

Multi-effect distillation system for seawater desalination driven by tidal energy and low grade energy

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Abstract: A multi-effect distillation technology for seawater desalination driven by tidal energy and low grade energy is presented. In the system, tidal energy is utilized to supply power instead of conventional electric pumps during the operation, resulting in the decrease of dependence on steady electric power supply and a reduction in the running costs. According to the technological principle, a testing unit is designed and built. The effects of the feed seawater temperature and the heat source temperature on the unit performance are tested and analyzed. The experimental results show that the fresh water output is 27 kg/h when the heating water temperature is 65 °C and the absolute pressure is 25 kPa. The experimental and theoretical analysis results indicate that the appropriate heating water temperature is a key factor in ensuring the steady operation of the system.

Key words: multi-effect distillation for seawater desalination; tidal energy; low grade energy; vacuum

Small-scale desalination units powered by renewable energy used for single buildings at remote shoreline areas have received considerable attention in recent years. Owing to the lack of electric networks in these areas, a desalination plant which is dependent on the existence of electric networks cannot normally operate. Besides, energy resources are always lacking in these areas. The growing demand of small-scale desalination units in these areas prompts efforts to design new systems which can operate public electric grids and do not require a supply of fossil energy sources. The state-of-the-art applications of renewable energy in desalination are presented in Refs. [1 – 2]. Most of these systems are reverse osmosis facilities or solar stills. The small reverse osmosis desalination plants driven by photovoltaic (PV) systems or wind power systems are widely studied^[3–4]. The reverse osmosis desalination systems powered by wave energy are also reported^[5–6]. Such kinds of desalination units are suitable for operating in large buildings such as hotels and large villas. Though these desalination units have high efficiency, owing to the complexity and high investment costs, they cannot replace simple solar stills primarily used for small single houses. Single solar stills are reliable, simple and inexpensive, but relatively unproductive. In order to improve their efficiency, a new design, through which the water input is preheated by a vapor, has been widely adopted^[7]. Low temperature distillation is also used to improve the per-

formance of these desalination units^[8].

Low temperature multi-effect solar distillation runs with high thermal energy efficiency because the latent heat of the vapor is reused. The main running costs of these kinds of units are the electric energy consumed by vacuum pumps and water pumps used for seawater supply and drainage. However, electricity is scarce in remote areas far away from electric networks. Herein, based on the analysis of the characteristics of solar and tidal energy, an innovative, multi-effect solar distillation unit for seawater desalination utilizing solar and tidal energy is designed. In this system, the tidal energy, instead of electrical pumps, is utilized to supply power for water supply and drainage. So the running costs of the system are greatly reduced.

1 System Description

The schematic diagram of the multi-effect desalination system driven by tidal energy and low grade energy is shown in Fig. 1. The system is based on multi-effect evaporation-condensation processes and consists of a solar energy collection device (or other low temperature heat resources), an evaporator, an evaporator-condenser, a condenser, a tidal energy storage system, and a vacuum extraction system utilizing tidal energy. The tidal energy storage system consists of a feed water tank, a concentrated brine tank and a fresh water tank. The evaporator, the evaporator-condenser and the condenser are set into the same vessel, which is set on a platform 6 m above the high tide water level. The concentrated brine tank and the fresh water tank are open to the atmosphere. The walls of the concentrated brine tank and the fresh water tank are above the high tide water level, while the walls of the feed water tank are below the high tide water level. Seawater is stored in the concentrated brine tank at the high tide level. But at the low tide level, seawater is withdrawn from the concentrated brine tank and the fresh water tank. Owing to the ebb and the flow of the tides, a water level difference of 2 to 7 m (depending on the local condition) is maintained between the feed water tank and the concentrated brine tank.

The operating process and the simulation of the system are introduced in Ref. [9]. Tab. 1 shows the main geometrical parameters of the unit.

2 Results and Discussion

Many factors can affect the unit performance, such as the temperature and the flow rate of feed seawater, heat source temperature and heat input, vacuum level, etc. In this paper, the effects of the feed seawater temperature and the heat source temperature on the unit performance are tested and analyzed.

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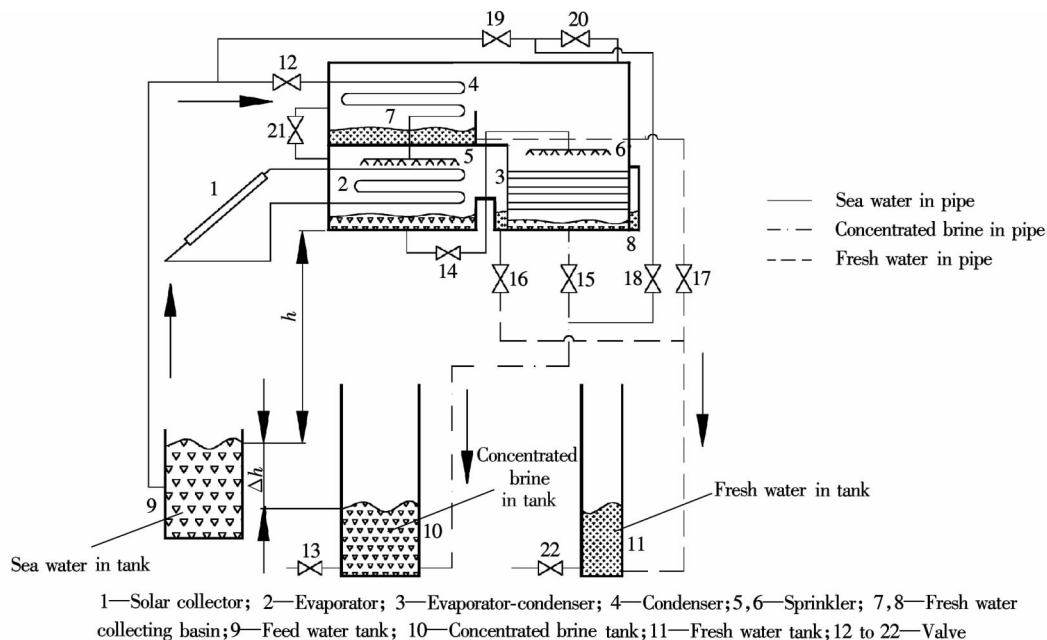


