for propelling systems in LNG carriers are researched, which are better in respect to fuel consumption, propelling efficiency or the usage of gas vapours from cargo tanks.

The future steam turbines, which could meet the above requirements, may be the following [7]:
- gas turbine,
- internal combustion engine (one fuel -LNG),
- dual-fuel internal combustion engine (LNG, heavy fuel).

Main operating properties of these three options applicable in propelling systems of LNG carriers were widely described in the article [2].

Presently, a few gas carriers in operation have new propulsion solutions, i.e.:
- DFDE (dual-fuel diesel electric),
- DRL (slow-speed diesel with reliquefaction).

Dual-fuel diesel electric (DFDE) propulsion system with combustion engine for heavy fuel and gas as well as propellers with electric drives were installed on BRITISH EMERALD gas carrier which was put into service in the middle of 2007. Driving power exceeding 40 MW provides operational speed of 19,5 knots. The advantage of such a solution is smaller fuel consumption and air pollution. Thanks to putting generators above propelling shaft, the size of the power plant was reduced and the cargo space increased by about 5%. DFDE solution is also applied on three ships built for Gaz de France in 2006/2007: GAZ de FRANCE ENERGY and PROVALYS and GASLEYS.

According to [6], DRL is applied on three ships: Al Gattara, Al Ruwais, Al Safliya. They were put into service at the end of 2007, each with the power of over 37 MW. Thanks to reliquefaction, the cargo is delivered to the recipient without loss.

3. Alternative methods of transporting natural gas

Alternative method of transporting LNG, very often from far-flung corners of the world, is transporting it compressed in CNG carriers. It is not a new solution but more cost-effective, safe and better for the environment. The advantage of CNG technology is avoiding costs of liquefying natural gas and its storage. Compressed gas may be delivered directly through the existing network of gas pipelines [2].

Big gas concerns have seen great potential in this transport technology in recent years. Many companies developed their own transport technology and designed their CNG ships, such as the following:
- EnerSea – VOTRANS – gas is transported in steel vertical pipes in temperature of - 29°C and under pressure of 130 bars,
- Coselle (Williams) – gas is transported in steel coils in ambient temperature and under pressure of 275 bars,

– Knutsen OAS – PNG (*Pressurized Natural Gas*) with steel vertical cylinders in which the gas is transported at ambient temperature and under a pressure of 250 bars, and others.

The advantages of transporting CNG are as follows:

– flexible chains of deliveries which means, among other things, the possibility of adjusting the volume of delivery to the present demand of the market,
– saving the costs of transport, storage and building gas terminals (Fig. 4),
– safety – in the case of spill, CNG evaporates and dilutes in the air, and,
– it is and ecological fuel – during combustion it emits less pollution than oil or carbon and reduces waste gases, i.e. CO, CO_2, NOx.

Costs of using LNG carriers

Costs of using CNG carriers

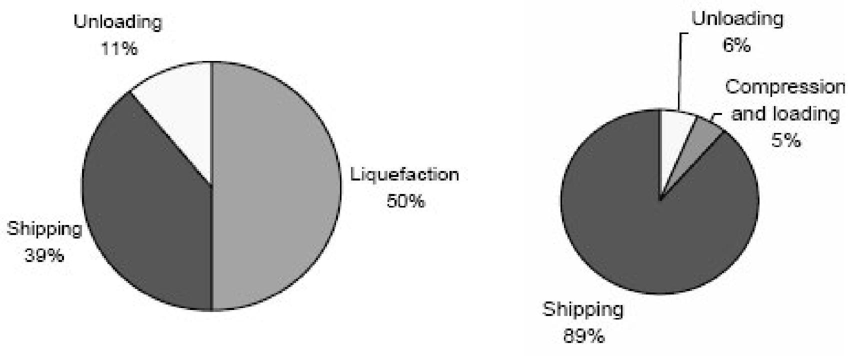

Fig. 4. Cost components for a LNG project and CNG project [2]

The disadvantage of CNG technology is that it has one half to one third of the shipping capability of LNG technology.

Conclusions

For many countries, including Poland, sea transport by gas carriers is the only way to become independent from Russia's gas and to improve their energy safety.

The article presents the main properties of natural gas and LNG safety problems. It also presents technical characteristics of LNG carriers, existing solutions of cargo space, and main propulsion. There are over 200 LNG carriers in service. Their total shipping capability has risen by 50% since 2001 and the rising trend is expected to continue (shipping capability in 2005 reached over 140mln tones per year). According to analysts, the world trade of gas in the form of LNG will exceed traditional delivery methods through pipelines in 2030.

Developing CNG technology and its economic advantages are worth being considered in the plans of importing natural gas to Poland, especially from Norway. The anticipated distances indicate great savings on investments, especially in transport.

References

1. Chairperson Chawki Mohamed Rahal: Liquefied natural gas. Report of Programme Committee D - TRIENNIUM 2003–2006, Algeria, 2006.
2. Deshpande A., Michael J., Economides CNG: An alternative transport for natural gas instead of LNG. University of Houston.
3. Kabaciński J., Kicińska M.: Exploitation of LNG carriers. WSM, Szczecin, 1994 (in Polish).
4. Więckiewicz W.: Outline of the sea ships' construction. Construction and theory of ship. Gdynia, 1998 (in Polish).
5. www.energy.ca.gov/lng/safety.
6. The world fleet of LNG carriers (as of November 12, 2007).
7. Chądzyński W.: Trends of the development of power transmission systems of LNG carriers. Zeszyty Naukowe, 10(82), AM w Szczecinie, Explo-Ship, 2006 (in Polish).
8. LNG Mottaksterminaler av mossmaritime. Norsk Offshore Dag, 2005.

Reviewer:
Oleh KLYUS

Analiza rozwiązań techniczno-eksploatacyjnych statków do przewozu gazu naturalnego

Słowa kluczowe

Statek wydobywczy, instalacja wydobywcza, projektowanie wstępne, oddziaływanie środowiska morskiego, moc systemu sterowania ruchem.

Streszczenie

W ostatnich latach obserwuje się dynamiczny wzrost zamówień na statki do przewozu gazu naturalnego. Wynika to z faktu, iż gaz ziemny stał się obecnie trzecim źródłem energii na świecie, zaraz po ropie i węglu. W artykule

przedstawiono ogólną charakterystykę nowo zbudowanych statków do przewozu LNG, m.in. kształtu kadłuba, rozwiązanie przestrzeni ładunkowej, konstrukcja zbiorników, rozwiązanie napędu głównego oraz charakterystykę innowacyjnej technologii transportu gazu przy wykorzystaniu statków CNG.