

Review Article

Application of Natural Gas in Ship Engineering

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ABSTRACT

Traditional ships are mainly fueled by diesel or gasoline, which are produced from the oil and are non-renewable. People are now rapidly consuming oil and burning oil generates poisonous gases day and night. Because of the soaring oil prices and the deteriorating ecology, many ship-owners are seeking an alternative energy to replace oil. Among all possible candidates, the calling of natural gas is getting higher and higher. This paper discusses the application of natural gas in ship engineering, and explains in detail the advantages and disadvantages. Natural gas may not be a new energy but has rarely been used in ship engineering so far. We conclude that its application in ship engineering helps to alleviate the fuel shortage in the future.

KEYWORDS: Natural gas; Ship engineering; Power plant specification

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1. The origin of natural gas-powered ships

Norway as the liquefied natural gas (LNG) producer, initiated the energy revolution. In order to improve the gas fuel technology and access to good environment, in 1996 the Norwegian Parliament decided to build CNG and LNG as fuel for two types of vehicles / passenger ferry. In 2000, the world's first ferry ship 'M / F Glutra', which was fueled by LNG, was completed by the Aker Shipyard. Using LNG fuel, the ship reduced emissions of nitrous oxides by 80%, but the cost was 30% higher than that of diesel fuel ferry. Shipyards and operators were aware that that the cost of applying a new technology would reduce when it matured in the future, and the cost increase was in the acceptable range.

2. Advantages of natural gas-powered ships

2.1. Environment-friendly

At present, oil and coal are the most prevailing ship fuel, while their burning emits a large number of toxic gases, including oxynitride and sulfur oxides, which are the main cause of acid rain. In addition, the large emission of carbon dioxide induces greenhouse effects. At present, the national sailing ships emit nearly 1.2 billion tons of carbon dioxide per year, accounting for ~ 6% of the global emission. Emitted oxynitrides and sulfur oxides account for 20% and 30% of global emissions, respectively. The ocean and atmosphere are also heavily polluted by mineral fuels as well. Therefore, reducing emissions of harmful gases in energy systems has become a key issue in improving the global environment.

The MEPC58, held in October 2008, passed the amendments to MARPOL Annex V1 to propose further requirements for the emission of air pollutants from ships. Revised from 1st January 2012 onwards, the sulfur content of the ship's fuel oil

decreased from 4.5% to 3.5%. It was estimated to gradually reduce to 1% by 2018 and to 0.5% by 2020. The main component of natural gas is methane, which is the simplest carbon fuel in nature. When at -160 °C or below, it is compressed by 600 times in volume and becomes solid concretes, easy to store or transport. Natural gas does not contain impurities such as sulfur and aromatics, and the sole combustion product is carbon dioxide, causing almost no pollution. Therefore, it is a reliable and environment-friendly fuel.

2.2. The Economies

The domestic diesel price was 2,000 RMB per ton in 2000 and increased to 9000 RMB per ton by the first half of 2012. The soaring prices greatly increased the shipowners' operating costs. At that time, natural gas as a less-cost fuel draw their attention. Per caloric value, the price of natural gas was only one quarter to one third of the fuel price. At present, China is the world's largest importer.

2.3. The Safety

Natural gas is usually stored in the cryogenic liquid form. When a leakage happens, it will soon gasify and rise above because it has a density lower than the air. Therefore, under no conditions it would pollute the water. Natural gas is usually mixed with thiol in storage, which is non-toxic but has an unpleasant smell. Thiol serves as the indicator to alarm people the leakage. Natural gas is hotter and brighter in burning than are gasoline and diesel. In terms of usage safety, it is much better than fuel.

3. Disadvantages of natural gas-powered ships

3.1. The bulky storage.

Natural gas storage tank occupies a large space: 4 times the volume of a traditional diesel tank, and weights 1.5 times the weight of a traditional diesel tank. This will significantly reduce the volume throughput of cargo transportation.

3.2. The higher operation cost.

The cost of a natural gas-fueled ship is 5-20% higher than the cost of a traditional diesel-fueled ship.

3.3. Lack of technical and safety regulations.

At present, only DNV has made the relevant classification standards for natural gas-fueled ships, while most countries have not yet introduced relevant government regulations for technical standards such as LNG marine fuels

3.4. The initial cost of natural gas vessels is higher.

It is understood that the cost of an LNG storage tank is a few million dollars. This price normally discourages a lot of ship owners. However, due to the increasingly stringent regulations for ship emissions, the Nordic countries such as Denmark and Norway have already started to employ LNG fuel ferry in ro-ro ship, coastal garrison, LNG ship and platform supply ship.

