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Co-operative Purification of Marine Flue Gas based on Renewable Energy Electrolysis of Seawater for Alkaline Production

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Abstract

The project addresses the problems of difficult directional changes, high noise levels, low wind energy conversion efficiency and high maintenance costs of traditional horizontal axis wind turbines. The ship wind energy collection and conversion electrolytic desulphurisation and denitrification system constructed in this paper can be widely used in various complex scenarios of ship operation, for wind power generation, ship emission pollution control, and other industries producing lye, all of which can be widely used; at the same time, this project improves and uses wind power generation and makes reasonable use of marine resources to reduce ship sulphur and nitrate pollutant emissions, which has positive significance for energy conservation and emission reduction.

Keywords

Wind Turbine Power Generation System; Energy Saving and Emission Reduction; Renewable Energy; Electrolysis of Seawater for Alkali Production.

1. Introduction

1.1 Project Background

The report of the 20th Party Congress explicitly calls for promoting clean and low-carbon transformation in transportation and other fields, and reducing emissions of air pollutants such as sulfur oxides and nitrogen oxides. According to the International Maritime Organization (IMO), NOx generated by ships is about 15% of global NOx emissions, and SOx generated by ships is about 8% of global SOx emissions. In recent years, IMO and various countries have successively introduced relevant control measures for fuel oil sulfur content and nitrogen sulfur oxide emissions, in order to make the pollutant emissions meet the relevant requirements, the existing wet flue gas desulfurization device after the transformation of the desulfurization tower in actual operation found that a variety of measuring meter installation position is unreasonable, the flue gas inlet scaling phenomenon is difficult to avoid, while the desulfurization is not complete or even cause secondary pollution; and NOx is both nitric acid type It is one of the main substances to form photochemical smog and destroy the ozone layer, and has strong toxicity, which is harmful to human body, environment and ecology as well as the damage to the society and economy, plus the large base of global ship ownership and fast growth rate, so there are still a lot of nitrogen and sulfur oxides emitted into the atmosphere every year, which seriously endangers the global environment. In addition, the operating cost of the ship climbs sharply with the reduction of nitrogen and sulfur oxide emission. If the sulfur content of the fuel used by the ship is reduced from 3.5%m/m to 0.5%m/m, the shipping cost will increase by more than 6 billion yuan, and if it is reduced from 3.5% to 0.1%, the cost will increase by 20 billion yuan. Therefore, it is significant to combine with the characteristics of ships themselves, and the innovative research for the efficient treatment of sulfur oxides and nitrogen oxides in ships[1].

1.2 Domestic and International Research Progress

Renewable energy includes solar energy, wind energy, hydro energy, geothermal energy, and more. They are widely used for power generation and reducing reliance on traditional energy sources. Electrolytic seawater alkaline production refers to the process of using electrolysis to decompose salt in seawater, generating hydrogen gas and sodium hydroxide (alkaline solution). This process requires a significant amount of energy. In the maritime industry, exhaust gas treatment is a crucial concern due to the presence of harmful substances such as sulfur dioxide, nitrogen oxides, and particulate matter in combustion emissions[2]. Currently, many vessels employ conventional exhaust gas purification technologies like desulfurization and denitrification systems to reduce the emission of these pollutants. However, research combining renewable energy, electrolytic seawater alkaline production, and exhaust gas treatment in maritime applications is relatively limited. One potential research direction is to utilize renewable energy sources to supply electricity, which can be used for electrolytic seawater alkaline production and exhaust gas treatment on ships. This approach can facilitate the decomposition of salts in seawater into hydrogen gas and alkaline solutions, while reducing the presence of harmful substances in ship emissions.

