

Prospects and Challenges for the Future Development of Ships

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Abstract. Due to the recent amendments to the rules of IMO Convention and the global "Sulfur Limitation Order" issued by IMO, which came into effect on January 1, 2020, has brought a greater impact on the shipping industry chain and economic chain. The traditional types of ships in terms of fuel and tail gas treatment and the large-tonnage ships on the EEDI energy efficiency index are gradually unable to meet the requirements of the new amendment convention to be implemented, so the shipowners are required to make technical breakthroughs. Starting from some conventions amended by IMO, the article analyzes the current method to deal with the "Sulfur Limitation Order", and introduces the convention taking force, as well as analyzes some of the technologies required and challenges faced of the ships in the future.

1 Background

The diesel engines have the advantages of high power, high reliability and high thermal efficiency, etc. Among today's marine power equipment, the diesel engines account for more than 95%, and diesel engine ships undertake most of the international trade and transportation^[1-2]. Up to October 9, 2018, the total inspection scale of China Classification Society (CCS) has reached 35,491 ships, with a total of 142 million tons, of which the gross tonnage of the international navigation class fleet has exceeded 100 million tons^[3]. With the change of the concept of green shipping, the social focus has also changed from the prevention and control of marine pollution (such as oil pollution) to the comprehensive prevention and control of water and air nowadays^[4]. Ships and the emission standards have changed due to the entry into force of the "Sulfur Limitation Order" in this year. In response to the global "Sulfur Limitation Order", most shipowners began to prepare in advance from 2 to 3 years ago. However, some new IMO conventions will come into force recently. Therefore, the shipowners are required to understand and prepare in advance, in case the technology, equipment or regulations does not meet the requirements of the future shipping industry.

2 Methods to meet sulfur limitation in 2020

Due to the features of large transport volume and low unit cost, the ocean-going vessels are widely used in the global transportation industry. As the number and scale of ships become larger, the nitrogen oxides, carbon dioxide and sulfur oxides contained in the emissions have caused serious pollution to the air. Therefore, the IMO's emission control of nitrogen oxides and sulfur oxides on international navigation vessels is divided into emission control areas and non-emission control areas for management. See Table 1 and Figure 1 for details. At the 70th Marine Environment Protection Committee Meeting held in 2016, the MARPOL Convention was amended to determine that from January 1, 2020, the sulfur content of fuel used by national navigation vessels is adjusted from not higher than 3.5% to not higher than 0.5%. The sulfur content limit for the use of fuel in non-emission areas is reduced from 3.5% to 0.5%, which is the "Sulfur Limitation Order". Currently, there are several methods to meet the requirements of the "Sulfur Limitation Order"^[5-6].

Table 1 NO_x emission limits specified in Annex MARPOL.

Stage	Implementation date / year	NO _x emission/(g.kw ⁻¹ .h ⁻¹)		
		Speed n<130	130≤Speed n < 2000	Speed n≥2000
I	2010	17.0	45·n ^{-0.2}	9.8
II	2011	14.3	44·n ^{-0.23}	7.7
III	2016	3.4	9·n ^{-0.2}	1.96

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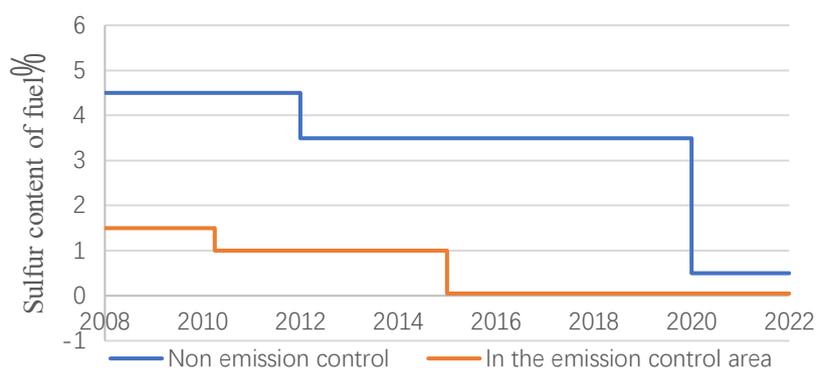


Figure 1 change of sulfur content control requirements of MARPOL convention ship fuel oil.

