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Filter Sea Core-Dynamic Light-Coupled High-Efficiency Solar Desalination Device

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ABSTRACT

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KEYWORDS

Mechanical engineering; Manufacturing technology; Electrical automation.

1. INTRODUCTION

As the global population continues to grow and industrialization accelerates, the demand for freshwater resources is rising steadily, while the total available freshwater resources are constrained. The ocean covers 71% of the Earth's surface, with its water volume accounting for 96.5% of the Earth's total water.

However, due to its high salinity, it cannot directly meet the water needs of human life and industrial and agricultural use. According to 2024 statistics, about half of the global population experiences severe water shortages during the annual cycle, with one-quarter of the population at an 'extremely high' risk level of water resource pressure. In these regions, the intensity of freshwater resource development has exceeded the sustainable threshold by 80%. In this context, developing efficient and environmentally friendly seawater desalination technology systems has become a strategic measure to address regional and global freshwater shortages.

Currently, the main technologies for seawater desalination include distillation, membrane technology, freezing, and solar distillation. Distillation, while mature and suitable for large-scale projects, has high energy consumption, significant initial investment, and high maintenance costs. Membrane technology is more energy-efficient, compact, and easy to operate, but it requires high-pressure pumps, has strict water quality requirements, and is prone to membrane fouling, necessitating regular replacement. It also demands high-quality ion exchange membranes, which can be inefficient when treating highly saline seawater. The freezing method is relatively energy-efficient but has low water quality requirements and produces water with a poor taste and slow processing speed. Solar distillation is environmentally friendly and energy-efficient, making it suitable for areas with abundant solar resources. Compared to other methods, solar seawater desalination reduces dependence on traditional energy sources by using solar power, which is a green energy source. This method can operate independently without external energy supplies like steam or electricity, and it produces no pollutants during operation, meeting environmental protection standards.

The Core of Sea Water Filtration-An Efficient Solar Desalination Device Coupled with Dynamic Light Tracking and Anti-fouling Membrane, a high-efficiency solar seawater desalination device that integrates dynamic light tracking and anti-fouling membranes, significantly enhances the efficiency and utilization of solar energy. The device uses light-tracking technology to track the sun's rays, maximizing energy absorption. It also employs advanced evaporation and condensation techniques to greatly improve the efficiency and quality of seawater desalination. This device is widely used in seawater desalination, water purification, and the extraction of concentrated brine.

2. PRINCIPLE OF DYNAMIC LIGHT TRACKING AND ANTI-FOULING FILM COUPLING FOR HIGH EFFICIENCY SOLAR SEAWATER DESALINATION DEVICE

2.1. Analysis of the principle of reverse osmosis membrane modification

2.1.1. Reverse osmosis membrane (RO) principle

As a core component of reverse osmosis technology, the reverse osmosis membrane is an artificial semi-permeable membrane designed based on the principle of biological semipermeable membranes, featuring specific separation properties. The key mechanism of reverse osmosis technology is driven by osmotic pressure differences. By applying external pressure greater than the inherent osmotic pressure of the solution, the selective permeability of the semi-permeable membrane enables the directional separation of solute components from the solvent (see Figure 1for the relevant principle model). Due to its sub-nanometer pore size (0.1-1 nanometers), the reverse osmosis membrane can effectively retain various pollutants, including dissolved salts, colloidal substances, microbial communities, and large organic molecules. This technology not only achieves excellent water purification but also offers significant advantages in energy efficiency, environmental compatibility, process simplicity, and ease of operation.

Method for modifying reverse osmosis membranes: A polyamide reverse osmosis membrane with anti-fouling properties is prepared through a hexanol surface grafting modification process. The residual acyl chloride groups on the polyamide surface, after interfacial polymerization, are used as anti-fouling functional monomers. Hexanol is applied as the anti-fouling functional monomer to modify the surface of the polyamide membrane, resulting in a high-flux reverse osmosis membrane with anti-fouling properties. Experimental results show that the modified reverse osmosis membrane exhibits a smaller contact angle, greater roughness, higher water flux, and stronger anti-fouling performance. The backwashing filter is triggered by the pressure difference between the inlet and outlet sides, automatically controlling the motor, valves, and other equipment to sequentially rinse the filter membrane, ensuring it remains clean. The liquid enters through the inlet and flows through the small holes in the diaphragm into the filter cores, which are neatly arranged around the drive shaft. As the liquid passes through the filter membrane, large particles are retained on the inner side of the membrane. When the RO membrane becomes dirty to a certain extent and the filtration efficiency decreases, the pressure difference between the inlet and outlet exceeds the set value, causing the internal clean water to flow back through the RO membrane, carrying the contaminants attached to the inner wall of the RO membrane with the concentrated water out through the discharge port.