1.3 Technical Route Study

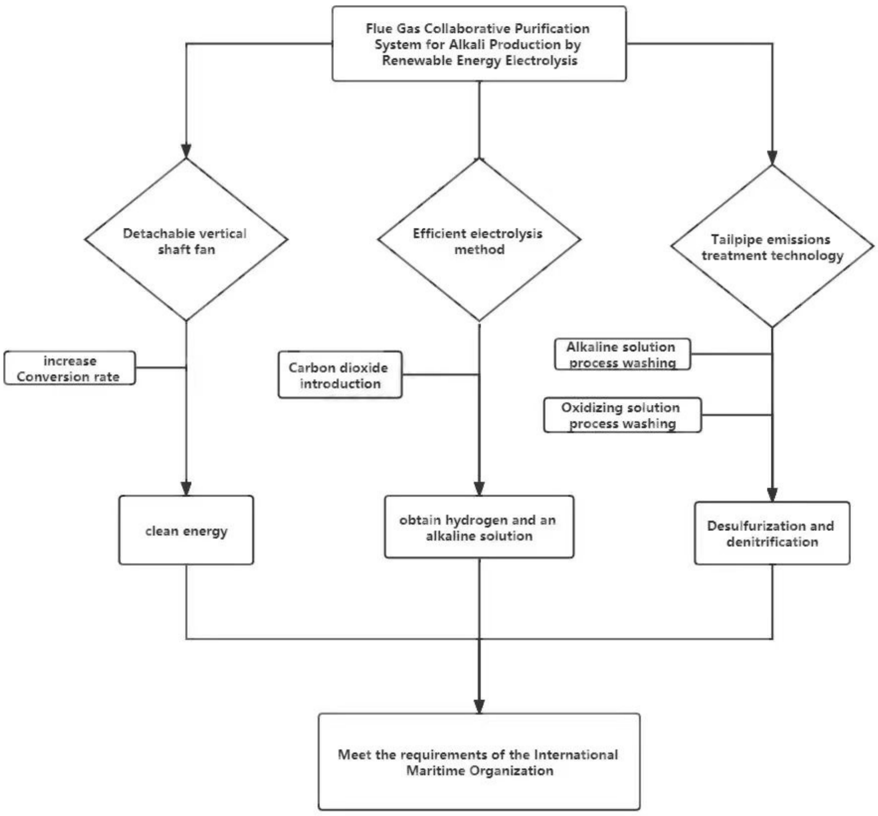

Figure 1. Technical ideas diagram

For the traditional horizontal axis wind turbine is difficult to change direction, noisy, low wind energy conversion efficiency and high maintenance cost, and can not be loaded and unloaded on the ship at will, the modularity is low; the traditional seawater electrolysis method has high energy consumption, low efficiency and high electrolysis cost, and there are a series of problems derived from low salt concentration, and the system is complicated and unstable power generation leading to unstable operation of alkali system; the traditional desulfurization device has low desulfurization efficiency and high cost of low sulfur fuel[3]. The technical idea of a closed-loop system consisting of a detachable modular vertical shaft fan power generation system, an efficient electrolysis method based on CO2-assisted economic desulfurization and an integrated system of integrated desulfurization and

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denitrification of electrolysis products is proposed. The current commercial electrolyzer method, the energy consumption level is about 4.5~5.5kwh/Nm3H2, the energy efficiency is between 72%~82%, the cost of hydrogen production by water electrolysis is equivalent to 30~40 RMB/kg, the price of producing gaseous hydrogen by electrolysis is about 65% higher than gasoline, and if producing liquid hydrogen, it is about 260% higher than gasoline or more[4]. Compared with the traditional horizontal axis wind turbine, the detachable modular multi-rotor vertical axis wind turbine under the control of intelligent yaw system can increase the wind energy conversion efficiency gain to more than 23.3%, while adapting to a larger range of wind levels and reducing the wind load on the wind turbine, and it is easy to disassemble and install to realize the rationalization of ship space utilization; based on the CO2 assisted realization of economic de-hybridization high efficiency electrolysis method by the derivation of the best electrolysis to make alkali The CO2-assisted electrolysis method improves the efficiency of electrolysis and achieves stable electrolysis of high concentration brine by deducing the optimal current. The wind energy collection and conversion electrolytic desulfurization and denitrification system for ships constructed in this work can be widely used in various complex scenarios of ship operation, for wind power generation, ship emission pollution control, and other industries producing alkali solution; meanwhile, the project improves and uses wind power generation to reduce sulfur and nitrate pollutant emissions from ships by rational use of marine resources, which is fully in line with the theme of the competition[5].