2.1 Low sulfur fuel

The sulfur content of low sulfur fuel is not greater than 0.1%, and some low-sulfur fuel can even be less than 0.01%. The low sulfur fuel has the features of low sulfur content, low viscosity, high calorific value, low impurities and low flash point, which is the most direct method to meet the requirements, but it does not match with the cylinder lubricant and system oil of the original marine diesel engine also because of these features of the low-sulfur fuel. Long-term use may cause problems such as alkaline corrosion and wear of the cylinder liner. In addition, low sulfur fuel cannot be used in the traditional high sulfur fuel pipelines and fuel supply systems. Otherwise, problems such as the wear of the plunger, sleeves and couplings of high-pressure oil pumps and the failure of boilers may be caused. Therefore, the following points shall be done when using low sulfur fuel: (1) to strengthen the management of the installation, storage and transportation of low sulfur fuel: the low sulfur oil tank for low sulfur fuel and the independent fuel delivery pipeline are specially set, and note the fuel parameters before refueling, etc.; (2) Improvement of boiler: due to the strong volatility of the low sulfur fuel, it will cause a large amount of gas to accumulate in the furnace, which is easily exploded. Therefore, it is required to transform the fuel conversion device, fuel supply system, display system and other system equipment of the boiler correspondingly, while at the same time, to add the pre-sweeping and post-sweeping program adjustments of the burner to extend the sweeping time; (3) improvement of ship piping systems: currently, the tracing pipes in common fuel piping systems are mostly applicable for high sulfur fuel. If used for low sulfur fuel, it will cause gas to be contained in the liquid due to low flash point of the low sulfur fuel, thus cause the oil to be discontinuous.

Therefore, the low sulfur fuel pipeline shall be set separately; (4) to strengthen the maintenance and repair of the machinery and equipment: for the boilers using low sulfur fuel, pay close attention to the condition of the fuel pump when working, note the changes of boiler oil pressure and oil temperature, and replace the plunger assembly for the high-pressure oil pump with low sulfur fuel for a long time^[7-9].

2.2 Exhaust gas cleaning system

Exhaust gas cleaning system is the widely used post-treatment technology in the field of marine transportation. There are two kinds of cleaning systems of dry and wet based on the media used. Since the dry exhaust gas cleaning system needs to consume additional reaction agents, the wet exhaust gas cleaning system using seawater as the desulfurizer is usually used on the ships. And the wet exhaust gas cleaning system can be divided into open type, closed type and mixed type in terms of function.

(1) Open type exhaust gas cleaning system: refers to a system that directly uses seawater to clean and desulfurize the exhaust gas, and the washing water after desulfurization is treated with a special water treatment device, which is directly discharged from the outboard system after all the indicators reach the emission standards. The washing effect of the open type system is equivalent to that of using fuel oil with a sulfur content of 0.5%. The schematic diagram is shown in Figure 2. The open type system is usually used in the high seas because the alkalinity of the seawater is high enough with good washing effect. However, the system is less flexible, and a large amount of seawater is used during the washing process, and the power consumption is also larger.

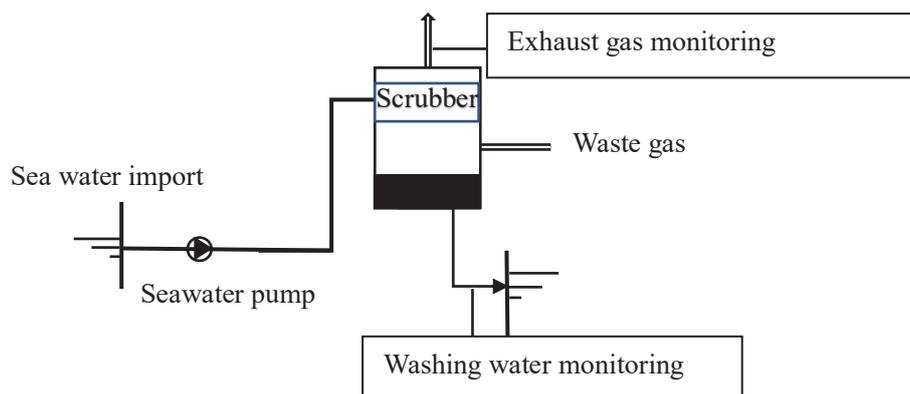


Figure 2 Schematic diagram of ship open desulfurization system.