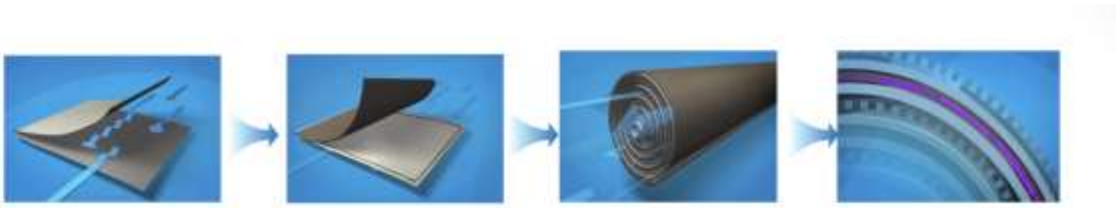

Figure 1 Schematic diagram of reverse osmosis membrane

2.1.2. Principle of reverse osmosis membrane modification

The technology for preparing anti-fouling polyamide reverse osmosis membranes using hexanol surface grafting involves innovatively modifying the surface of traditional polyamide reverse osmosis membranes through molecular engineering, as illustrated in Figure 3. This technique leverages the chemical reaction properties of the amide bonds in polyamide molecules. Initially, the membrane surface is activated using dichlorosulfone, converting the carboxyl and amide groups at the ends of the polyamide molecular chains into highly reactive acyl chloride groups. This process significantly increases the chlorine content on the membrane surface to 3.2 atomic percent, as detected by X-ray photoelectron spectroscopy (XPS), setting the stage for subsequent grafting reactions. Subsequently, under nitrogen protection, the multiple reactive sites of the six hydroxyl groups in hexanol molecules react with the acyl chloride groups on the membrane surface through esterification, forming stable covalent bonds. The characteristic absorption peak at 1720cm^{-1} in Fourier transform infrared spectroscopy (FTIR) confirms the successful formation of the ester bond.

The modification technique significantly improved the membrane's surface properties by incorporating hexanol molecules. AFM observations revealed that the surface roughness (Ra) of the modified membrane decreased from 58nm to 32 nm, resulting in a more uniform nano-scale topography. Contact angle measurements indicated a significant enhancement in the membrane's hydrophilicity, with the water contact angle dropping from 65° to 28°, primarily due to the introduction of numerous hydroxyl groups in the hexanol molecules and changes in surface energy. The oxygen-to-carbon ratio (O/C) of the modified membrane increased from 0.18 to 0.25, further confirming the changes in surface chemical composition.

In terms of performance, the modified membrane maintains excellent desalination performance (NaClretention rate of 98.5%) while achieving an initial water flux of 1.8 L/(m^2 h bar), which is about 40% higher than that of traditional polyamide membranes. More importantly, the modified membrane exhibits outstanding anti-pollution characteristics. The adsorption test with bovine serum albumin (BSA) shows a 62% reduction in pollutant adsorption, and the flux decay rate during dynamic pollution tests is controlled within 15%, significantly better than the 40% decay rate of unmodified membranes. This improvement in anti-pollution performance is attributed to enhanced surface hydrophilicity and optimized nano-scale topological structure, which effectively inhibit the adsorption and deposition of pollutants on the membrane surface. Long-term operation tests show that after 30 acid-base cleaning cycles, the modified membrane can still maintain a retention rate of over 97%, and the flux decay during continuous operation for 500 hours does not exceed 8%, demonstrating excellent stability. After grafting hexanol onto the surface, the surface properties of the polyamide reverse osmosis membrane have undergone significant changes: Anti-pollution performance has improved: The introduction of hexanol increases the hydrophilicity and anti-adhesion of the membrane surface, reducing the tendency of pollutants to adsorb and deposit on the membrane surface. Therefore, the modified membrane can maintain a high flux recovery rate and low pollution rate during long-term operation. High flux performance: The grafting of hexanol alters the roughness and pore structure of the membrane surface, making water molecules pass through more easily, thus improving the membrane's flux performance. Enhanced stability: The covalent bond between hexanol and polyamide enhances the chemical stability and mechanical strength of the membrane, so that the modified membrane can maintain good performance under harsh operating conditions.

