Comparative Analysis of Marine Methanol Fuel Supply System

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***Abstract*—The design of the marine methanol fuel supply system is a crucial aspect for the application of methanol-powered ships. It requires a systematic planning of the entire process of methanol storage, transportation, pressurization, heating, filtration, and safe injection into the engine. This thesis will describe and compare different design routes of the marine methanol supply system from various aspects such as system functionality, complexity, and economy, in order to provide different design ideas and development direction analyses for coping with the trend of fuel diversification and the application of methanol fuel in the ship industry.**

***Keywords*—methanol fuel, supply system, ship**

I. OVERVIEW

In the process of global shipping industry's carbon neutrality transformation, methanol fuel has emerged as the core choice in the market for ship alternative fuels due to its 30%-60% carbon emission reduction advantage throughout the entire life cycle, convenient storage and transportation characteristics, and mature technical system. According to statistics from the Norwegian Classification Society (DNV), as of the end of 2024, the global orders for methanol fuel ships reached 322 vessels, far exceeding those of ammonia fuel ships (27 vessels), and it holds a dominant position in the alternative fuel ship market. The methanol fuel supply system, as the "power heart" of methanol dual-fuel ships, its design route directly determines the operational safety, energy utilization efficiency, and compliance of the ships, and is a key technical support for promoting the industrialization of methanol-powered ships [1].

II. METHANOL FUEL SUPPLY SYSTEM DESIGN ROUTE

Methanol is a substance that possesses both solvent and fuel properties. Its main characteristics include strong combustion performance, being an easily flammable and explosive hazardous material, high volatility, the ability to form combustible vapors in the air, corrosive effect on metals and rubber materials, boiling and vaporization at relatively low temperatures (approximately 65℃), a low flash point, and the ease of ignition [2]. The core design objective of the methanol fuel supply system is to provide stable fuel that meets the requirements of temperature, pressure, and flow for the engine. Its core equipment includes pump sets, heat exchangers, filters, and other key components. Due to significant differences in deck space layout, loading requirements, and navigation conditions among various ship types, it is necessary to design highly adaptable methanol fuel supply systems specifically for each type. Based on the two aspects of "presence or absence of methanol service tank" and "arrangement form of methanol transfer pump", this article divides methanol fuel supply system into three main design routes and provides detailed explanations.

A. Conventional Service Tank Scheme

According to the requirements of the classification society and the design guidelines for dual-fuel methanol main engines by Everllence, the currently widely adopted design concept for methanol fuel supply systems is one that includes a dedicated service tank.

As shown in Fig. 1, this system consists of five core modules: the methanol bunkering unit, the storage tank, the service tank, the transfer pump, and the methanol supply unit. The fuel transfer process is as follows: After methanol is injected into the storage tank at the bunkering station, it is pumped by the pump into the service tank, and then flows by gravity to the methanol supply unit. After passing through pressure boosting, temperature control, and filtration purification, it is finally transported to the engine end to meet the fuel demand.

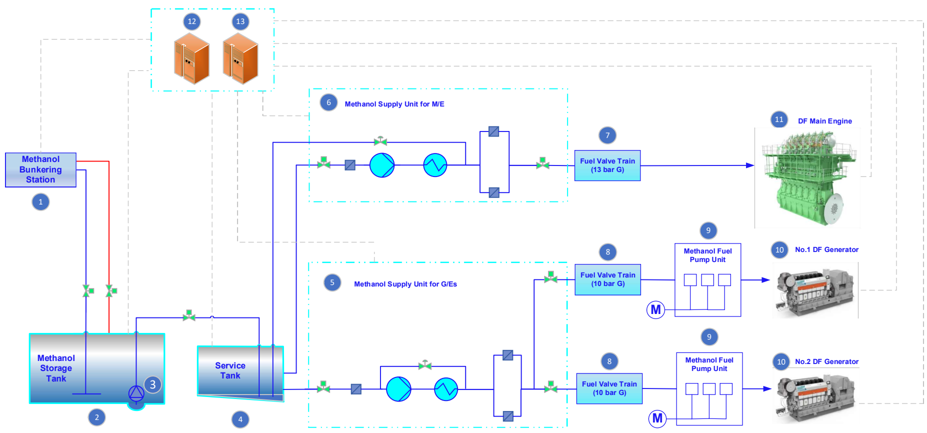

Fig. 1. Conventional service tank scheme.