3.5. The Noise

For gasoline-fueled ships, diesel engine is the largest noise source. Modern diesel engine commonly requires high pressure: the cylinder burning (burst pressure can be up to 20 MPa) will issue a spiking noise. The supercharger may speed up to 20000 rpm and yields severe high-frequency noise. The exhaust valve of a four-stroke diesel engine keeps repeating the cycle of opening and closing, producing a harsh percussion. Large-scale ocean-going vessels have higher technical standards and relevant specifications, and there are soundproofing devices well equipped in the cabin. They are generally able to meet the requirements of China's *Transport Ship Chamber Noise Standard* and *Transport Ship Chamber Noise Measurement Method*. Small ships use loud-noise medium and high-speed diesel engine as a power plant, many of which had no control room. Long-term exposure to loud noise may lead to severe hearing loss, physical and mental health.

Natural gas turbine uses gas turbine. When in use, there are three main sources of noise: intake/exhaust noise, body radiation noise and structural noise. Under normal circumstances, the body radiation and structural noise are smaller than the noise of a diesel engine, but a gas turbine requires a large air flux so its intake and exhaust noises are significantly louder than the diesel engine.

4. Introduction of natural gas power plant

4.1. Steam Turbine

The steam turbine propulsion system mainly consists of boilers, steam turbines and gear reduction gears. Its working principle is that the steam generated by the boiler flows through the steam turbine, converting its heat energy to kinetic energy to drive the turbine rotor. Steam turbine dominates today's global LNG ship propulsion system because of its high output power. Other turbines cannot output sufficient power to drive the LNG ship at a high speed. In the steam turbine system, both LNG evaporation steam and heavy oil can be used as fuel for the boiler. It is said that mixing LNG evaporation steam and heavy oil at appropriate proportion will increase the power in combustion. The combination of the main propulsion system, the main boiler and the steam turbine effectively enables a safe handle of the steam evaporator. For a long time this combination has only been mastered by a few developed countries, while the market for a long time was in a state of oversupply. As LNG price decreased, the steam turbine system became more economic friendly. Other main propulsion systems were more or less at technical bottlenecks and became an obstacle to LNG owners' propulsion systems. After decades of development, the steam turbine system now has to some extent become the standard power system for LNG ships.

4.2. Gas Turbine

LNG ships using gas turbine can be driven by mechanical or electric power. The gas turbine is lighter in weight, has no vibration, and can use dual fuel (using heavy oil as a backup fuel). Its inefficiency can be compensated to some extent through a combined cycle system. However, gas turbines have higher demands on power stations and gas pressures, which make installations more complex and costly.

4.3. Compound Turbine Unit

The compound turbine unit (i.e., the gas turbine engine or steam turbine engine) is used to produce steam turbines while using steam turbines to burn steam. The fuel efficiency of this engine is better than that of a typical steam turbine, and the exhaust gas is the as clean as the steam turbine engine. The disadvantage is the need of high-quality petroleum fuels and cannot be combusted with steam. The future may also be considered in conjunction with the electric propulsion device. From environmental factors to consider the future may be the use of such a propulsion system.

4.4. Dual fuel power propulsion

The development of dual-fuel engines (fuel and steam) has made it possible to make efficient use of vaporized fuels, which have evolved from heavy oil diesel engines. So the employment of dual fuel engine propulsion device makes a modern LNG much more competitive. The internal combustion chamber of a dual fuel engine is specially engineered, which can burn LNG vapor and fuel directly, with high or low pressure. The low-pressure dual-fuel diesel engine can pump the vaporized LNG gas to the ship at a lower pressure (about 4 bar / cm²), and the high-pressure dual-fuel diesel engine can inject the LNG gas injected into the combustion chamber. The jet gets into the combustion chamber, burning under light oil ignition. The former faces potential high-pressure LNG pipeline leakage, and the latter need additional configuration of the ignition device. According to the relevant information, in the Norwegian offshore project, a small LNG ship employed a dual-fuel engine as the main propulsion device, but the system needs an additional evaporative steam oxidation device to support it.

Compared with the conventional power plant, the use of dual-fuel engine not only maximized the use of steam, but also greatly reduced the fuel consumption and operating costs (can save 20-30% fuel) and therefore improved the efficiency.