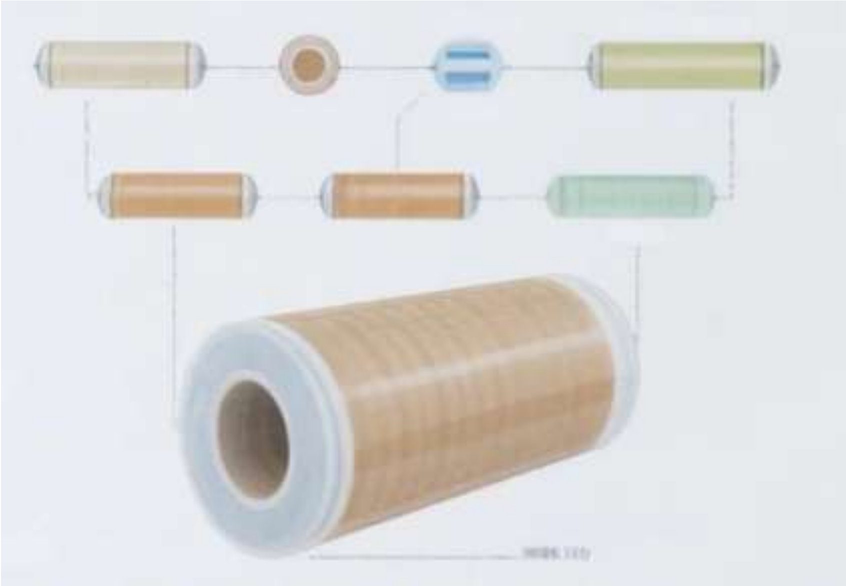

Figure 2 Schematic diagram of reverse osmosis membrane modification

2.1.3. Reverse osmosis membrane modification process

First, the polyamide reverse osmosis membrane is pre-treated by immersing it in deionized water and ultrasonically cleaning for 30 minutes to remove surface impurities. It is then dried to a constant weight in a 60°C vacuum drying oven. This step ensures the membrane's surface is clean, providing an ideal interface for subsequent chemical reactions. Next, the membrane material is immersed in a 2% (v/v) dichlorosulfone ($SOCl_2$) toluene solution and reacted for 2 hours under a 40°C constant temperature water bath. Nitrogen gas is introduced during the reaction to protect the membrane from moisture interference. This step converts the amide bonds and terminal carboxyl groups in the polyamide molecular chains into highly reactive acyl chloride groups. Following this, the membrane undergoes intermediate washing. After the reaction, the membrane surface is immediately rinsed three times with anhydrous toluene to thoroughly remove unreacted $SOCl_2$ and by-products. It is then dried at room temperature in a vacuum drying oven for 30 minutes. Next, the hexanol grafting reaction is carried out by immersing the acyl chloride-treated membrane in a 5% (w/v) hexanol N,N-dimethylformamide (DMF) solution and reacting for 4 hours under a 60°C oil bath. The reaction system is maintained under a nitrogen atmosphere to prevent hydroxyl oxidation. In this step, the hydroxyl groups of hexanol undergo esterification with the acyl chloride groups on the membrane surface, forming covalent bonds. Finally, post-treatment is performed by ultrasonically cleaning the membrane 15 minutes each time with DMF, ethanol, and deionized water to remove physically adsorbed hexanol molecules. The membrane is then dried for 12 hours in a 60°C vacuum drying oven to ensure the grafting structure is fully stabilized.

2.1.4. Analysis of modified characteristics of reverse osmosis membrane

The anti-fouling polyamide reverse osmosis membrane prepared by grafting modification on the surface of hexanol exhibits significantly optimized comprehensive performance characteristics. The synergistic changes in the surface chemical composition and physical structure have led to a breakthrough in performance. X-ray photoelectron spectroscopy (XPS) analysis shows that the oxygen-to-carbon atom ratio (O/C) on the modified membrane surface increased from 0.18 to 0.25, confirming the successful grafting of numerous hydroxyl groups from the hexanol molecule. The characteristic absorption peak at $1720cm^{-1}$ in Fourier transform infrared spectroscopy (FTIR) clearly indicates the formation of ester bonds, providing solid molecular-level evidence for the grafting reaction. Atomic force microscopy (AFM) characterization reveals that the surface roughness (Ra) of the modified membrane has decreased from 58nm to 32nm, resulting in a more uniform nano-scale topological structure. This optimized surface morphology, combined with the enhanced hydrophilicity demonstrated by contact angle tests (water contact angle from 65° to 28°), effectively inhibits the adsorption and deposition of pollutants on the membrane surface, preventing them from adhering and accumulating.