In the design of key system parameters, the volume of the service tank needs to be configured based on the fuel consumption during 8 h of continuous operation at the maximum load of the main engine; the tank structure adopts a left-right compartment design, with the left side used to collect the methanol and fuel mixture returned by the main engine, and the right side as the clean fuel supply area. An overflow plate is set in the middle to ensure that the upper layer of clean fuel can overflow to the supply area; the service tank is equipped with high-precision pressure sensors and liquid level sensors to monitor the internal conditions [3]. The transfer pump is preferably a submersible pump or a deep well pump, and the driving method uses hydraulic or electric drive to ensure the stability of the transfer; the methanol supply unit includes methanol supply pump, methanol heat exchanger, and a dual-filter : Methanol supply pump uses a PID algorithm combining reflux regulation and frequency control to stabilize the fuel pressure within the range required by the main engine; the heat exchanger uses water-ethylene glycol as the intermediate medium to precisely control the temperature of the methanol (temperature control range 25-50℃), and the intermediate medium is then thermally exchanged through the marine low-temperature fresh water system [4]; the dual-filter has an online reverse flushing function and a manual switching mechanism, which can complete the inspection and cleaning of blocked filters without interrupting the system operation.

Key features of the conventional service tank scheme:

a. High technical maturity, being the mainstream design route for current methanol fuel supply systems, with strong adaptability;

b. Each storage tank requires a separate pump unit, and the cost of the pump group accounts for a high proportion of the total system cost;

c. When the pump is maintained, all the fuel in the corresponding storage tank needs to be emptied, resulting in poor operational convenience.

This scheme is mainly applicable to structural compartments below the main deck with sufficient space, with container ships as the typical application scenario. For example, the 16,000-container methanol dual-fuel container ship project of Dalian Shipyard uses this design.

B. No Service Tank + Pump Inside the Tank Scheme

Since there is no mandatory requirement for the provision of a service tank in the classification society's regulations, an option without the service tank can also be regarded as a design concept for the methanol system, as shown in Fig. 2.

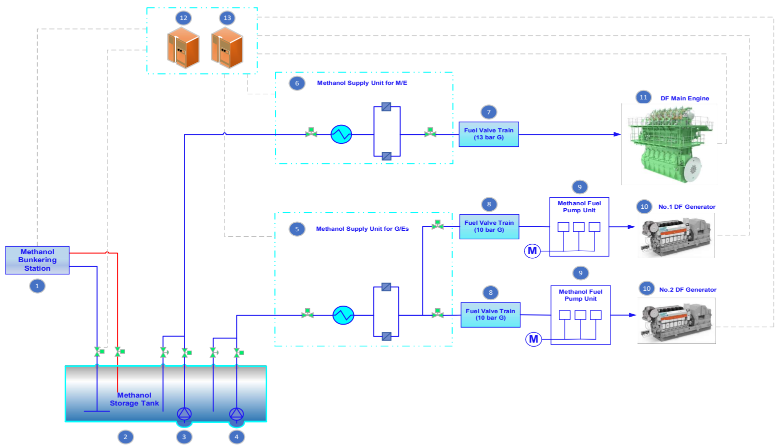

Fig.2. No service tank + pump inside the tank scheme.

This system mainly consists of methanol bunkering station, methanol storage tank, methanol transfer pump, and methanol supply unit, etc. Due to the removal of the design of the methanol service tank, the methanol in the storage tank is transported/supplied to the methanol supply unit through the methanol transfer pump, and then undergoes heat exchange and filtration before being transported to the consumers to meet their fuel requirements.

