Compressor for LNG Carriers

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Abstract

Due to the need to comply with environmental regulations for ships, dual-fuel engines that can use natural gas in addition to heavy fuel oil have been adopted in nearly all newly-built LNG carriers in recent years. While there are two types of propulsion engines, low pressure (X-DF) and high pressure (ME-GI), our company offers the optimal compressors for fuel gas supply for each type. This paper outlines the fuel gas supply system for propulsion engines that uses boil-off gas (BOG) generated from the LNG tank of LNG carrier, including the re-liquefaction of excess BOG while also explaining the characteristics of oil-flooded screw compressors and reciprocating compressors for this application. Furthermore, it discusses the prospects of technological development for other environmental vessels, such as liquefied hydrogen carriers.

Introduction

Tighter environmental regulations imposed by the International Maritime Organization (IMO) have caused the shipping industry to focus on low-speed, dual-fuel engines capable of burning both heavy fuel oil and natural gas. Nearly all LNG (liquefied natural gas) carriers built in recent years have these types of propulsion engines. Examples include MAN Energy Solutions' electronically controlled gas injection diesel engine (hereafter, ME-GI) and WinGD's dual-fuel engine (hereafter, X-DF), which employs a low-pressure gas injection system for premixed, lean-burn fuel. Both require a compressor to supply natural gas as fuel. The projected rate of LNG carrier construction is anticipated to be around 30 per year around the world, meaning there will be continuous demand for compressors for propulsion engines. Kobe Steel has a strong track record in providing fuel gas supply compressors (screw compressors and reciprocating compressors) for this application. This paper discusses compressors for LNG carriers and the prospects for their application to liquefied hydrogen carriers, which have seen progress toward commercialization in recent years.

1. Gas supply system for LNG carriers

LNG carriers have systems that use the boil-off gas (BOG) generated by the LNG tank during navigation. BOG is used as fuel for the propulsion engine. In most systems, when the engine is stopped or operating at low load, surplus BOG is recovered by a re-liquefaction system, liquefied, and returned to the LNG tank. This section provides an overview of representative gas supply systems and key compressor specifications.

1.1 Gas supply system of ME-GI

Fig. 1 depicts the gas supply system of an LNG carrier with an ME-GI. The amount of BOG generated depends on the tank and its insulation capacity and ranges from 3.0 to 5.0 t/h. A reciprocating compressor boosts the pressure of the BOG to around 30 MPa for supply to the ME-GI. Some BOG is pressurized to around 1 MPa and sent to the dual-fuel diesel engine (DFDE) for shipboard power. Surplus BOG is pressurized to around 15 MPa and sent to the re-liquefaction system, where it is liquefied and returned to the tank to improve LNG transport efficiency.

1.2 Gas supply system of X-DF

Fig. 2 depicts the gas supply system of an LNG carrier with an X-DF. A screw compressor boosts the pressure of the BOG generated for supply to the X-DF at around 1.3 MPa. Some BOG is diverted and reduced to a pressure of about 1 MPa for supply to the DFDE. The reciprocating compressor further pressurizes surplus BOG to around 15 MPa and

