Design and Research of a Seawater Desalination Device Powered by Solar Energy and Wave Energy

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Abstract. A seawater desalination device powered by new energy sources is proposed against the high energy consumption in the fresh-water generating industry. The designed seawater desalination device utilizes the vacuum tube of its thermal piping to collect solar energy, uses the multi-effect distillation system to perform thermal desalination, and makes use of the Edinburgh duck to acquire mechanical energy and ultimately produces fresh water out of seawater. The safe and efficient device can provide fresh-water resources for a variety of offshore engineering.

1. Introduction
Seawater desalination is an important means of solving the global shortage of freshwater. Seawater desalination refers to the use of distillation and osmosis to obtain freshwater from salts of seawater. The traditional seawater desalinating technology normally requires high energy consumption. Hence, the study and development of new desalination devices powered by renewable energy sources are the inevitable trend facing the advancement of the fresh-water production industry under the technical level that prevents the reduction of energy consumption. In response to the high-consumption problem, a seawater desalination device using solar energy and wave energy is proposed in this paper, which collects heat for thermal desalination and seawater evaporation, as well as realize the production of freshwater from seawater powered through wave energy.

2. The Principle of the Seawater Desalination Device Driven by Solar Energy and Wave Energy
The solar-and wave-powered seawater desalination device consists of a solar energy utilization module, a wave energy utilizing module, and a seawater desalinating module. The operating principle of the device is presented as follows: firstly, heat is collected with the solar energy collecting device for heating the working medium of the heat exchange; secondly, the working medium of heat exchange conducts heat exchange with seawater in the multi-effect distillation system to form vapor through evaporating seawater; and then, the vapor is cooled to obtain fresh water that is saved in the water storage tank; meanwhile, the necessary mechanical energy for the device is provided by wave energy to drive the water pump to input seawater and output fresh water. The principle of energy conversion is shown in Fig. 1.
3. The Solar Energy Utilization Module

The solar energy utilization module functions by converting solar energy into thermal energy through collecting solar energy with the vacuum solar energy collecting tubes. Two-way heat-pipe vacuum solar collector tubes are adopted in the solar energy collecting system of the solar-and-wave-energy-powered desalination device, as shown in Fig. 2.

![Figure 2. Structure of the heat-pipe vacuum solar collector tube (two-way).](image)

Solar radiation reaches on the body of the heat-pipe vacuum solar tube, and applies on the heat absorbing copper tube through the glass tube. After that, the copper tube converts the solar radiation energy into the internal energy of the copper tube. Heat is transferred to the low-temperature heat transfer fluid via the contact heat transfer, heating up the liquid working medium. When the temperature is increased to the boiling point, the fluid working medium is evaporated into the gas working medium. The gas working medium carrying a large amount of latent heat of evaporation rises along the copper tube body and enters the heat exchange tube of the multi-effect distillation system through the glass air duct. The latent heat of evaporation released by the gas working medium at the heat exchange tube is then used for desalinating seawater, which is re-condensed into the liquid working medium after the temperature reduction. The liquid working medium flows back from the lower end of the heat exchange tube under the effect of gravity and returns to the bottom of each copper tube via the liquid passing pipeline. At this point, a circulation is completed. A plurality of heat-pipe vacuum solar collector tubes in the heat collecting system of the desalination device driven by solar energy and wave energy are constructed side by side on a stand in a row at a certain angle (as shown in Fig. 3).
4. Seawater Desalination Multi-Effect Distillation System

The seawater desalination device designed in this paper utilizes the principle of thermal desalination. Meanwhile, a multi-effect distillation system was also designed to improve the efficiency of freshwater generation. The multi-effect distillation system of seawater desalination is composed of a first-effect distillation system, a second-effect distillation system, and a third-effect distillation system. Each effect system is installed on every duck-shaped body that takes the form of a tank and equipped with a corresponding heat exchange tube. Seawater is sprayed on the heat exchange tubes of the three-effect system to complete the output of fresh water from seawater.

The heat exchange tube in the first-effect distillation system is a spiral heat exchange tube with a helix angle of 10°, which is connected to the solar collector tube. The high-temperature gas working medium outputted by the solar collector system first enters the heat exchange tube of the first-effect distillation system to warm the heat exchange tube. Material seawater falls on the heat exchange tube in the form of small water droplets for evaporation upon passing through the atomizing nozzle driven by the reciprocating pump. The formed freshwater vapor is outputted from the vapor outlet at the upper part of the tank to the second-effect distillation system. The unutilized water droplets continuously fall to the bottom of the tank and flow back to the ocean from the seawater outlet at the bottom.

The heat exchange tube of the second-effect distillation system is a straight heat exchange tube that is meant to be placed at an oblique orientation, and the heat exchange tube overhead is connected to the freshwater vapor outlet of the first-effect distillation system through the heat preservation passage. The fresh water vapor warms the heat pipe through passing the heat exchange tube of the second-effect distillation system. Likewise, material seawater falls on the heat exchange tube in the form of small water droplets for evaporation upon being atomized. Freshwater vapor formed is outputted from the vapor outlet at the upper part of the tank to the third-effect distillation system. The unevaporated water droplets fall to the bottom of the tank and flow back to the ocean from the pipeline at the bottom. Simultaneously, the freshwater vapor in the straight heat exchange tube is condensed into freshwater after releasing the latent heat of evaporation, which is flowed to the freshwater tank driven by the gravity for collection.
The third-effect distillation system is similar to the second-effect distillation system in structure. The only difference is that the freshwater vapor outlet of the third-effect distillation system is connected to a heat exchanger that utilizes waste heat for preheating material seawater.

![Figure 4. Working principle of the multi-effect distillation system.](image)

5. Wave Energy Utilization Module
The Edinburgh duck, i.e., the duck-shaped wave energy converter, is selected for obtaining wave energy for the device, which is composed of a duck head, a duck body, a spindle, and a double-connecting-bar device.

The duck head is installed on the duck body and connected with the spindle. The duck body, as a supporting component for the entire seawater desalination device, is semi-submersible. The upward and downward swinging motion on the duck head caused by the wave motion drives the spindle to make reciprocating rotations less than 90° around the duck body. Meanwhile, since the spindle connects to the double-bar linkage mechanism, the reciprocating pump is operated through mechanical movement. The energy transfer process is shown in Figure 6.

![Figure 5. Mechanical energy transfer of the solar-and wave-powered desalination device.](image)

6. Conclusion
A seawater desalination device powered by new energy is introduced in this paper, which is primarily made up of a solar-powered heat collecting unit, a seawater desalination multi-effect distillation unit and a wave energy collection unit. The seawater desalination device powered by new energy is characterized by (1) comprehensive utilization of solar energy and wave energy for seawater desalination treatment, which is distinct from the seawater desalination device using a single energy source; (2) direct conversion of wave energy into mechanical energy, which is different from other wave energy utilization devices due to its operation free from electricity; (3) semi-submersible design that can allow the device to float in the ocean, which can generate freshwater by being externally hanged in the ocean near the offshore working platform and provide freshwater for ships and isolated islands.
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