In terms of actual performance, the modified membrane maintains excellent desalination performance (NaCl rejection rate 98.5%) while achieving an initial water flux of 1.8 L/(m^2 h bar), which is about 40% higher than that of traditional polyamide membranes. This breakthrough overcomes the trade-off between flux and selectivity in conventional reverse osmosis membranes. More importantly, dynamic fouling tests show that the flux decay rate of the modified membrane is controlled within 15%, significantly better than the 40% decay rate of unmodified membranes. After 30 acid-base cleaning cycles, the rejection rate remains above 97%, and the flux decay during continuous operation for 500 hours does not exceed 8%, demonstrating outstanding long-term operational stability. This comprehensive performance improvement is attributed to the enhanced surface hydrophilicity introduced by a large number of hydroxyl groups from hexanol grafting and the inhibitory effect of optimized surface morphology on pollutant adsorption. The synergistic effect of these two factors ensures that the modified membrane possesses high flux, high selectivity, and excellent anti-fouling properties, providing an innovative solution for the long-term stable operation of reverse osmosis membranes under complex water conditions.

2.2. Analysis of prism focusing principle

2.2.1. Principle of prisms

The optical principle of a prism is based on the refraction of light. When light rays enter a transparent medium with a different refractive index from another medium at an angle, their direction of propagation will be deflected at the interface, following Snell's law ($n_1\sin\theta_1=n_2\sin\theta_2$). In a prism, light typically undergoes two refraction processes: —— first, when it enters the prism material from air at the incident interface, it deflects towards the normal; then, when it exits the prism material and re-enters air at the exit interface, it deflects away from the normal. This double refraction effect resultsin a specific deflection angle for the light, which depends on the refractive index, geometric shape, and angle of incidence of the prism material. For polychromatic light, due to the difference in refractive indices of different wavelengths of light (dispersion), each component of the light produces a different deflection angle, leading to the splitting of the spectrum. This characteristic enables prisms to be used for spectroscopic analysis. Additionally, by precisely designing the apex angle and the orientation of the refractive surfaces of the prism, specific functions such as the redirection of the optical path, rotation of the image, or deflection of the beam can be achieved. These features make prisms valuable in optical instruments, spectroscopic analysis, and optical communication.

2.2.2. Principle of prism focusing

The principle of prism focusing is based on the precise control of the law of refraction and geometric optics. It involves using a specific angle prism array to direct and spatially reorganize incident sunlight. When parallel sunlight strikes the inclined surface of the prism at a specific angle, the light undergoes two refractions inside the prism, resulting in a controlled angular deflection. The array structure, formed by multiple prism units arranged in an optimized configuration, can re-focus the scattered incident light to the target area. This focusing method differs from traditional reflective focusing, with its unique advantage being the high light transmittance of the prism material, which reduces energy loss. By precisely matching the prism's apex angle and refractive index (typically using optical glass or polymers with a refractive index of 1.4-1.8) and combining it with an adaptive light-following system that adjusts the incident angle in real time, it can achieve an optical efficiency of over 85%. The anti-reflection coating on the prism surface further reduces interface reflection loss to below 2%, while the specially designed asymmetric prism structure can selectively filter out ultraviolet and infrared bands, preventing overheating in the focusing area. This technology, which combines refractive focusing with spectral management, provides a more compact and weather-resistant solution for the next generation of high-magnification photovoltaic systems, particularly suitable for achieving uniform high-density light energy collection in limited spaces. The focusing optical path is shown in Figure 3.

The core of the mobile solar tracking device in this work is its tracking system. This system typically includes multiple light sensors, which are placed around the solar panels or arranged in a quadrant pattern to comprehensively monitor light intensity from all directions. These sensors continuously monitor the intensity and position of sunlight and send the collected data to the control system. The control system analyzes this data and uses algorithms to determine the optimal angle at which the solar panels should be oriented to maximize sunlight exposure. It then sends commands to the actuator, such as a stepper motor or a servo motor, to rotate the solar panels along one or more axes (single-axis or dual-axis tracking system) to ensure they always face the sun.