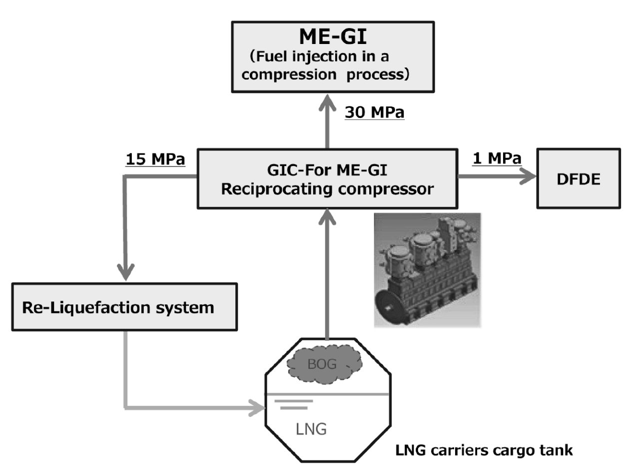

Fig. 1 Gas supply system of LNGC ME-GI

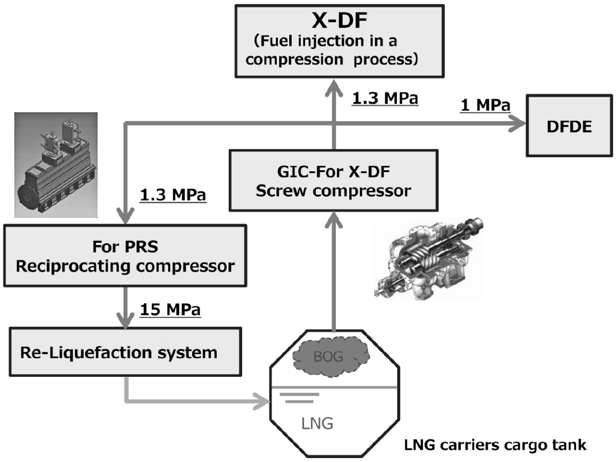

Fig. 2 Gas supply system of LNGC X-DF

sends it to the re-liquefaction system, where it is liquefied and returned to the tank to improve LNG transport efficiency. There are at least two other valid system setups. One is to use a refrigeration unit to reliquefy gas at the supply pressure of the screw compressor (around 1.3 MPa) instead of using a reciprocating compressor to boost pressure. Another is to install a re-liquefaction system with a refrigeration unit directly on the LNG tank to minimize BOG generated by the tank.

2. Screw compressor for LNG carriers

2.1 Structure and basic system

Kobe Steel's X-DF gas supply systems use oil-flooded screw compressors. Screw compressors combine the characteristics of positive displacement and rotary compressors to feature high efficiency, compactness, and long-term operating capacity. Oil-flooded screw compressors, which inject oil into the compressed gas, can achieve high discharge pressure and compression ratios in a single stage.[1)] **Figs. 3** and **4**, respectively, show Kobe Steel's screw compressor for LNG carriers and its system configuration.

Gas at around atmospheric pressure is brought to the appropriate temperature using a pre-heater. It then passes through a filter and a check valve before being compressed to about 1.3 MPa. In an oil-flooded screw compressor, oil is injected into the gas stream for multiple purposes, including lubricating the rotors and bearings and removing heat from compression. This oil must be separated and removed from the gas to meet the permissible oil content limits of the X-DF and the re-liquefaction system.