On a 135,000-cubic-meter LNG ship, MAN B0026W Diesel Engine Company compared the steam turbine with heavy oil with a dual-fuel engine with heavy oil and natural gas. Dual-fuel engine had a very low emission: the nitrogen oxide emission was only equivalent to 1/10 of the nitrogen oxide emission of a common diesel engine. Carbon dioxide emission were also quite low. Since the dual fuel engine could be operated alternately in both the gaseous fuel and the liquid fuel mode, and the two modes are automatically switched, the engine does not stop running when the gaseous fuel supply is stopped but is automatically switched to the liquid fuel mode. With the continuous development of marine power plant, dual-fuel engine with its use of dual fuels, light weight, lower manufacturing costs, etc. will become an important choice of propulsion device for LNG owners in future.

5. China's natural gas fuel power ship specifications

With the increasing use of natural gas in ships, the 'Natural Gas Fuel Power Vessel Code' was released. It is based on the CCS 'Gas Fuel Power Boat Inspection Guide' (2011), 'natural gas fuel power ship key technology research', 'marine LNG fuel tank structure key technology research' and a large number of practical research results, in accordance with the target type standard (GBS) and risk assessment concept developed for the natural gas fuel for the steel specifications.

Relative to the 2011 version of the 'Guide', the main changes in this specification are:

- (1) On the basis of 'Guide', adjusted the specification structure from the point of view to ease of use, and add the technical requirements of the four key products of the gas tank, the gas fuel engine, the electronic control system and the heat exchanger 4 as the 4 Appendix.
- (2) Revise some of the contents of the original guide, increased the requirements of the gas tank connection, the piping test, the gas valve unit, the storage area in the semi-enclosed space, the layout of the air supply pipe valve, Tank space, the cabin air supply system, the gas fuel engine functional requirements and other contents.
- (3) The new gas fuel filling, natural gas standard filling the relevant technical requirements.
- (4) The risk analysis concept throughout the specification had always been the new failure mode and impacted analysis (FMEA) requirements.

6. Status of natural gas-powered ships in the global market

In the global marine gas development, only a few ferry, cruise ships and other fixed-point transport of ships in a few sporadic countries use natural gas as a marine fuel. Most of the world's marine natural gas applications are in Norway. Natural gas carriers are mostly diesel and BOG dual power systems, and the propulsion systems without exception are steam turbine power plant. At present, more than 300 LNGCs and BOG are used as fuel for steam turbines.

However, the LNG fuel economy advantage is driving the development of marine LNG. The prices of crude oil supply are unstable, and the international LNG prices in 2009 decreased after the sharp decline in oil prices. From the fuel costs and other economic considerations, burning LNG is much less costly than burning diesel.

At the same time, the international ship emission standards will promote the rapid development of marine LNG. In recent years, the International Maritime Organization (IMO) has strengthened mandatory provisions for marine ship emissions, and if countries have implemented mandatory emission regulations for IMO, most of the world's vessels for offshore trade will use LNG after 5-10 years as a marine fuel. The focus area of future LNG marine fuel international market development is the Baltic region, the North Sea and the Mediterranean region.

At present, the international LNG fuel ship power system is produced mainly by four companies: Wärtsilä, MAN, Rolls-Royce and Mitsubishi Heavy Industries. Wärtsilä and MAN produce dual-fuel engine-based, and Rawls Royce and Mitsubishi Heavy Industries produce gas engine.

Japan and South Korea are the main LNG hull manufacturers. Mitsubishi Heavy Industries is the supplier of many LNG fuel ships. In 2009, Japanese merchant ship Mitsui announced the design concept of LNG fuel ferry 'ISHIN-II'. Daewoo

Shipbuilding and Marine Company are currently developing large-scale container for LNG-fueled ships. MAN and other companies are working together to develop the ME-GI engines and DSME high pressure cryogenic fuel supply systems for 14,000 TEU container ships.

7. Development of natural gas-powered ships in China

At present, the domestic use of marine natural gas is basically blank. In China, LNG fuel has not yet been applied to the marine field, but in the past two years, some of the LNG industry technology companies have tried to promote it. There are a variety of mainstream diesel engine models have been carried out bench test, and through the relevant departments of the identification of acceptance, the technical and economic feasibility were proved. In addition, under the government's 'energy-saving emission reduction policy' guidelines, the riverboat converted LNG fuel will become the focus of development.

In future, on the one hand China's inland river LNG ship number will grow rapidly. China's inland waterway is rich in resources, with 5800 large and small natural rivers, with the total river length of 430,000 km, and with the huge demand for inland waterways. In the context of energy saving and emission reduction, it is of great practical significance to develop river LNG vessels to prevent and control ship pollution on the basis of increasing LNG receiving stations. It is expected that over the past three years, there will be more than 50,000 ships to be converted, directly driving the value of energy equipment up to 26 billion RMB in the market increment. On the other hand, the state is to increase capital investment to promote the development of inland waterway, and LNG shipbuilding constitutes a strong support. Ministry of Transport Deputy Minister Xu Zuyuan said, during the 'Twelfth Five-Year Plan' period, the central government will arrange 45 billion RMB of financial funds to broaden the channel to support the security system and the central and western regions of the port and other capital investment, while arranging 5 billion RMB financial guidance funds to promote the standardization of river ship type and structural adjustment of capacity. This means that the inland shipping investment of the '12th Five-Year' period increased by 2.7 times than the 'Eleventh Five-Year' period.