Fig. 1 Schematic diagram of multi-effect desalination system driven by tidal energy and low grade energy

Tab. 1 Geometric parameters of desalination system

Parameter	Heat exchange area/m ²			Solar collector area/m ²	Size/(m × m × m)		
	Evaporator	Evaporator-condenser	Condenser		Feed water tank	Concentrated brine tank	Fresh water tank
Value	1.4	2.2	0.9	23	3 × 2 × 1	2.5 × 2 × 1	2 × 0.5 × 1

2. 1 Effect of temperature on fresh water output

The effects of the feed seawater temperature and the heat source temperature on the fresh water output are shown in Fig. 2. It can be found that the fresh water output increases with the increase in the feed seawater temperature and the heat source temperature.

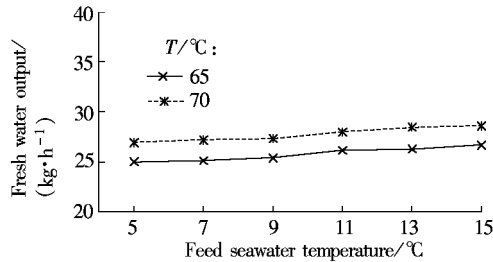


Fig. 2 Effects of feed seawater temperature and heat source temperature on fresh water output

2. 2 Effect of heating water temperature on unit performance

Heating water is the heat source of the system. The temperature and the flow rate in the heating water directly affect the first-effect brine evaporation rate, and also affect the vacuum level of the first-effect evaporation chamber. The pressure difference between the two effects changes the condensation rate of the first-effect vapor as well as the evaporation rate of the second-effect liquid brine. In this experiment, the heating water temperature is 60 to 80 °C and the flow rate is 1.5 m³/h. The experimental results are shown in Figs. 3 and 4.

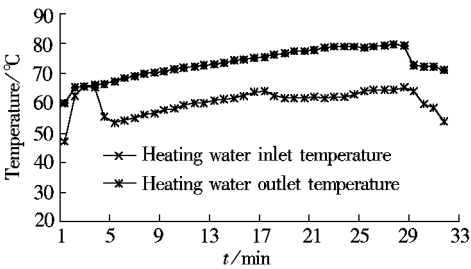


Fig. 3 Effect of heating water temperature on unit performance

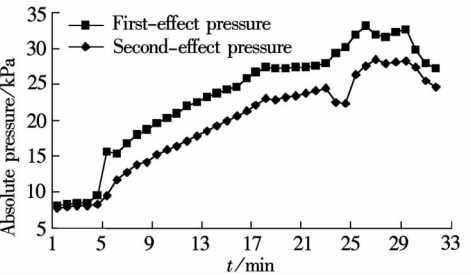


Fig. 4 Variation in unit operating pressure

It can be seen that the system pressure increases with the increase in the heating water temperature. The rising water temperature accelerates the production of the vapor, and subsequently the pressure increases. When the heating water temperature rises to 70 °C, the first-effect pressure reaches 20 kPa. And with the increase in the temperature, the first-effect pressure can even rise to 33 kPa. The heating water outlet temperature is below the evaporation temperature corresponding to the pressure, so the system has no fresh water output for some time. After 35 min of operation, the plant

pressure decreases with the decrease in the heating water temperature. Therefore, the operating pressure of the system has a reasonable scope. The experimental results show that it is better to control the first-effect pressure within 15 to 20 kPa. Once the pressure goes over 20 kPa, the water production rate significantly decreases. When the pressure is too low, the fresh water and the concentrated brine produced by the system cannot be exhausted by its own gravity, which affects the operation of the system. Thus, the appropriate heating water temperature is a key factor in ensuring that the system can steadily run.

3 Conclusions

An innovative multi-effect solar distillation unit for seawater desalination utilizing solar and tidal energy is designed and tested. The conclusions can be drawn according to the experimental results as follows:

- 1) The fresh water output increases with the increase in the feed seawater temperature and the heat source temperature.
- 2) The system pressures increases as the heating water temperature rises. The rising water temperature accelerates the production of the vapor, and the pressure subsequently increases.
- 3) The appropriate heating water temperature is a key factor in ensuring that the system can steadily run.

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低品位热能与潮汐能驱动的多效蒸馏海水淡化装置

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摘要:提出了一种利用低品位热能和潮汐能驱动的多效蒸馏海水淡化技术,其特点是利用潮汐能代替传统电泵为系统运行提供动力,从而减少了系统运行对稳定电力供应的依赖,降低造水成本. 根据该技术的原理,设计搭建了一套试验系统,测试并分析了给海水温度和加热水温度对该系统运行性能的影响. 试验结果表明,当加热水温度为 65 ℃,系统绝对压力为 25 kPa 时,系统的淡水产量为 27 kg/h. 通过试验和理论分析发现,选择合适的加热水温度是维持系统稳定运行的关键因素.

关键词:多效蒸馏海水淡化;潮汐能;低品位热能;真空

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