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Large-Scale Ammonia Receiving Terminal for Power Generation

1. Introduction

A Cabinet decision on the "6th Strategic Energy Plan, Agency for Natural Resources and Energy" was adopted in October of 2021, and identified ammonia-fired thermal power as a leading option for promoting decarbonization of thermal power generation toward achievement of carbon neutrality, since burning ammonia does not cause CO_2 emissions and many existing thermal power plants can be used as-is. The "Action Plan of the Growth Strategy, Cabinet Secretariat" also targets introduction and popularization of 20% ammonia co-firing in coal-fired thermal power generation by 2030, and aims to introduce a maximum of 3 million tons of ammonia by 2030 and expand the supply to around 20 million tons in 2050. Based on the fact that Japan's domestic consumption of ammonia for use as a chemical feedstock in 2019 was approximately 1.08 million tons and imports accounted for about 20% of that amount, a large increase in the logistics network will clearly be necessary in order to achieve the targets for 2030 and 2050.

This paper introduces JFE Engineering's track record in the field of cryogenic liquefied fuel gas and efforts in connection with large-scale fuel ammonia receiving terminals based on those technologies.

2. Large Volume Transportation of Ammonia

The states of ammonia in case of transportation and storage are considered to be normal temperature and low pressure (gas), normal temperature and high pressure (liquid) and low (cryogenic) temperature and low pressure (liquid). Many of the ammonia-related facilities which are already in operation in Japan are used for NOx removal when treating combustion exhaust gas, and almost all of those facilities handle normal temperature and high pressure liquid ammonia due to their small capacity (scale of several tens of tons).

To be effective for carbon neutrality, ammonia must be synthesized using green hydrogen produced as a feedstock, but because there are no sources of inexpensive green hydrogen in Japan that are large enough to meet demand, green hydrogen must inevitably be imported from overseas, where renewable energy is abundant. In that case, the low temperature and low pressure liquid state is the optimal alternative in terms of energy transportation efficiency, since the hydrogen content per unit volume is large and upscaling of cargo tankers is possible. In fact, cryogenic liquefied ammonia carriers with a capacity of several 10 000 m^3 scale are already in commercial use.

Cryogenic liquefied ammonia receiving storage facilities also exist already in Japan and other countries. However, these facilities are used for chemical feedstocks, represented by raw materials for fertilizer, and as an additional problem, the number of these facilities in Japan is also extremely limited. Thus, new large-scale receiving terminals capable of handling cryogenic liquefied ammonia will be necessary in order to achieve large volume transportation of fuel ammonia.

3. Cryogenic Liquefied Fuel Gas and JFE Engineering

3.1 Track Record

JFE Engineering has delivered cryogenic liquefied fuel gas-related facilities for LNG, LPG and ethylene for energy and chemical companies in Japan and other countries. Among these, the company began development of LNG storage tanks in the 1970s, which was the initial period of LNG introduction in Japan, and has constructed a large number of plants for energy companies utilizing its total engineering technologies, which include receiving, storage and delivery facilities.

3.2 Fuel Ammonia

Table 1 shows the typical physical properties of various fuel gases which are transported in the liquid phase. After ammonia is received as a low temperature liquid, comparing the liquid density, boiling point and vapor pressure of ammonia and LPG (propane), it can be handled at a temperature and pressure level similar to that of LPG (propane) in secondary transportation as a normal temperature liquid and in the process of vaporization and combustion. This means that JFE

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Table 1 Properties of fuel gas transported in low temperature liquid phase

Gas*		LNG (Methane)	LPG (Propane)	NH_3 (Ammonia)
Liq. density at 10 kPa (gauge)	(kg/m^3)	421	578	670
Boiling point at 10 kPa (gauge)	(°C)	− 160	− 39.7	− 30.9
Vap. pressure at 20°C	(MPa)	NA	0.844	0.862
Lower heating value	(MJ/kg)	50.0	46.3	18.6
Min. rate of combustion	(cm/sec)	36	41	8
Min. ignition energy	(mJ)	0.280	0.250	170

*The values of pure components at lower row is listed.
All of values are estimation by JFE, or citation from the literature.

Engineering can fully meet the mechanical design requirements for fuel ammonia based on its proven track record, as described above.