(2) Closed type exhaust gas cleaning system: refers to an exhaust gas cleaning system that uses the aqueous scheme added with the desulfurizer to clean and desulfurize the exhaust gas, and the washing water after desulfurization is recirculated after treatment of desulfurizer supplement, water supplement and cooling, etc. Normally, alkaline chemicals such as sodium hydroxide scheme (NaOH) are added into the circulating water to neutralize the acid in the washing water. The

washing effect of the closed type system is equivalent to that of using low sulfur oil with a sulfur content of 0.1%. The schematic diagram is shown in Figure 3. Compared with the open type system, the closed type system is more flexible and applicable for fresh water areas and low alkalinity areas. However the cost of its equipment and operation is also higher because of the need to consume chemicals during operation.

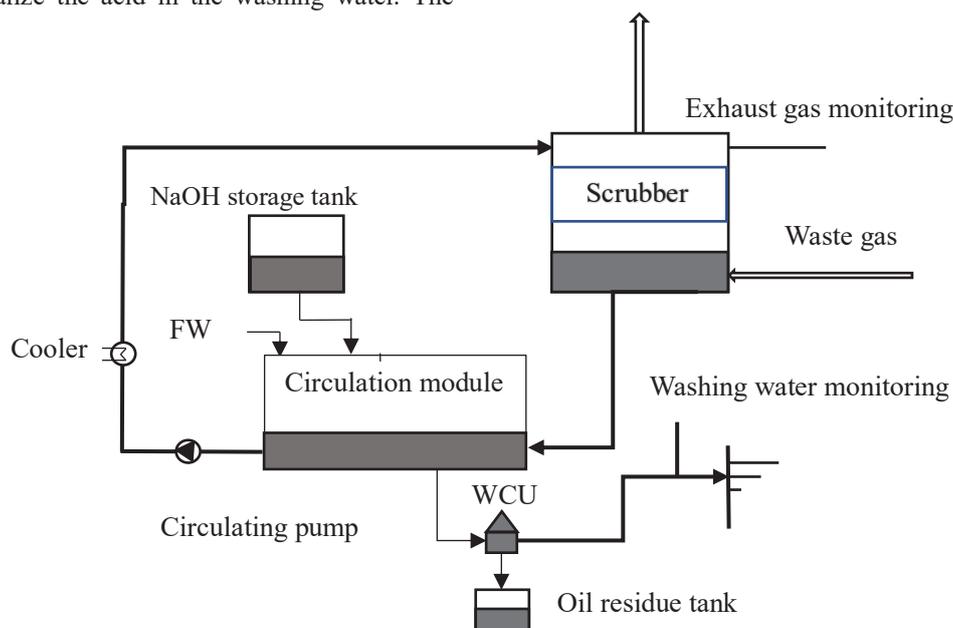


Figure 3 Schematic diagram of ship closed desulfurization system.

(3) Mixed exhaust gas cleaning system: Both the open type system and closed type system have their own limitations. In order to meet the needs of sailing in different sea areas/waters, a system combining the open type and closed type-mixed exhaust gas cleaning system is used. The schematic diagram is shown in Figure 4. The

open type or closed type cleaning system can be switched at any time according to the sea area conditions of the ship to meet the most economical emission requirements, but it greatly increases the complexity of the system design and the investment cost is higher^[10-12].