2. Design of Ship Flue Gas System for Electrolysis of Seawater to Alkali

2.1 Build a Dismantleable and Easy to Install Multi-wheel Vertical Axis Fan System

Figure 2. Vertical axis fan and horizontal axis fan comparison chart

For the problems of poor structural stability of horizontal axis wind turbine, low energy conversion efficiency of single wind turbine, poor force conditions and low modularity, etc. In this project, a dismountable and easy-to-install vertical axis wind turbine system is designed for power generation[6]. The wind turbine is flexible and rapid in changing direction, has low noise, has almost no impact on the normal working life of the crew, has low maintenance cost, has reasonable space utilization, and reduces the impact on the original use of the ship. As the vertical axis fan wheel space position is more downward, the fan center of gravity is lower, easy to replace the blade, and the blade has more choice types, greatly reducing the production cost, solving the traditional horizontal axis fan wheel due to its overhang on the outside of the fan, easy to be affected by gravity resulting in structural damage defects. At the same time, because the vertical axis fan wheel and fan pillar with screws connected, easy to load and unload, the stability of the wind wheel and blade protection also has a large improvement. For the energy conversion efficiency, the project team adopted the optimized design of multiple vertical axis wind turbine wheels[7]. The tail vortex generated by the wind turbine wheel in front of the wind direction will have a positive impact on the flow field around the wind turbine wheel in the backward direction, increasing its corresponding conversion efficiency. Wind tunnel experimental measurement data show that the wind energy conversion efficiency gain of the double rotor reaches 8.92%; the four rotor wind energy conversion efficiency gain reaches

23.3%[8]. The use of vertical axis wind turbine can be applied to the wind speed and wind direction changes are large that is easy to cause the wind turbine engine speed too fast or too slow marine environment, to ensure that the maximum wind power conversion efficiency at the same time, to ensure the good operation of the equipment itself. The use of multi-wheel vertical axis wind turbine can achieve efficient and stable wind energy harvesting, and apply to more sea conditions to obtain more energy[9].

2.2 Design of an Efficient Electrolysis Method based on CO2 Assisted Realization of Economic Decontamination

For today's traditional seawater electrolysis method electrolysis efficiency is low, electrolysis energy consumption is large, the system is complex, power generation is not method, and the use of CO2 introduction combined with gas turbulence reinforcement, regulation of electrolysis system ion concentration distribution to reduce alkaline precipitation formation, to achieve efficient electrolysis of composite brine and product orientation preparation. That is, when the desalination device on the ship is working, a continuous stream of concentrated seawater will be discharged outboard, and the concentrated seawater will be collected and introduced into the electrolyzer for electrolysis, and CO2 can be passed into the flocculated solution that is about to be precipitated from different directions at low speed during the electrolysis process, so that the generated precipitates such as Ca(OH)2 and Mg(OH)2 can be processed in time to generate soluble bicarbonate, which can solve the problems caused by precipitation to the membrane. Due to the barrier separation of cation exchange membrane, only sodium ions can pass freely and anions cannot pass through, therefore, the modified anode chamber generates acidic solution with hypochlorous acid as the main oxidizing component and cathode chamber generates alkaline solution with sodium hydroxide as the main alkaline component, the schematic diagram of electrolysis device is shown in Figure 3.