4. Fuel Ammonia Receiving Terminals

4.1 General Flow

Figure 1 shows a flow chart of a cryogenic liquefied ammonia receiving terminal. After berthing of a cargo tanker (i.e., cryogenic liquefied ammonia carrier), the tanker is connected to the receiving storage tank by the liquid receiving piping and vapor return piping. The cryogenic liquefied ammonia is then repressurized and pumped by a cargo pump installed on the ship side, and is introduced into the land-side receiving storage tank at almost the same temperature and pressure as in the cargo tank, and is then kept in that state. Because the liquefied ammonia in the receiving storage tank reaches the boiling state due to various types of heat inputs, the ammonia gas that evolves in the tank is vented, cooled and reliquefied, and then return the liquid ammonia to the storage tank in order to maintain a low temperature and low pressure condition.

Two typical delivery methods are shown in Fig. 1. In one method, the ammonia is repressurized by a loading pump and then pumped to a vaporizer, where ammonia gas is produced by vaporizing the liquid by heat exchange with seawater, etc. This ammonia gas is then transferred to a boiler for use in power generation or to some other facility. The other method is secondary transportation, which also employs the same method of heat exchange with seawater, etc., but in this case, the ammonia is stored temporarily in an intermediate storage tank as normal temperature and high pressure liquid and then delivered to customers via truck shipments.

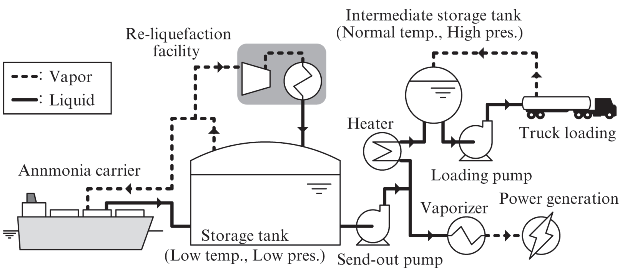

Fig. 1 Flow sheet of Ammonia receiving terminal

4.2 Features of Operation and Requirements for Equipment

Assuming a system in which one power plant with an output of 1 million kW × 2 units is supplied directly with the received ammonia, and nearby power plants with an output of 100 000 kW × 3 plants are supplied by trucks, the ammonia handling capacity required to cover an ammonia co-firing rate of 20% at all of the plants is estimated to be approximately 1.3 million t/y (delivery as gas: 1.1 million tons, shipment as liquid: 200 000 tons). This value would exceed Japan's total annual consumption of feedstock ammonia in 2019, as mentioned above.

This handling capacity supposes 30 ammonia receiving operations per year in case of transportation by 38 000-ton class LGC (semi-large class carrier), and about 40 shipments per day by truck (10-ton load).

In other words, when a fuel ammonia receiving terminal is compared with the existing terminals, the handling capacity at one site will be extremely large, and the operating rate of the equipment must also be very high. Moreover, considering the fact that a decrease in the output of any of the power plants due to trouble with the fuel ammonia supply facilities is unacceptable, the reliability of the facilities must be increased by automation or redundancy, and continuous operation must be maintained.

4.3 Large-Scale Receiving Storage Tanks

Carbon steel plates for pressure vessels for low temperature service (SLA material) are used in parts of cryogenic liquefied ammonia storage tanks that are in contact with liquid or gaseous ammonia. However, considering both the fact that there has been a series of cases of stress corrosion cracking (ammonia SCC) accidents of high strength steel, and the upper limit of plate thickness at which on-site stress relief annealing becomes necessary during welding, the upper limit of the buildable storage tank capacity is approximately 40 000 tons.

On the other hand, in case ammonia is to be used as a fuel for power generation, an orientation toward reducing transportation costs by using the largest scale cargo ships possible is likely. If the necessary separation distance and other site restrictions, ease of operation, and construction cost are considered, the land-side storage tanks for receiving and storing ammonia should preferably be as large as possible. Concretely, this means the capacity should exceed 100 000 tons, which will make it possible to receive the entire cargo of one Very Large Gas Carrier (VLGC) in one storage tank.

To meet these needs, JFE Engineering is engaged in technical development of materials, structures and construction methods that will contribute to larger scale receiving storage tanks.

5. Conclusion

Social implementation of fuel ammonia to realize carbon neutrality is increasingly important, and moves to design a system for introduction and popularization and establish international standards are accelerating day to day. JFE Engineering intends to contribute to the decarbonization of electric power sources not only through its experience and track record in the field of cryogenic liquefied fuel gas, but also by promoting an acceleration of technical development related to fuel ammonia receiving terminals through cooperation and partnership with Ishii Iron Works Co., Ltd. and cooperation with JFE Steel.

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