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The Development and Research Exploration of Today's Green Shipping Industry and Related Devices

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Abstract: With the booming development of the global shipping industry, the problem of pollutant emissions from water transportation is becoming increasingly serious. Statistics show that the annual emissions of SO_x (sulfur dioxide) from ships worldwide account for over 7% of the global total, while NO_x (nitrogen oxides) account for about 15% of the global total. These pollutants not only exacerbate air pollution but also pose a serious threat to the environment, ecology, and human health. Based on this background, the development of green shipping is particularly important today, and it is necessary to reduce marine pollution and prioritize the protection of the marine environment. Adhering to the six annexes of the MARPOL Convention, the country has also introduced relevant policies for the development of green shipping, contributing to the protection of the marine environment and the promotion of sustainable development.

Keywords: Green shipping; Pollutants; Development; Pollutant emissions

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1. Current status and causes of marine pollutants

The ocean, as a source of life, plays an increasingly important role in the process of human development. With the development of automatic control technology and the continuous growth of the robotics industry, various advanced ships have sprung up like mushrooms after rain, which will also cause marine pollution. Traditional ships are mostly propelled by electricity or rely on thermal energy generated by fossil fuel combustion, which has shortcomings such as high energy consumption and short endurance. This has also led to a gradual shortage of global energy, an accelerated consumption rate, and massive greenhouse gas emissions, exacerbating environmental pollution and climate deterioration on Earth. How to effectively develop green shipping and reduce consumption costs has become a focus of attention for many marine-related industries. Pollution from marine vessels today is shown in **Figure 1**.

Figure 1. Current status of pollution from major ships

2. The urgency of the development of green shipping

2.1. The severity of today's marine pollutants

Plastic accounts for 85% of marine litter and warns that the amount of plastic pollution flowing into the ocean will nearly triple by 2040, increasing by 23–37 million tons per year [1]. This means that there are about 50 kilograms of plastic per meter of coastline globally. As a result, all marine life—from plankton, shellfish, birds, to turtles and mammals—is at serious risk of poisoning, behavioral disorders, starvation, and suffocation. Corals, mangroves, and seagrass beds are also inundated with plastic waste, leaving them without access to oxygen and light.

2.2. The need for green shipping

The shipping industry has made great efforts to reduce emissions [2]. Statistics show that as of the beginning of June, the proportion of desulfurization towers installed in the global active ship capacity is about 22%; LNG (liquefied natural gas) powered ships accounted for about 21% of the new ship orders. However, the task of reducing emissions in the whole industry is still very arduous. Ship emissions are one of the major sources of pollution in ports and waters around the world. The demand for green and low-carbon technologies continues to expand, and new power and zero-carbon ships have become an important direction for the development of the shipbuilding industry. In addition, based on the current pollution situation, more anti-pollution ships and garbage disposal ships should be built, and more instruments and equipment for treating ship exhaust should be designed and studied, so as to achieve the purpose of green shipping, energy conservation and emission reduction, and pollution prevention.

3. Comparison and technology of anti-pollution equipment at home and abroad and research by our team

Based on the domestic perspective, as early as 2014, Pei [3] adopted low-temperature multi-effect distillation technology, using the waste heat of the ship's diesel generator as the driving energy, and proposed a complete whole-process scheme for the low-temperature single-effect distillation of seawater desalination device for the ship's waste heat, and first proposed the technical idea of using the waste heat of the ship's diesel engine flue gas to distill seawater and produce fresh water.

In 2015, Xu [4] designed a new type of seawater desalination device based on the low-temperature distillation seawater desalination method, which transformed the existing evaporator and condenser, so that the seawater was evaporated with high-temperature flue gas in the designed high-efficiency seawater desalination evaporator, and entered the shell-and-tube condenser to be condensed into fresh water, realizing the improvement of the waste heat desalination device. By 2019, He *et al.* [5] used atomizing nozzles to achieve seawater treatment, accelerate the vaporization process, and further improve the efficiency of the waste heat desalination device in combination with the heat exchange in the condenser. **Figure 2** shows advanced technology at home and abroad.

3.1. Domestic flue gas desulfurization technology

In 2011, Zhao [6] conducted a theoretical analysis and summary of the seawater flue gas desulfurization process, analyzed the design rules of key parts such as the absorption system, and corrected the parameters. In 2012, Ma *et al.* [7] conducted an in-depth study on the effects of various parameters on the desulfurization efficiency and pH value of seawater after desulfurization in the process of seawater desulfurization of ship flue gas, and provided quantitative suggestions for seawater flue gas desulfurization. Feng *et al.* [8] designed four rows of liquid nozzles and optimized the start and stop mode of the nozzles under different sulfur content conditions according to the sulfur content at the outlet, the pressure distribution in the tower, and the flow velocity distribution, which effectively reduced the operation cost of ship desulfurization.