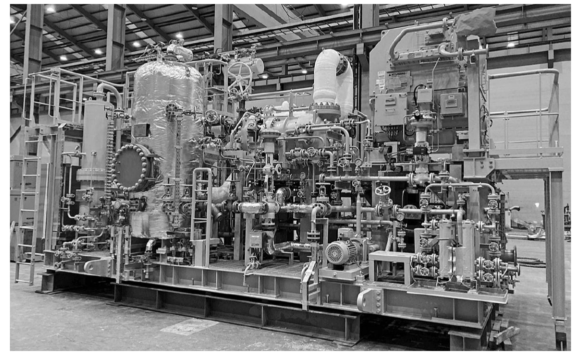

Fig. 3 Appearance of oil-flooded screw compressor for X-DF

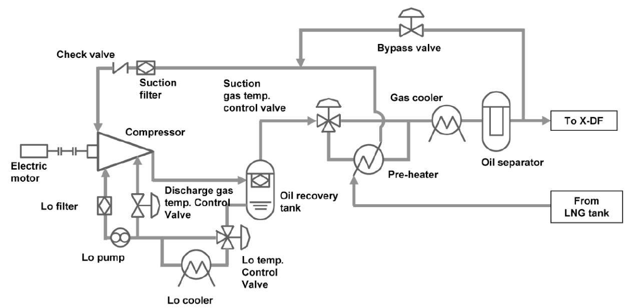

Fig. 4 System flow of oil-flooded screw compressor for X-DF

2.2 Features of the compressor system

2.2.1 Preheating system

BOG generated by the LNG tank is in the cryogenic temperature range (around -160℃). The pre-heater (Fig. 4) uses the heat of compression from the compressor to heat the BOG to around -90℃ as a suitable suction temperature for the oil-flooded screw compressor ("Compressor" in Fig. 4). The discharge gas temperature control valve (Fig. 4) controls how much oil is sent to the compressor, ensuring appropriate removal of the heat of compression and holding constant the temperature of the compressed gas discharged from the compressor. The suction gas temperature control valve (Fig. 4) maintains the appropriate temperature of the gas supplied to the oil-flooded screw compressor by controlling the flow of compressed gas to the pre-heater.

2.2.2 Oil separation system

Oil in the compressed gas undergoes primary separation in the oil recovery tank (Fig. 4). The separated oil is then sent back to the compressor via the oil cooler ("Lo cooler" in Fig. 4). The secondary separator ("Oil separator" in Fig. 4) separates and removes oil remaining in the compressed gas after primary separation. The secondary separator uses a special fine-fiber filter (coalescing filter), the same type used in helium gas liquefaction applications with strict oil removal standards. Adding an activated carbon adsorber downstream as needed provides further oil separation and removal.

2.2.3 Coordinated control of screw compressors and reciprocating compressors

In one example of an X-DF gas supply system, the screw compressor supplies gas not only to the X-DF and DFDE, but also the reciprocating compressor and re-liquefaction system. In such a system, pressure must remain stable even upon fluctuations in the gas demand of each load. Kobe Steel is the only manufacturer with a proven track record of supplying both screw compressors and reciprocating compressors for this application. Hence, we have the ability to implement coordinated control that accurately reflects the control and flow characteristics of both types of compressors. This makes it possible to maintain a constant screw compressor discharge pressure (i.e., gas supply pressure) even upon the large fluctuations in gas flow rate typical of reciprocating compressor startup. In turn, it is possible to ensure stable operation during normal operation and upon fluctuations in load.

3. Reciprocating compressors for LNG carriers

3.1 Reciprocating compressor for ME-GI gas supply

3.1.1 Structure and basic system

Reciprocating compressors used for shipboard applications must generally be vertical reciprocating compressors because of space constraints. Kobe Steel uses a six-stage reciprocating compressor for the ME-GI gas supply system, with stages one through five having non-lubricated cylinders and stage six having an oil-lubricated cylinder. The system flow of these sections is shown in **Fig. 5** (non-lubricated) and **Fig. 6** (lubricated). This six-stage reciprocating compressor pressurizes the BOG generated by the LNG tank from approximately atmospheric pressure to 30 MPa. Reciprocating compressors have various sliding components made of resin, including piston rings, rider rings, and piston rod packings. To enhance the durability and reliability of these components and thus enable long-term continuous operation, lubricating oil is fed into the sixth-stage cylinder, where friction is highest. However, the oil content of the gas must be reduced to a permissible level for the ME-GI. As such, there is an oil separator (Fig. 6) with a high-performance filter downstream of the discharge of the compressor's sixth stage to separate and remove lubricating oil entrained in the gas.[2)]

3.1.2 Features

The reciprocating compressor in this system supplies gas not only to the ME-GI, but also to the DFDE and to the re-liquefaction system for surplus BOG. The system adjusts the processing volume of each stage based on the demand of the ME-GI and DFDE. Furthermore, the stringent oil contamination requirements for the 15 MPa gas sent to the re-liquefaction system are met. These requirements are necessary because of heat transfer with the cryogenic BOG generated by the LNG tank and the return of re-liquefied LNG to the LNG tank. Hence, the cylinders of stages 1 to 5, which boost the pressure to 15 MPa, are non-lubricated. When gas in the system backflows during shutdown, oil-laden gas may flow from the high-pressure lubricated line (stage 6) to the low-pressure non-lubricated line (stage 5). Therefore, there is a check valve (Fig. 6) to prevent backflow and a coalescing filter (Fig. 6) to collect oil contained in the leaking gas between stages 5 and 6.