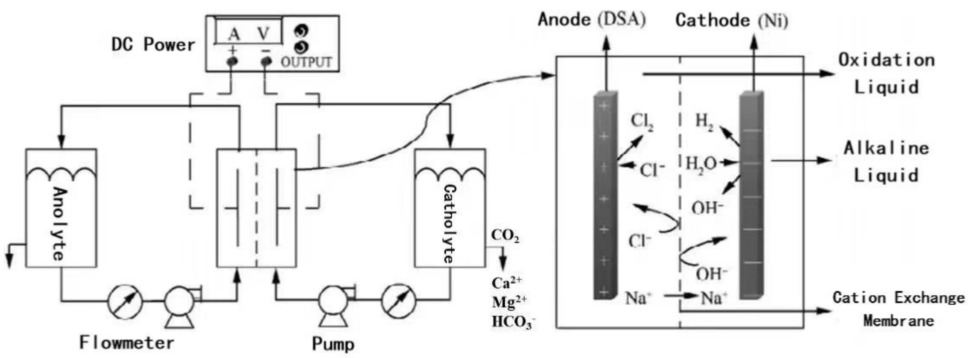

Figure 3. Schematic diagram of the electrolysis device unit

2.3 Designing an Efficient Post-treatment Technology for Ship Exhaust Gas

Aiming at the problems of high investment cost and complicated system of photocatalytic, electrocatalytic and plasma activation technologies for desulfurization and denitrification, as well as the traditional wet scrubbing technology which hardly absorbs the insoluble NO in the exhaust gas, the project team designed an efficient and applicable post-treatment technology for ship exhaust gas, the oxidizing solution and alkaline solution process scrubbing method, which provides a new method and a new way for desulfurization and denitrification of ship exhaust gas. The project team designed a highly efficient and applicable post-treatment technology, oxidizing solution and alkaline solution process scrubbing method, to provide a new method and approach for ship exhaust gas desulfurization and denitration. The method performs desulfurization and denitrification through the oxidizing solution and alkaline solution produced by electrolysis of seawater. The device mainly consists of exhaust gas simulation device, exhaust gas purification and scrubbing tower and exhaust gas analysis detector, which can be retrofitted to the ship's desulfurization tower with good marketability. It is known from the standard electrode potential that the electrode potential of HClO/Cl-(1.698 V) redox

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pair is significantly higher than that of NO2/NO(1.049 V), NO3-/NO(0.96 V), NO3-/NO2(0.775 V), SO42-/ SO2 (0.158 V), and SO42-/SO32- (0.93 V) electrode potentials for redox pairs. Theoretically, HClO can oxidize SO2 and NO to their highest valence states, only the reaction paths are different; while SO2 has good water solubility, hydrolysis will produce HSO32- and SO32-, and further oxidation can produce SO42-, therefore, after hydrolysis, oxidation Therefore, the three processes of hydrolysis, oxidation and absorption can basically be completely removed, and the main removal pathways involved are shown in the reaction equations (1) to (6) in Table 1. In addition, the inherent alkalinity of seawater (HCO32-) also has the effect on SO2 removal, and the main removal pathway is shown in the reaction equation (7) in Table 1. This method solves the problems of ineffective removal of nitrogen oxides and low removal rate of sulfur oxides in the exhaust gas, and achieves net flue gas emission[10].

Table 1. Reaction equation of seawater for diaphragm spotting

Contaminant	Reaction formation	Reaction equation	Serial numbef
SO_2		SO_2 (g) ↔SO_2 (aq)	(1)
	SO_2 Hydrolysis	SO_2 (aq) +H_2O (l)↔HSO_3^-(aq) +H^+(aq)	(2)
		HSO_3^-(aq)↔SO_3^{2-} (aq) +H^+ (aq)	(3)
	HC IO Oxidization	HClO(aq) +SO_3^{2-}(aq) →SO_4^{2-} (aq) +HCl (aq)	(4)
		HClO(aq) +HSO3 $^-$ (aq)→SO_4^{2-} (aq) +Cl^- (aq) +2H^+ (aq)	(5)
	NaOH Absorption	SO_2(aq) +2OH^-(aq)→SO_3^{2-} (aq) +H_2O (1)	(6)
	HCO_3^- Absorption	SO_2(aq) + HCO_3^- (aq) →HSO_3^-(aq) +CO_2(aq)	(7)
NO		NO(g) ↔ NO(aq)	(8)
	HClO Oxidization	HClO (aq) + NO (aq) →NO_2 (aq) + HC1 (aq)	(9)
		3NO_2 (aq) + H_2O (l)→2HNO_3 (aq) +NO (aq)	(10)
		2NO_2 (aq) + H_2O (l)→2HNO_3 (aq) + HNO_2 (aq)	(11)
	NaOH Absorption	2NO_2 (aq) +2OH^- (aq)→NO_2^- (aq) + NO_3^- (aq) +H_2O (l)	(12)

3. Applications of Renewable Energy-powered Electrolysis of Seawater for Alkali Production

3.1 Alkali Manufacturing Industry

The renewable energy-powered electrolysis of seawater for alkali production has significant potential for application in the alkali manufacturing industry. Traditional alkali production processes typically rely on mineral extraction and chemical synthesis, which consume substantial amounts of energy and contribute to environmental pollution. Utilizing renewable energy for seawater electrolysis in alkali production can reduce energy consumption and environmental impact.