3.2. Foreign technical equipment

Although Norway's seawater desulphurization technology (e.g. Flakt-Hydro process) has good application prospects worldwide, the high COD (chemical oxygen demand) of the external drainage of this technology may be difficult to meet increasingly stringent environmental requirements.

(1) India may have high energy consumption in the application of seawater desulphurization technology, especially in the case of pre-coolers.

(2) Regardless of the dedusting process, the final discharge of seawater may contain solid particulate matter such as catalysts, which may have an impact on the environment of the nearby sea.

(3) Switzerland power turbine equipment requires high precision and high-quality manufacturing, so the equipment cost is relatively high. At the same time, maintenance costs can also be high due to the complexity and high technical requirements of the equipment.

(4) Energy recovery efficiency: Although power turbine technology can improve energy efficiency, under some operating conditions, recovery efficiency may be affected by exhaust temperature, flow rate, and other factors, resulting in unstable recovery efficiency.

(5) Finland technology integration complexity: This solution includes a variety of technologies, such as power turbines, waste heat boilers, steam turbines, etc., and the technology integration complexity is high, which increases the complexity of the system and the difficulty of maintenance.

Figure 2. Advanced technology at home and abroad

3.3. Development of a new type of device to create green shipping based on the current pollution situation in the shipping industry

Using seawater as the medium, seawater is evaporated and desalination by using the waste heat of the ship's smoke to obtain concentrated seawater, and the higher alkalinity of the concentrated seawater is used to neutralize the acidic gas. Compared to conventional scrubbers, this device is not affected by the salinity of seawater and does not require additional strong alkali reagents. In addition, this device is also very suitable for the flue gas purification of the island factory, which not only effectively solves the problem of island flue gas purification, but also reduces the cost of island flue gas treatment.

Feasibility verification of the flue gas cleaning system. Assuming that there is no loss in the ship's flue gas waste heat recovery desalination system, all the flue gas flow is sent to the flue gas purification system. The upper and lower two-stage spray devices inside the pneumatic emulsification desulfurization cylinder adopt 316L stainless steel spiral nozzles, and each spiral nozzle is equipped with a turbulent device with swirl blades to form a stable emulsion layer, improve the contact area between flue gas and concentrated seawater, and increase the efficiency of flue gas purification. The phase equilibrium equation for SO_2 at standard atmospheric pressure is:

$$y = -2 \times 10^{12} x^4 + 7 \times 10^{8} x^3 - 13490 x^2 + 0.7212 x + 6 \times 10^{-7}$$

The molar expression of SO_2 in the exhaust area is:

$$Y_2 = Y_1 \left(1 - \eta_\alpha\right)$$

The formula for calculating the liquid-gas ratio of the actual flue gas cleaning system is:

$$\frac{V_g}{V_c} = 1.5\left(\frac{Y_1 - Y_2}{X_1 - X_2}\right)\left(\frac{M_{sea} / \rho_{01,sea}}{M_{gas} / \rho_{11,gas}}\right) \times 100$$

The above formula is used to calculate and verify, and the spray amount can meet the concentrated seawater flow rate required by the pneumatic emulsion desulfurization cylinder, which verifies the rationality of the design. The dimensions of each partition of the flue gas purification system are shown in **Table 1**.

Table 1. The size of the flue gas cleaning system

Design parameters	Numeric value/m
Slurry pools	1.105
Air intake zone	1.6
Desulfurization cylinder	3.155
Secondary wash area	3.2
Scheduling area	0.6
The total height of the flue gas cleaning system	9.66

3.4. Economic analysis

(1) The coupled flue gas purification device for ship flue gas waste heat recovery and dilution is to make full use of ship waste heat for ship exhaust gas treatment, which has a better treatment effect than other traditional devices under the same flue gas treatment capacity. Taking the flue gas flow of the diesel engine as the object of the design of this work, the actual flue gas volume is 110,000 m^3/h, and the SO_2 content in the flue gas is 80.41 m^3/h, and the treatment effect is shown in **Figure 3**.