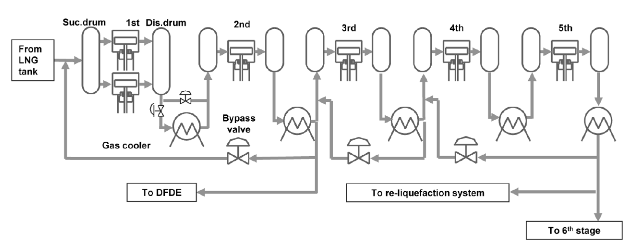

Fig. 5 System flow of reciprocating compressor for ME-GI (Non-lubrication line)

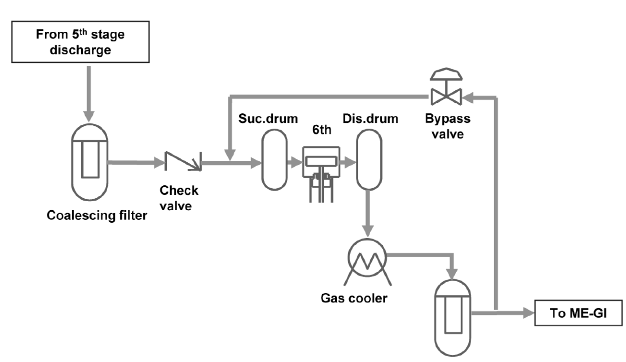

Fig. 6 System flow of reciprocating compressor for ME-GI (Lubrication line)

3.2 Reciprocating compressor for surplus gas re-liquefaction system of X-DF

3.2.1 Structure and basic system

Fig. 7 shows the system containing the reciprocating compressor that re-liquefies surplus gas for the X-DF, and **Fig. 8** shows the unit itself. The preceding oil-flooded screw compressor boosts the BOG generated by the LNG tank from atmospheric pressure to about 1.3 MPa. The reciprocating compressor then further boosts the BOG to about 15 MPa. To maximize re-liquefaction efficiency, gas undergoes heat transfer with the cryogenic BOG generated by the LNG tank. Its pressure is then reduced to around 0.1 to 0.3 MPa before re-liquefaction. Because there are strict limits on the oil content of gas in the re-liquefaction system, Kobe Steel offers a three-stage reciprocating compressor that can boost pressure from 1.3 MPa to 15 MPa without lubrication. The flow rate as well as the pressure range of the third, fourth, and fifth stages are the same as for the aforementioned ME-GI reciprocating compressor. Standardizing the cylinder design with that of the ME-GI reciprocating compressor minimizes variety in consumable parts, thereby minimizing maintenance costs.

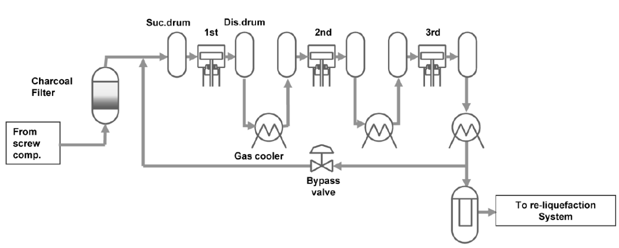

Fig. 7 System flow of reciprocating compressor for re-liquefying surplus gas of X-DF

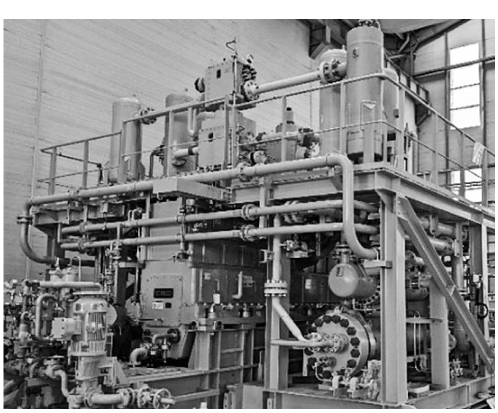

Fig. 8 Appearance of reciprocating compressor for re-liquefying surplus gas of X-DF