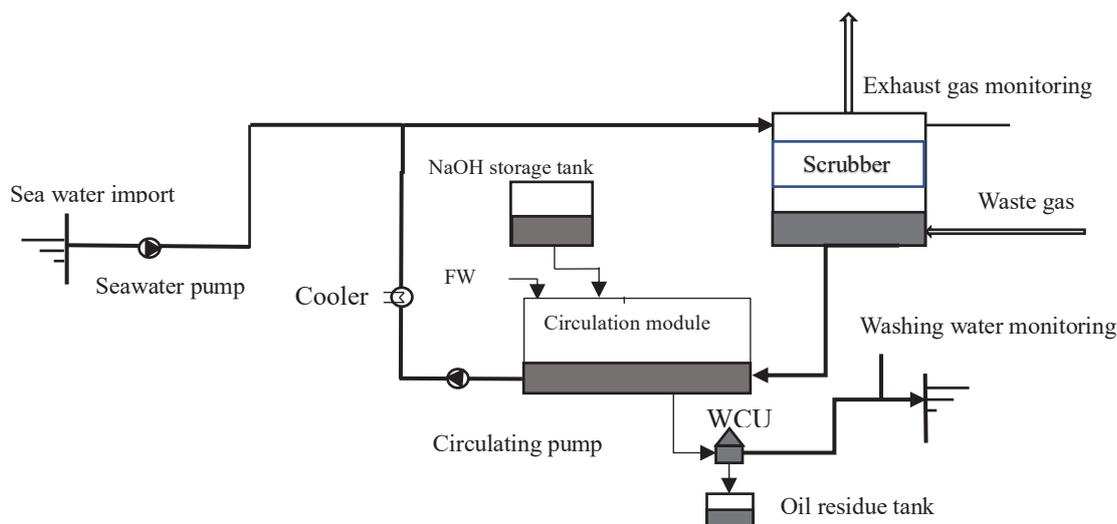


Figure 4 Schematic diagram of mixed desulfurization system for ships.

2.3 Use of LNG fuel

Currently, LNG, as a clean and low carbon energy source, under the situation of meeting the requirements of international conventions and domestic standards, its relative core technologies are more mature than other new energy sources, which are favored by shipowner companies from all over the world. However, due to the limitation of its own features, currently, the scheme with high market acceptance is the dual fuel scheme of LNG + fuel oil, which has (1) rich reserves, and the global proven reserves have increased with the development of shale gas technology to more than 200 Trillion cubic meters, which can meet at least 60 years of mining and utilization; (2) LNG fuel has high heat value, good safety, high ignition point, and good security; good environmental protection. Compared with traditional fuel, LNG, as a fuel, can reduce CO₂ emissions by 15%-20%, NO_x emissions by 85%-90%, and SO_x emissions by 100%, which meets the requirements of the rules and current IMO "Sulfur Limitation Order". However, there are also some problems: (1) high LNG transportation cost, limited number of filling stations and filling ships and insufficient regional supply chain, as well as the regional pricing regulations have not yet been formed; (2) high operating cost that the construction cost of LNG-powered ships is higher than that of ordinary ships of the same tonnage; the modification cost of LNG ships is more expensive; the labor cost of the LNG ships are also about 22% higher than that of traditional diesel ships; (3) high safety requirements of the system and too complex system, which increase the cost of ship construction and affects the completion time of the ship; (4) incomplete technical specifications: The application of LNG fuel power on ships is still at an early stage of exploration, and the relevant technical specifications are also constantly being improved, so the experience of conversion of large ocean-going ships is very limited; (5) not high system technology level: although single LNG fuel and LNG diesel dual fuel marine natural gas engines of various powers have been developed and produced in

domestic, and great progress has been made in the design and manufacture of supporting ships, storage tanks, control systems, etc., but due to immature technology, system failures often occur during operation of LNG engines, safety alarm systems, and ECUs (Central Control System)^[13-14].

2.4 Method evaluation and comparison

The above three schemes have been applied, but each has its own disadvantages. The analysis is based on the difficulty of overcoming the disadvantages, and the reliability of the measures: (1) long-term use of low sulfur fuel can easily increase the wear and block of the moving parts, unavailable mixed oil fuel tanks, inadequate supply and other disadvantages, increase the management difficulty and maintenance; (2) high maturity of the technology of the desulfurization tower scheme, good safety and controllable conversion amount; the reasonable arrangement of space and outlets during the design phase, application of special coatings and addition of variable flow devices of seawater and other effective technical methods can overcome the problems such as space, sea areas/water areas, and drainage; (3) the dual fuel scheme of LNG + fuel oil has high requirements on ships with excessive conversion and too high difficulty as well as less conversion case experience, which is not applicable for universal implementation. Therefore, from the technical perspective, the desulfurization tower schemes meets the requirements of regulations and ship safety compared to the other two.

From the perspective of investment cost: due to low cost of low sulfur fuel, the cost of LNG dual fuel and the cost of seawater desulfurization are mainly compared. Since the cost of the two schemes depends on the type of the marine main engine and the fuel consumption level, a scheme is listed. Taking the type III bulk carrier as a reference, the desulfurization scheme is considered in accordance with the open type desulfurization system. The main costs are desulfurization equipment costs and construction costs; and the cost of chemicals added and

maintenance cost are about 5% of the equipment cost. The main costs of converting a dual fuel system include the costs of storage and gas supply systems. The maintenance cost is about 2% of the equipment cost. The

depreciation cost is considered based on every 5/10/15 years, and see table 2 for the calculation of the annual cost under different years.