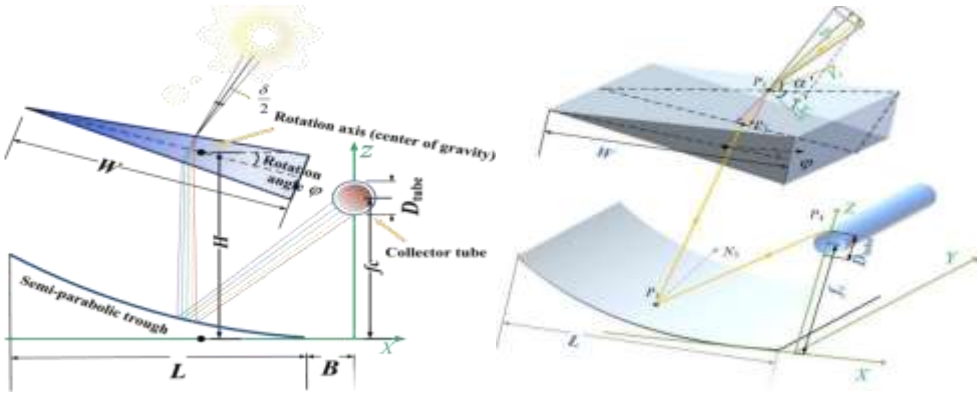

Figure 3 Prism focusing optical path

2.2.3. Analysis of prism light concentration characteristics

High efficiency, multi-functionality and good stability:

Prism focusing tracking solar technology can significantly enhance the power generation efficiency of solar cells. According to research conducted by Mitsubishi Rayo Corporation and the Yamada Research Laboratory at Chokoku University of Technology, solar cells using this technology generate about 1.8 times more power per unit area compared to those without prism technology. Prism focusing tracking solar products can not only be used as solar power generation equipment, but also as window glass. This versatility makes the technology has a wide range of applications in the field of architecture.

Due to the use of advanced materials and technologies, prism focusing tracking solar products have good stability, can operate and generate electricity in a variety of climate conditions, prism focusing tracking solar technology correctness test is shown in Figure 4.

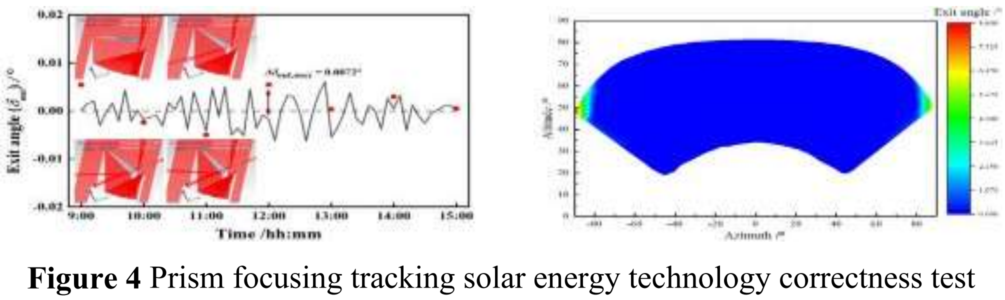

Figure 4 Prism focusing tracking solar energy technology correctness test

3. DESIGN SCHEME OF THE WORK

3.1. Title of work

Filter Sea Core —— Dynamic light-coupled high-efficiency solar desalination device

3.2. Overview of the work

The team has innovatively developed a dynamic light-tracking coupling high-efficiency solar seawater desalination device. This device meets the specific usage scenarios and operational requirements of customers. It uses prism focusing tracking technology to track the sun's rays, maximizing energy absorption. By employing anti-pollution polyamide reverse osmosis membrane preparation technology, a tracking-based dynamic screen control and fresh water conversion management platform, and solar-powered compressed carbon dioxide energy storage, the efficiency and quality of seawater desalination are significantly enhanced. This device can be widely applied in seawater desalination, water resource purification, and the extraction of concentrated brine.

3.3. Works show

Figure 5 The physical picture of the dynamic light-coupled high-efficiency solar desalination device

3.4. Overall design scheme of the work

This system innovatively constructs an intelligent seawater desalination solution integrating solar energy efficient utilization and advanced membrane treatment technology. The system adopts the modular design concept, and realizes the optimization of the whole chain of energy collection, conversion and utilization through multi-technology collaborative innovation.

At the core technology level, the system primarily comprises three innovative modules: Firstly, a solar tracking collection system based on the principle of prism focusing, which enhances the light concentration efficiency per unit area by 23.28% through a dual-axis light-tracking structure and special optical design. Secondly, an anti-pollution reverse osmosis membrane component modified with interface polymerization, which significantly boosts the membrane's flux and anti-pollution performance through hexanol surface grafting technology. Lastly, an innovative compressed carbon dioxide energy storage module that achieves organic coupling between solar energy and supercritical

CO_2 energy storage (over 7.38 MPa), with a system cycle efficiency exceeding 50%. The flowchart for this module is shown in Figure 6.

Figure 6 Schematic diagram of energy storage module

The system architecture is designed with a three-tier modular structure: 'collection, energy storage, and desalination.' The front end features a prism concentrating solar array for energy collection, the middle end includes a CO_2 compression energy storage and conversion unit, and the rear end comprises a five-stage filtration desalination module. The system is available in two forms: a fixed box type and a portable backpack type, catering to different customer needs. Both versions are coated with C5-grade anti-corrosion coating to ensure environmental adaptability.