3.2.2 Features

In non-lubricated cylinders, the sliding action between resin components (piston rings, piston rod packings) and their mating parts (cylinder liners, piston rods) causes resin to adhere to the mating parts and form a transfer film. This extends service life by reducing wear between the surfaces. However, an extremely small amount of oil (on the order of ppmwt) in the gas will inhibit the formation of the transfer film on the mating surface and lead to abnormal wear. The oil separator on the screw compressor side can reduce the oil content to below 0.5 ppmwt. However, sudden failure of the oil separator would lead to oil dispersion into the reciprocating compressor or the re-liquefaction system. An activated charcoal filter (Fig. 7) upstream of the reciprocating compressor mitigates this risk and thus enhances reliability. There is also an oil separator (Fig. 7) downstream of the reciprocating compressor to separate oil carryover and enable the detection of oil accumulating at the low point. This separator also prevents other foreign matter aside from oil from entering the re-liquefaction system, further increasing reliability.

4. Expansion into liquid hydrogen transport

The forthcoming hydrogen supply chain is undergoing technological development in support of a carbon-neutral society. The liquid hydrogen transport sector is working on foundational designs and plans for constructing liquefied hydrogen carriers. To transport liquid hydrogen, it must be stored at a lower temperature than that required for LNG. Specifically, it is transported near the cryogenic temperature of -253℃. Therefore, as with LNG transport, the carrier must have a system for utilizing the BOG generated by the tank during navigation. There is progress in the development of diesel engines fueled by hydrogen gas, and these engines also require compressors for the supply of hydrogen gas as fuel. Hydrogen BOG generated by the tank is near atmospheric pressure. Boosting this to the pressure required for the engine (around 1 MPa) generally necessitates a compressor with a high compression ratio. This is a challenging requirement to meet because hydrogen gas leaks easily due to its low molecular weight. Hence, multi-stage compressor systems are often used for this application.

Oil-flooded screw compressors suppress the increase in temperature of the compressed gas and reduce gas leakage between the rotors by injecting lubricating oil into the rotor chamber during compression. This design yields a high compression ratio in a single stage even for hydrogen, with its low molecular weight. Kobe Steel's proprietary tandem compressor (rotors for single-stage and two-stage compression in a single unit) enables a space-saving design that eliminates the connecting piping and interstage cooler normally required in two-stage compression systems.[1)]

Reciprocating compressors can efficiently boost the pressure of hydrogen despite its low molecular weight. Technology for LNG BOG applications with gas intake temperatures around the cryogenic temperature of -160℃ can be used to minimize the heating of cryogenic gas in hydrogen BOG applications. This enables the intake of hydrogen gas while maintaining a high gas density, offering the advantages of a compact compressor size and reduced power consumption.

Kobe Steel has extensive operational experience with both screw compressors and reciprocating compressors in the onshore hydrogen gas sector. We have combined considerations for maritime use with the cryogenic BOG preheating systems used in LNG carrier applications to support the specification and supply of compressors suitable for liquefied hydrogen carriers. This will contribute significantly to the development of the hydrogen supply chain.

Conclusions

Stricter environmental regulations have led to the mainstream use of dual-fuel engines in LNG carriers. This paper describes typical gas supply systems for LNG carriers and the screw compressors and reciprocating compressors used in these applications. Kobe Steel will continue to play a role in ensuring stable, large-scale LNG transport through our operational track record and technical reliability. Furthermore, we will provide suitable compressors for emerging fields such as liquid hydrogen transport by leveraging the technologies we have cultivated for LNG carrier applications. Our focus on efforts such as these will help solve current and future energy and environmental challenges.

References

1) Y. Amano. R&D Kobe Steel Engineering Reports. 2009, Vol.59, No.3, pp.17-20.
2) K. Seyama. R&D Kobe Steel Engineering Reports. 2018, Vol.67, No.2, pp.77-81.