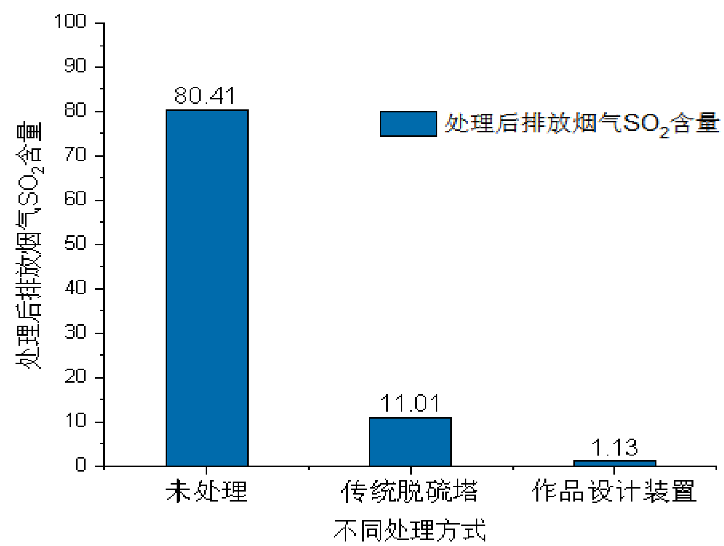

Figure 3. SO_2 content in exhaust gas after different treatments

(2) This technology reduces the size of the purification system and saves space on the basis of ensuring functional efficiency. According to the initial flue gas purification system, the empty tower flow velocity is 3 m/s, then the residence time of flue gas in the tower is 3.22 s, and it is calculated that when the tower diameter is rounded to 4 m, the calculated tower spray density will meet the minimum spray requirements. As a result, the cargo capacity

of the ship is increased, which improves the economic efficiency.

4. The outlook for the development of this device and the shipping industry

The design device is mainly suitable for offshore ships, and its research or overall design plays an important role in reducing the energy consumption of the ship and reducing the exhaust gas generated by the ship. It has the advantages of easy installation, small size, saving ship space, and lower economic cost. At the same time, this work uses seawater as the medium, uses the waste heat of the ship's flue gas to evaporate the seawater to desalinate and obtain concentrated seawater, and uses the high alkalinity of concentrated seawater to neutralize the acid gas, greatly reducing the cost of treating exhaust gas, and achieving the effect of green emission reduction.

4.1. A vision of the installation designed by the team

The device has the effect of coupling desalination and neutralizing ship exhaust, and can also be applied to the port ship docking place to reduce the pollution of the environment near the port. In the future, a coupled purification device for industrial use can be studied and designed, which can purify industrial wastewater and neutralize nitrogen and sulfur compounds generated in industry by using industrial waste heat, thereby reducing industrial pollutant emissions and adhering to the purpose of "emission reduction."

The device is very efficient on its own, but in the future, with the rapid development of social science and technology, the industrialized industry will be more prominent, and the coupling purification device alone may achieve a result of low efficiency. The double-coupled purification device was designed to make its work efficiency more significant and in line with the process of industrialization.

4.2. Prospects for the development of green shipping

Optimizing the industrial structure: On the basis of rationalization, it is recommended to optimize and upgrade the industrial structure, and strive to develop a high-tech industry and service industry, promote a green environmental protection industry, encourage and support the development of tertiary industry.

Adjusting the energy structure: At present, the use of old fuel oil ships is an important cause of environmental pollution in shipping. Increase the power, transformation, and renewal of the ship, strengthen the clean energy of ships (hydrogen energy, electric energy, biofuel), green transformation of ships (new energy passenger ships, electric propulsion ships, etc.), implement ship type standardization projects, and actively promote pollution-free power ships.

Optimizing the way transportation is organized: At present, the transportation system is mainly waterway, road, and railway transportation, among which, the freight turnover of the water transportation mode is the largest, followed by road transportation, and railway transportation is the smallest. The adjustment of the transportation structure will effectively reduce the energy consumption and air pollutant emissions of ships, improve the shipping supply capacity by optimizing the shipping network, developing iron-water combined transport, and building a modern green port, effectively increase the proportion of shipping, and give full play to the natural green advantages of shipping.

4.3. National Policy for the Development of Green Shipping (See Table 2 for details)

Table 2. Implementation of national policies

Type	Release date	Filename
National policy	2017-02-03	The 13th Five-Year Plan for the Development of a Modern Comprehensive Transportation System
National policy	2015-08-27	Implementation Plan for the Special Action on the Prevention and Control of Pollutants in Ships and Ports (2015–2020)
National policy	2017-12-06	"Opinions on Comprehensively and Deeply Promoting the Development of Green Transportation"

5. Conclusion: An important element in the development of green shipping

Green shipping elements mainly include green waterways, green ports, green ships, green transportation organization methods, etc. [9].

(1) Green waterway refers to the development concept of environmental protection, energy saving, emission reduction, recycling, and sustainability in the whole life cycle of waterway construction and operation.

(2) Green port refers to the protection of the ecological environment and intensive utilization of resources, and at the same time, can ensure the normal production of the port and create economic benefits, so that the two can be coordinated and achieve sustainable development.

(3) Green ship refers to the promotion of ship standardization, large-scale, new-type, and green development through technological upgrading in the whole life cycle of the ship, which can not only meet the requirements of ship operation at a lower cost, but also maximize energy conservation and carbon reduction.

(4) The organization mode of green transportation refers to advocating advanced transportation organization and management, rationally adjusting the structure of ships and shipping capacity, improving the organization of water transportation, scientifically planning transportation routes and transit locations, optimizing the allocation of port resources, using modern information technology, giving full play to the advantages of water transportation energy conservation and environmental protection and the combined efficiency of various modes of transportation, maximizing transportation efficiency and promoting the green development of shipping [10,11].

Disclosure statement

The authors declare no conflict of interest.

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