(1) Energy savings

Renewable energy sources such as solar and wind power can be employed as energy sources for the electrolysis process, replacing conventional coal or oil consumption. This not only reduces dependence on finite resources but also lowers greenhouse gas emissions during energy production.

(2) Environmental friendliness

By utilizing renewable energy sources instead of traditional energy sources during electrolysis of seawater, emissions of pollutants such as carbon dioxide and sulfur dioxide can be reduced. This has positive implications for reducing air and water pollution and improving overall environmental quality.

(3) Sustainable development

The use of renewable energy-powered electrolysis of seawater for alkali production not only contributes to the sustainability of the alkali manufacturing process but also promotes the development of the renewable energy industry. With advancements in renewable energy technologies and cost reductions, the application of renewable energy-powered electrolysis in the alkali manufacturing industry will become more widespread and economically viable.

The alkali manufacturing industry widely utilizes alkali products, including sodium hydroxide (caustic soda) and potassium hydroxide, which play important roles in industries such as glass manufacturing, fertilizer production, detergent manufacturing, paper, and textiles. By adopting renewable energy-powered electrolysis of seawater for alkali production, dependence on conventional alkali production processes can be reduced, providing a more sustainable and environmentally friendly alternative. Promoting the use of renewable energy-powered electrolysis of seawater for alkali production in the alkali manufacturing industry requires further research and development, improvement in the design of electrolysis equipment and process parameters to enhance energy utilization efficiency and alkali product quality. Additionally, government support and industry investment are crucial factors in driving the application of renewable energy-powered electrolysis of seawater for alkali production.

3.2 Water Treatment and Desalination

Renewable energy-powered electrolysis of seawater has significant applications in water treatment and desalination processes. This technology offers various advantages in addressing water scarcity and meeting the increasing demand for freshwater resources. The applications of renewable energy-powered electrolysis of seawater in water treatment and desalination include:

(1) Desalination

Seawater desalination is a critical process for producing freshwater in areas with limited access to freshwater sources. Renewable energy-powered electrolysis can play a vital role in desalination by utilizing the electrical energy generated from renewable sources to separate salt from seawater through the electrolysis process. This allows for the production of fresh water suitable for various applications, including drinking water supply, irrigation, and industrial processes.

(2) Brackish Water Treatment

In addition to desalination, renewable energy-powered electrolysis of brackish water (water with lower salinity compared to seawater) can be employed for treating brackish water sources. This process effectively removes dissolved salts and contaminants, improving the water quality and making it suitable for agricultural use, industrial processes, and human consumption.

(3) pH Adjustment

Electrolysis of seawater using renewable energy sources allows for precise control of pH levels in water treatment processes. By adjusting the alkalinity of water through the electrolysis process, the pH can be optimized for specific applications, such as enhancing the effectiveness of disinfection or supporting desired aquatic ecosystems.

The application of renewable energy-powered electrolysis of seawater in water treatment and desalination processes offers several advantages. It reduces reliance on conventional energy sources and mitigates the environmental impact associated with traditional desalination methods. Additionally, it promotes the utilization of renewable energy and contributes to sustainable water management practices. To further advance the application of renewable energy-powered electrolysis of seawater in water treatment and desalination, ongoing research and development efforts are necessary. This includes optimizing electrolysis system designs, enhancing energy efficiency, exploring innovative materials for electrolysis electrodes, and evaluating the economic viability of

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large-scale implementation. Collaboration between research institutions, industry stakeholders, and policymakers is vital for the successful adoption and integration of this technology into water treatment and desalination processes.