In the system composition, the methanol transfer pump not only needs to meet the transportation requirements but also needs to have a pressurization function to meet the supply pressure requirements. Therefore, the selection of the transfer pump is crucial, and it is usually in the form of a submersible pump. Considering the resistance of the pipeline and the supply pressure requirements, the pump's head needs to be above 14 barG [5]; since the methanol transfer pump already has the supply function, the methanol supply unit does not need to be equipped with a methanol supply pump. The rest of the design is consistent with the conventional service tank scheme.

The characteristics of the no service tank + pump inside the tank scheme include:

a. No methanol service tank design, which can save costs and space layout;

b. Each storage tank needs to be equipped with at least one methanol transfer pump, which accounts for a relatively high cost;

c. Removing the methanol supply pump, the size of the methanol supply unit and the fuel preparation room can be reduced; or the fuel preparation room can be cancelled, and the equipment in the fuel preparation room can be arranged in the storage tank TCS.

d. The maintenance of the methanol transfer pump requires emptying the entire storage tank.

The no service tank + pump inside the tank scheme is mainly applicable to structural compartments below the main deck, such as container ships.

C. No Service Tank + Pump Outside the Tank Scheme

Another alternative solution without a service tank is shown in Fig. 3.

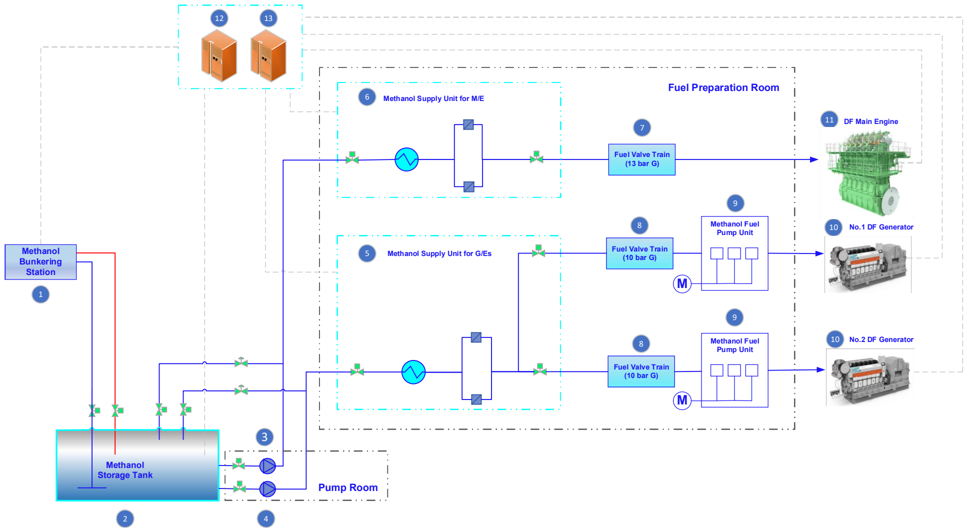

Fig.3. No service tank + pump outside the tank scheme.

This system mainly consists of methanol bunkering station, methanol storage tank, a low-pressure pump unit, and a methanol supply unit. The design of the internal pump in the tank has been eliminated, and a low-pressure pump unit has been equipped to achieve the transportation and supply functions of the original internal pump.

In the system composition, the low-pressure pump in the low-pressure pump unit is arranged outside the methanol storage tank, such as in the TCS or pump room. Therefore, the selection can choose a more common centrifugal pump with a magnetic coupling. The low-pressure pump unit can achieve the transportation function and the first-stage boosting function. However, since the centrifugal pump does not have self-priming function, to avoid pump damage caused by cavitation, it is necessary to ensure that the minimum liquid level of the storage tank is higher than the inlet of the low-pressure pump. The design of the methanol supply unit is basically the same as the conventional service tank scheme. Since the low-pressure pump has already achieved the first-stage boosting, the head of the supply pump selection can be appropriately reduced.

The characteristics of the no service tank + pump outside the tank scheme include:

a. No methanol service tank design, which can save costs and space for layout;

b. Only one low-pressure pump unit is needed in total, with a relatively low cost proportion;

c. A pump room needs to be set up at the bottom of the methanol storage tank to install the methanol supply pump;

d. The maintenance of the low-pressure pump unit does not require emptying the entire storage tank.