Table 2 Cost of desulfurization tower and LNG dual fuel.

Model	Seawater desulfurization scheme			Annual increase cost of desulfurization tower			LNG dual fuel scheme			Annual increased cost of LNG dual fuel		
	Procurement fee	Construction cost	Dimensional premium	5 years	10 years	15 years	Procurement fee	Construction cost	Dimensional premium	5 years	10 years	15 years
6G50	100	55	5	42.2	27.48	22.57	655	15	13.1	180.6	113.6	91.3
6G70	150	75	7.5	61.5	40.13	33.00	1185	20	23.7	325.0	204.5	164.3
7G80	210	90	10.5	82.5	54.00	44.50	1920	30	38.4	525.9	330.9	365.9

Analysis from revenue: although low sulfur oil has low front-end investment costs, there are problems such as high operating costs in the later stage and not guaranteed low sulfur fuel amount. It is only applicable to small ships with low fuel consumption, which is not universal. The cost of the desulfurization tower is more flexible. According to Figure 5, it can be seen that the desulfurization tower is applicable for multiple types and different ship ages. The longer the time period, the lower the cost and the higher the profit. Compared with the desulfurization tower, the LNG dual fuel scheme has higher maintenance expenditures and costs. Therefore, integrated technology maturity and cost analysis, the desulfurization tower has more advantages than the other two schemes, which is the direction that the shipowners shall study^[14].

3 Challenges for the future development of ships

In addition to the ‘‘Sulfur Limitation Order’’ that has been implemented this year, there are some new conventions that will enter into force in the near future: (1) Amendment of the IBC Code: IMO Marine Environment Protection Committee at its 74th Meeting and the Maritime Safety Committee At its 101st session, have amended Chapters 1, 15, 16, 17, 18, 19 and 21 of IBC Code to mainly aim at the restrictions on the construction of chemical carriers and cargo transportation. The regulation will take effect on January 1, 2021; (2) Amendments of the standard of Stage III of the energy efficiency design index (EEDI) of new ships: considering the requirements for the Stage III of EEDI, the EEDI baseline for large tonnage ships, shaft power restrictions and other aspects at the MEPC74 meeting in May 2019, adjusting the requirements of starting time and reduction rate requirements for EEDI applicable ship types, advancing the container ships to 2022, increasing the maximum reduction rate to 50% and advancing the general cargo ships, LNG carriers of 10,000 DWT and above, non-traditional propulsion cruises and gas carriers of 15,000 DWT and above to 2022, the remaining ship types remained unchanged^[15].

It is worth noting that the adjustment of the requirements of Stage III of EEDI proves the further restrictions of IMO on the three main ship types, which is inseparable from the green background of the current era.

EEDI is the proportional index of the energy consumed by ships converted into CO₂ emissions and the effective energy converted into CO₂ emissions of the ships, and the factors that affect the EEDI size are related to the deadweight, speed, main engine rated power and fuel consumption, as well as fuel carbon conversion coefficient. Then according to the new regulation adjusted, EEDI needs to start from the three aspects of energy conservation and emission reduction of diesel engines, optimization of propulsion systems and ship resistance reduction. This has led the industry to jointly explore the reduction of the emission reduction capabilities of large ships and research on high energy efficiency or new fuel technologies^[16].

Currently, some large tonnage bulk carriers and liquid cargo carriers are still insufficient to meet the requirements of the stage II of EEDI, because in order to reduce the EEDI index for these large tonnage ships, it is necessary to optimize the structure and profile of large tonnage ships to improve the structural strength of the ships and reduce the quality of empty ships, but also to optimize the main engine of the large tonnage ships, to select a main engine which is suitable for matching the performance of the ship, and also to reduce the size and quality of the main engine as much as possible, and to reduce greenhouse gas emissions, which requires various industries to work together to meet the future needs of large tonnage ships^[17].

4 Summary and prospects

From the historical background and regulations of the current industry, in the future, ships will pursue intelligence and greenization, and green will become a label for the ship industry. In the future, regardless of large ships or inland vessels, they will gradually become cleaner and greener under the regulation restrictions. However, there are still many challenges for ships in the future, such as breakthroughs in main engine emission reduction technologies and new equipment to reduce sulfur oxides, nitrogen oxides and carbon dioxide emissions need to continue to be developed, researched and tested. This is not just the task of the ship industry, but also requires all industries in the world to go hand in hand and work hard for the green environment in the future.

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