The intelligent control system is a key feature of this project, with its core being a dynamic multi-screen control platform based on IoT technology. This system integrates a multi-parameter sensor network to monitor 28 critical indicators in real time, including light intensity, pressure, and water quality. It uses machine learning algorithms to autonomously optimize operational parameters. A specially designed adaptive adjustment mechanism can automatically adjust the working mode based on environmental changes, such as adjusting focusing parameters based on sunlight intensity and dynamically controlling RO pressure based on water quality feedback.

In terms of sustainability, the system has achieved several innovative breakthroughs: the utilization rate of renewable energy exceeds 80%, concentrated brine is treated and recycled, and the recovery rate of key materials reaches 75%. Performance tests show that the system has a desalination rate of over 99.7%, energy consumption is less than 2.5kWh/m^3, the lifespan of the reverse osmosis membrane has been extended to 7 years, and the overall efficiency is 40% higher than that of traditional solar desalination systems.

This design solution effectively addresses the challenges of traditional seawater desalination in terms of energy consumption, maintenance, and environmental adaptability through technological innovation. It is particularly suitable for islands, coastal arid regions, and emergency water supply scenarios. The system integrates the efficient use of solar energy, the development of new membrane materials, and intelligent control technology, offering an innovative solution with significant environmental benefits and broad application potential for distributed seawater desalination.

3.5. Composition of the work

3.5.1. Portable light-tracing solar device

The device employs a dual-axis automatic tracking architecture, utilizing a micro-prism array and GPS/GPS sensor for composite positioning, with a tracking error of less than 0.2. This design improves power generation efficiency by over 30% compared to fixed systems. The device features a foldable design, allowing it to expand to a light-receiving area of 5m² and reduce its storage volume by 70%, enabling rapid deployment by a single person in less than 10 minutes. It is designed to withstand wind and sand, featuring a streamlined frame and self-cleaning coating (with a contact angle greater than 150°), ensuring stable operation in wind and sand conditions up to level 8. The device includes a phase change material (PCM) heat dissipation module, which keeps the photovoltaic modules operating at a temperature of 25±5°C, preventing efficiency degradation. The specific design is shown in Figure 7.

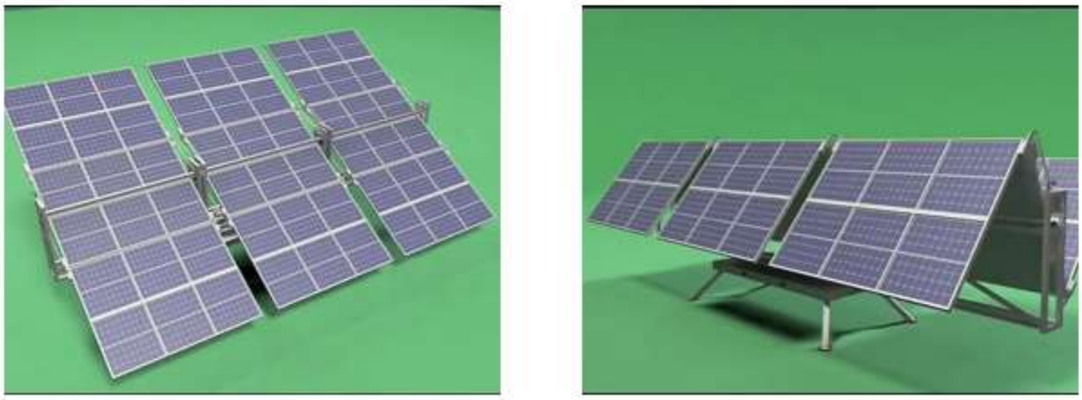

Figure 7 Shape design of mobile light-tracing solar device

The stored output vector is processed and analyzed as all the outgoing angles corresponding to all the rotation angles and the corresponding transmittance.

Filter out the minimum absolute value of the incidence angle and determine if it is below the set limit. If so, then check whether the prism transmittance exceeds the set threshold. If this judgment is also positive, it indicates that the device can track and maintain high energy transfer. In this case, the corresponding prism rotation angle, light emission angle, and transmittance are output to the tracking prism. Otherwise, if one of the two judgments is negative, the prism parameters need to be readjusted and re-entered, and the solar tracking process will repeat steps 2-4.