III. Prospects for Future System Design

At present, the most commonly used methanol fuel supply system is the conventional service tank scheme, which has a relatively mature and reliable design. For example, the 16,000-ton methanol dual-fuel container ship project of Dalian Shipyard; the application of the scheme without service tank + pump outside the tank is mainly concentrated on PCTC vehicle roll-on/roll-off ships and ore carriers. This type of ship usually has more methanol storage tanks, and if an internal pump is set, the cost will be higher; the application of the scheme without service tank + pump inside the tank is relatively rare, and it is related to the selection difficulty of high-head submersible pumps.

Based on the current design experience of methanol systems and in combination with the future ship design route, the following new design routes are envisioned.

A. Gravity-driven

The gravity-driven solution achieves pumpless transportation by positioning the fuel tanks at a high level ($\geqslant$6 meters from the supply unit), reversing the traditional pumping logic. Its core innovation lies in:

a. Space reconfiguration design:

Taking the 49,500-ton chemical tanker as an example, the methanol storage tank is placed on the deck layer (12 meters above the main deck), connected directly to the supply unit in the engine room through vertical pipes, and the methanol pumping unit is eliminated. After actual measurement, the system failure rate decreased by 70%, and the total life cycle operation and maintenance cost was reduced by 55%.

b. Liquid level stabilization technology:

Using a double-stage buffer tank and an air-liquid separator to eliminate pressure fluctuations caused by free liquid surface oscillation (controlled within ±0.02 MPa), meeting the strict pressure stability requirements of MAN dual-fuel main engines (fluctuation $\leqslant$ ±0.05 MPa) [6].

B. Real-time Data Control

Based on real-time data-driven intelligent control, it has become the key to the energy efficiency upgrade of the methanol fuel supply system. The system learns from over 2,000 hours of operation data, alerts for pump unit bearing wear and other faults 48 hours in advance, and combines a dual-core controller for hot backup (with switching time $\leqslant$ 10ms) to achieve zero downtime power supply [7].

C. Multi-fuel Supply System

To cope with the future trend of fuel diversification, the new generation methanol fuel supply system is equipped with modular interfaces [8], such as the methanol-ammonia fuel supply system. Through the switching valve group and adaptive control algorithms, it can be compatible with both methanol and ammonia fuel supply.

IV. Conclusion

The design road for the marine methanol fuel supply system has taken shape, focusing on precise energy supply as the core, ship type adaptation as the foundation, and cost-effectiveness as the benchmark. The current mainstream solutions feature the conventional service tank design, which dominates the container ship market due to its mature reliability, but is constrained by space occupation and high costs of pump sets; the no service tank + pump inside tank scheme optimizes 12% of space utilization through integrated booster function of submersible pumps[9], but is limited by the difficulty in selecting high-head pumps and the bottleneck of tank emptying and maintenance; while the no service tank + pump outside tank scheme uses magnetic-driven centrifugal pumps for primary boosting, reducing pump set costs by 40% and facilitating maintenance, becoming the economic choice for bulk carriers and roll-on/roll-off ships. Looking to the future, technological evolution focuses on three major directions: gravity-driven design, through the high-position arrangement of fuel tanks, completely eliminating the need for pump sets, verifying a breakthrough effect of a 70% reduction in failure rate[10]; intelligent control systems, relying on digital twin technology, compressing pressure fluctuations to ±0.03 MPa and achieving 48-hour fault warning and zero downtime backup; a multi-fuel compatibility architecture reserves technical interfaces for flexible switching between methanol/ammonia fuels. However, industrialization still faces challenges such as high costs of green methanol, inconsistent seismic regulations for gravity supply, and insufficient depth of ship type customization. In the future, it is necessary to base on safety, be guided by ship types, and empower with intelligence, through policy coordination and industry chain integration, to promote the methanol fuel supply system from a transitional option to a core pillar for shipping decarbonization.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Ding Ding conducted the research; YuDong Su wrote the paper; all authors had approved the final version.

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