3.3 Hydrogen Energy Production

The application of renewable energy-powered electrolysis of seawater extends to the production of hydrogen, a versatile and clean energy carrier. Electrolysis of seawater using renewable energy sources allows for the simultaneous generation of hydrogen gas and alkaline solution. This application holds significant potential for advancing the development of sustainable hydrogen energy. The applications of renewable energy-powered electrolysis of seawater in hydrogen production include:

(1) Green Hydrogen Production

Green hydrogen refers to hydrogen produced through electrolysis using renewable energy sources, such as solar or wind power. Electrolyzing seawater with renewable energy not only produces hydrogen without carbon emissions but also utilizes an abundant resource, seawater, as a feedstock. Green hydrogen can serve as a sustainable fuel for various applications, including transportation, power generation, and industrial processes.

(2) Energy Storage

The production of hydrogen through renewable energy-powered electrolysis offers a means of energy storage. Excess renewable energy generated during low-demand periods can be used for electrolysis, converting it into hydrogen for later use. This enables the storage of renewable energy in the form of hydrogen, which can be utilized during high-demand periods or when renewable energy supply is limited.

(3) Fuel Cell Applications

Hydrogen produced from renewable energy-powered electrolysis can be used in fuel cells for electricity generation. Fuel cells convert hydrogen and oxygen into electricity through an electrochemical process, with water as the only byproduct. This provides a clean and efficient energy conversion method for various applications, including portable power systems, electric vehicles, and stationary power generation.

The application of renewable energy-powered electrolysis of seawater in hydrogen production contributes to the decarbonization of energy systems, reducing dependence on fossil fuels, and promoting the utilization of sustainable energy sources. It also supports the development of a hydrogen economy, where hydrogen serves as an important energy carrier and facilitates the integration of renewable energy into various sectors.

To fully realize the potential of renewable energy-powered electrolysis of seawater for hydrogen production, continued research and development efforts are essential. This includes improving electrolysis efficiency, exploring advanced catalyst materials, reducing costs, and establishing robust infrastructure for hydrogen storage, distribution, and utilization. Additionally, supportive policies, incentives, and international collaborations are crucial to accelerate the deployment and commercialization of renewable energy-powered seawater electrolysis for hydrogen production.

4. Conclusion

(1) Using multiple rotors to collect and convert wind energy to improve the conversion rate. Wind tunnel experimental measurement data show that the wind energy conversion efficiency gain of two rotors is 8.92%; four rotors wind energy conversion efficiency gain of 23.3%, so the use of multi-rotor work can greatly improve the conversion rate.

(2) Design and structural optimization of intelligent yaw system for vertical axis wind turbines. When the wind speed is less than wind level 7, the windward angle tends to be close to ninety degrees to make full use of wind energy. Different working wind speed levels of the fan are distinguished, and

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different wind speed levels use different windward angles, which can reduce the wind load on the wind wheel and also improve the efficiency of the use of wind energy. The wind turbine wheel and the wind turbine pillar are connected by screws, with a high degree of modularity, good ship adaptability, low space occupation, easy loading and unloading, and a large improvement in the stability of the wind turbine and the protection of the blades.

(3) The optimal manufacturing alkali operating current is derived, and the optimal alkali making current is verified by multiple methods. The optimal running current is verified by data regression method and cross and algorithm, and the main factors affecting the optimal running current are obtained to improve the efficiency of electrolysis.

(4) Stable electrolysis of high concentration brine was achieved. We have studied the way of carbon dioxide feeding into the electrolysis device, optimized the electrolyzer design, facilitated the extraction of products and the replacement of electrolyte, and provided theoretical guidance for the structural optimization design of the new electrolysis device to realize the stable electrolysis of high concentration brine.

(5) Improve the removal rate of nitrogen oxides. The removal efficiency of SO2 can reach more than 96%, and the removal efficiency of NO can reach more than 80%. The difference between the removal efficiency of SO2 and direct seawater scrubbing is not obvious, but there is a significant difference in the removal efficiency of NO, which is beneficial to denitrification.

(6)oxidation absorption coupled reaction desulfurization and denitrification. As an efficient integrated technology of desulfurization and denitrification with stable operation, simple operation and easy control, and good adaptability, it is expected to be suitable for construction on ships.

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