8. Natural gas power ship in the future development prospects

The Lloyd's Register (GL) is currently studying the feasibility of using LNG as a marine fuel. A member of the board said that taking the volume of LNG storage tanks into account, large ocean-going container ships were unlikely to fuel LNG, but for small-scale feeder vessels operating in the Baltic region, LNG was more feasible. Although container ships using LNG will be more expensive than conventional fuel container ships, the former has lower fuel costs and fewer emissions. 'The natural gas propulsion system will be one of the main contributors to future green shipping', said Bernard A. Nne, general manager of the ship's department. 'The use of natural gas as a ship fuel has the advantage of reducing pollution emissions', said the French classification society. Natural gas supply is abundant, has a price advantage and low sulfur content. We have been studying the possibility of retrofitting existing vessels. According to GL, two 1,500 TEU container ships with LNG and heavy oil fuel are compared each year. The income for the owner will be \$200,000 lower than the latter. This is because the volume of LNG storage tank is larger, resulting in a 3% lower carrying capacity than the latter.

However, with the increasingly stringent regulations on ship emission, the latter is more economic due to the cost carbon dioxide emissions. According to calculation, the profits of shipowners using two types of fuels are almost the same. Based on the above analysis, GL predicted that by 2012, LNG-fueled container ships would appear in the Baltic area where ship emission control was stringent. At a World Gas Forum held in northern Europe, the company learned that under the relevant convention, the Nordic would promote the use of LNG marine fuel systems to protect the marine environment. Haworth company officially said that LNG fuel system could improve the ship's economy and environmental protection, reducing its operating costs and storage costs.

By 2015, nearly a thousand ships in the Nordic region would stop using diesel but use natural gas, and thereafter the new ships operating in this area will also install LNG fuel systems. It is predicted that the Nordic market demand for the system

will reach hundreds of units each year. Wu Fang said that the using natural gas to replace diesel would reduce the fuel cost for about 1/3. ‘The global shipping industry has the potential to achieve a 30% reduction in emissions by 2030’, said Remi Eriksen, executive vice president of DNV (Det Norske Veritas), ‘The most effective measure is to use LNG as fuel’. The Nordic countries, such as Denmark, Norway, have begun to use LNG as fuel ferry on ro-ro ship, coast guard ship and platform supply ship.

9. Natural gas power ship development problems

9.1. Reconstruction of existing fleet and natural gas storage infrastructure is lacking

First of all, the biggest obstacle is the construction of supporting infrastructure, because most of the port natural gas supply facilities are not matched, although the supply is not difficult. The port has not established a complete and practical supporting system, as lack of popularity of gas vehicles, natural gas on the use of the ship has also received constraints. The construction of natural gas supporting infrastructure involves the planning and layout of the port, which require the planning and cooperation between governments.

9.2. Natural gas fuel tank life is still weak

At present, the highest endurance capacity of natural gas as ship fuel is still low. Studies showed that natural gas-powered ships could be operated for no more than 22 days, which is below the requirement of long-distance ocean transportation. The reason is the large size of the fuel tank. Multiple small tanks can be placed anywhere on the ship but the control system is complicated and the layout is difficult. The installation of the cylindrical natural gas storage tank will also occupy part of the transportation space. This is a great difficulty for the design and alteration of the ship.

9.3. No uniform standard for natural gas technology

There is no uniform standard for natural gas technology, and there is a difference between the various classification societies. In view of these problems, first of all, we should increase the ‘oil to gas’ efforts to strive for faster popularization of this technology; secondly, to accelerate research and development of ‘Note barge’ and other new technologies, the government needs to increase LNG infrastructure construction.

10. Conclusion

LNG industry can be described as a great potential for development and with greater uncertainty in the emerging industries, which has not yet achieved a wide range of promotion and application at this stage. At present, the main factors that affect the rapid development of LNG fuel ships include the lack of infrastructure, the constraints of shipbuilding technology, the lag of standardized development, the obvious advantages of natural gas prices compared with the advantages of oil prices, the different attitudes of governments and the public's understanding of natural gas, so a wide range of joint efforts in future are in need to conquer these limitations.

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