In the beam steering method, tracking is achieved by adjusting the deflection angle of the steering element (mirror or prism) before focusing the light, redirecting sunlight to a more perpendicular aperture of the focusing element. A compact and small solar concentrator, as shown in Figure 8, consists of a prism track with a variable apex angle and a CPC reflector. By rotating the prism, the system can achieve an annual thermal efficiency of about 22% after 7.2 hours of daily tracking. The team proposed a fixed solar concentrator composed of two lens arrays, where the relative translation of the lens arrays enables solar tracking, achieving an average annual concentrating efficiency of 73.4%. The solar tracking concentrator, specifically consisting of two independent PMMA prism arrays, as shown in Figure 9, refracts sunlight by rotating the prism. Additionally, a tracking technology for adjustable microfluidic prism panels has been developed and applied to compact concentrators, where the prism apex angle is adjusted by the electrowetting principle to emit light vertically into the concentrator (such as a Fresnel lens). Two transparent cubic units filled with two immiscible liquids are stacked to form an adjustable prism, and experiments show that this adjustable prism can achieve a maximum deflection range of 19.9 (±10.4 —-9.5). Considering the dispersion effect of materials when sunlight refracts within a specific wavelength range, it was found that a fourlayer prism configuration with an apex angle of 30 can achieve a maximum concentrating ratio of 2000x and a minimum reflection loss of 4.4%, thus eliminating the need for bulky mechanical motion components to drive the solar tracker.

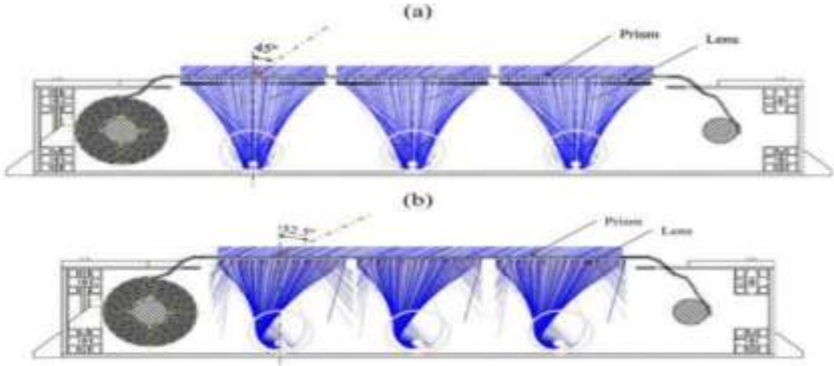

Figure 8 Prism track movement tracking

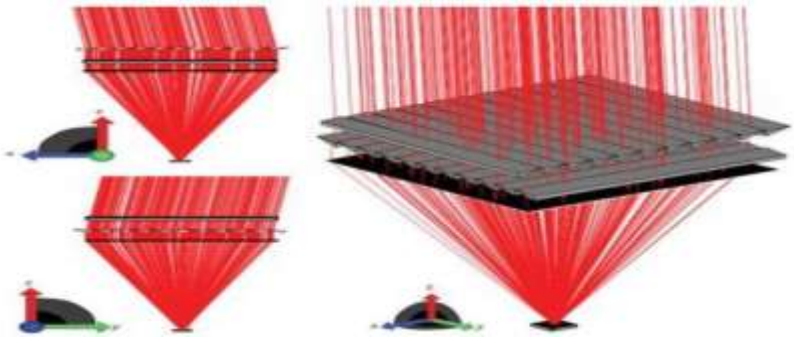

Figure 9 Prism array rotation tracking

3.5.2. The traceable dynamic split-screen control technology is coordinated with freshwater transformation and control

The team has innovatively developed a full-spectrum energy dynamic adjustment device, which is based on two core technologies: prism rotation tracking and the multi-window composite frequency division membrane component. The device uses an adaptive prism rotation mechanism at the top of the trough mirror to achieve high-precision tracking of incident light throughout the day. The multi-window composite frequency division membrane component, located in the focusing focal area, works in conjunction with the prism mechanism's 360-degree periodic rotation to create a coupling effect in the optical path, resulting in a specific geometric distribution of the focused light spot on the membrane surface. This design can dynamically adjust the ratio of photovoltaic to thermal energy in real time and implement energy utilization based on spectral characteristics: high-energy spectrum segments are directed towards converting into electrical energy, medium-energy spectrum segments are used for thermal energy supply, and low-energy spectrum segments are used for cooling output.

3.5.3. Seawater desalination conversion device

In the portable seawater desalination device, the seawater is first pumped into the device, and then enters the pretreatment stage of five-stage filter layer, RO membrane fine filtration and taste improvement stage in sequence. In the process of RO membrane fine filtration, pure water reaches the outlet through the water quality detection table, and waste water is discharged through the concentrated water port. Through the box design, and the outer layer of the box is coated with high corrosion resistance, high anti-pollution coating, to ensure the service life of portable box products under harsh conditions

scope of application:

The device has a water production efficiency of 5 cubic meters per hour, and its water production capacity is just right for the scale of 400 to 500 people

Sea water → multi-medium filter → precision filter → high pressure pump → reverse osmosis system → water production

First to create the optimal combination technology

Reverse osmosis membranes are selective separation membranes made from special polymer composites. At their core is a nanoscale separation layer formed through precision interfacial polymerization technology. Under pressure, these membranes allow water to pass through while retaining inorganic salts, organic substances, and microorganisms dissolved in the water, thus purifying and separating the water.

In the reverse osmosis process, when salt water (or a solution containing other solutes) and fresh water are separated by a reverse osmosis membrane, water naturally moves from the fresh water side through the membrane to the salt water side, following the principle of osmosis. When an external pressure exceeding the osmotic pressure of the solution is applied to the salt water side, it promotes the reverse migration of water molecules, facilitating the reverse osmosis process from the high concentration solution to the low concentration solution. Meanwhile, solute components, such as salts and suspended particles, are selectively retained and concentrated on the high-pressure side. This pressure-driven membrane separation mechanism effectively separates solutes from solvents in the solution system.

This filtration system consists of five layers, capable of efficiently filtering out 99.9% of impurities from the water, optimizing the water quality to a very clean level, making it safe for direct consumption. However, if the initial treatment is inadequate or the cleaning is not frequent enough, the water production will gradually decrease, eventually requiring the replacement of the reverse osmosis membrane. Therefore, when designing a reverse osmosis system, it is essential to plan the pre-treatment system in advance to ensure that the water entering the reverse osmosis membrane meets all standards.

4. SUMMARY

Future prospects of the work with the increasing global demand for fresh water resources and the emphasis on clean energy, box-type solar-powered seawater desalination devices have broad prospects for development.

In terms of technological innovation, the efficiency of solar energy conversion is expected to improve further. The application of new materials, such as perovskite solar cells, could boost the efficiency of photovoltaic conversion to over 30%, enhancing the energy collection capabilities of devices. The seawater desalination process will continue to be optimized, with the development of higher-performance reverse osmosis membranes and other technologies aimed at reducing energy consumption and costs. The integration of multiple processes is also expected to become a trend. Intelligent control systems, leveraging big data and artificial intelligence, can automatically optimize based on environmental and operational parameters, achieving precise control.

In terms of application expansion, in island regions, besides meeting the water needs of residents, it will also support the development of tourism, fisheries, agriculture, and industry. By integrating with other renewable energy sources, it will help build microgrids and smart water networks, promoting sustainable development. Coastal cities and industrial clusters can use these systems as distributed units to provide customized fresh water to various urban areas and industrial enterprises, ensuring water safety and reducing costs. The flexibility and independence of marine mobile platforms and remote operation sites will effectively address the challenge of fresh water supply. Their miniaturization and efficiency will also accelerate their widespread application on platforms like ships. In emergency rescue and humanitarian aid, these devices can be rapidly deployed to play a crucial role in disaster areas or special regions, providing essential fresh water support.

From the perspective of market and industry development, global demand is rapidly growing due to water scarcity and the energy transition. Developing countries have a pressing need for water resources, while developed countries are increasing their investment for strategic reasons. The industrial chain will innovate collaboratively, with upstream and downstream companies working together from component production to equipment manufacturing and service provision, forming a complete industrial chain. In regions with resource advantages and industrial foundations, clusters will form, each developing its unique characteristics. For example, the Middle East will focus on large-scale projects, Europe will concentrate on high-end product R&D and manufacturing, and China will leverage its manufacturing strengths to promote large-scale and international applications.

However, this project also faces several challenges. In terms of technology costs, the initial investment is high, and the need for energy storage systems due to the intermittent nature of solar power increases costs. The return on investment cycle is long, necessitating increased R&D efforts to reduce costs and relying on policy and financial support to enhance competitiveness. Regarding system reliability, the harsh marine environment can lead to issues such as component corrosion, aging, and scaling and contamination in seawater desalination systems. These challenges must be addressed through design improvements, material selection, process optimization, and the establishment of monitoring and maintenance systems. The lack of standards and market regulation results in inconsistent product quality and disrupted market order. Therefore, it is essential for the state and international organizations to establish standards, strengthen market supervision, and ensure the healthy development of the market.

Overall, despite the challenges, this work has the potential to play an important role in water and energy and create a better future.

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