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Performance analysis and experimental verification of a multi-sleeve tubular still filled with different gas media

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HIGHLIGHTS

- A novel multi-sleeve tubular still for solar desalination is described.
- The yield of the unit with the oxygen is 31.82% higher than that for air.
- The semi-empirical expression of the water production rate is given.
- The trend of theoretical results is consistent with the experimental results.

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ABSTRACT

A novel nonconcentrical multi-sleeve tubular still for triple-effect solar desalination device is described in this study. An experimental and analytical analysis is given to investigate how the water production performance is affected by different gas media, which are air, oxygen, helium and carbon dioxide. The water production rate and the temperature value of every measured point inside the device with different gas media were obtained through the experiments. Experimental results show that, when the heating temperature is 85 °C and the gas medium is oxygen, the water production rate can reach to 0.58 kg·h^{-1}. It is increased by 31.82% compared with the rate when the gas medium is air. In addition, the internal heat and mass transfer mechanism of the device with different gas media was analyzed. The semi-empirical expression of the water production rate is given. According to the experimental data, the D_v under different conditions is obtained. The results obtained are then compared against the experimental results, and it is found that the trend of theoretical water production rate is consistent with the experimental results. The reasons for deviation are analyzed.

1. Introduction

The tubular still is one of the design options for seawater desalination. Its advantage is a simple structure and pressure-bearing. Shafiul and Teruyuki [1] have analyzed the mechanism of heat and mass transfer of the tubular still under the steady-state condition, and presented a heat and mass transfer model. The model can forecast the water production rate of the device, which was validated by indoor experiment. Murase et al. [2] have carried out both the outdoor and indoor experiments to investigate the performance of the tubular solar still. For the solar intensity of about 17 MJ/m^{2}day, the device can produce 2 kg fresh water per day. Ahsan et al. [3] have studied the influence of different shell materials on the performance of tubular still. They used a vinyl chloride sheet and a polythene film as tubular shell. The experiments of two devices were carried out under the same operating condition. As a result, the fabrication and the water production cost will be reduced when the device with the polythene film is sealed properly, an empirical equation in their study is proposed to predict the hourly production. The empirical equation was verified by the experimental results. It was seen that the calculated results had a good agreement with the experimental data.

A lot of researches have been completed in order to improve the water production rate of the still. Dutt et al. [4] designed a slope double stage basin solar distiller, Tiwari et al. [5] designed a slope three-stage basin solar distiller, and Kumar et al. [6] designed a double slope surface and double stage basin solar distiller. These improvements are useful for reusing the latent heat of condensation. By doing this, the energy utilization ratio of the apparatus was raised. Abu Arabi and Reddy [7] have carried out performance evaluation studies for desalination processes that are based on the humidification/dehumidification

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principle with different carrier gases. This study found that carbon dioxide is the best carrier gas to achieve more fresh water under the same operating conditions.

In this paper, with an aim to improve the tubular still on the basis of previous studies, a new nonconcentrical multi-sleeve tubular still is proposed for triple-effect desalination. The device can make full use of latent heat of condensation to give higher energy utilization. The performance of the device filled with different gas media is particularly investigated.

2. The structure of device and its working principle

The structure of the triple-effect tubular still and its working principle are illustrated in Fig. 1 and Fig. 2 shows a photograph of the experimental set-up.

As shown in Fig. 1, solar heat or industrial waste heat is input to the device through the heat exchanger tube (7), by which the seawater in the first-trough (6) is heated up. The hot seawater in the first-trough (6) will evaporate and produce a vapor. Because the temperature of the seawater in the second trough (4) is lower, the vapor produced in the first-trough will condense on the inner surface of the first sleeving. Finally, the condensed water naturally trickles down toward the bottom of the shell due to the gravity. The released latent heat of condensation heats the seawater in the second trough (4). This may be also accompanied with the convection and radiation heat transfer from the first trough to the second trough. The same processes occur between the second trough and the third trough and this therefore forms a triple-effect still. The vapor from the third trough condenses on the inside of the shell and the heat is eventually dissipated to the environment. The fresh water produced in each effect will accumulate and flows into the fresh water tank (8).

3. Prediction of water production with different gas media in the still

3.1. heat and mass transfer

The heat and mass transfer processes in the still are illustrated in Fig. 3. In the first effect, the seawater is heated up by the heat exchange tube. The vapor evaporated from the seawater diffuses through the gas medium due to the difference in the vapor pressures between the first trough and the inner surface of the first sleeving.

Indeed, the density of a gas media in a still will influence on the generation and condensation of the vapor. This is mainly due to the difference in the diffusion and stack effect of the vapor for different gas media. Different gas media also affect the condensation process of the

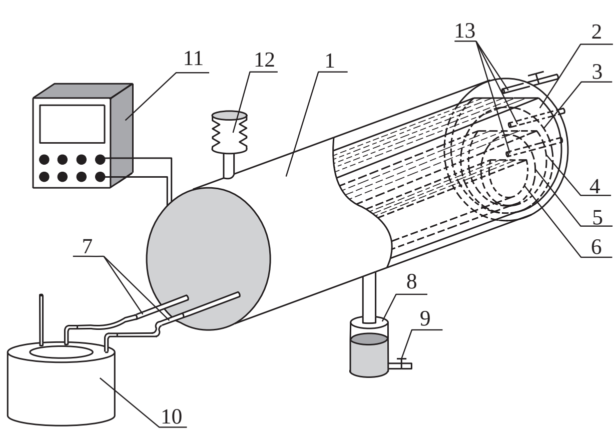

Fig. 1. Structure of the experimental device. 1—tubular shell; 2—the third trough; 3—the second sleeving; 4—the second trough; 5—the first sleeving; 6—the first trough; 7—heat exchange tube; 8—fresh water tank; 9—value; 10—constant temperature water bath; 11—measuring device; 12—pressure buffer balloon; 13—seawater inlet.

Fig. 2. A photograph of the experimental set-up.

vapor in the tube. Of simplicity, the gas filled in the device is considered as a whole. During the period of device operation, the mixed gas in the device is consisted of gas medium and vapor, as shown in Fig. 4.

Around the ambient pressure, the ideal gas state can be assumed for the components of the mixed gas:

$$p_a V = m_a R_{ga} T \tag{1}$$

$$p_w V = m_w R_{gw} T. \tag{2}$$

The density of the mixed gas:

$$\rho_m = \frac{m_a + m_w}{V} = \frac{p_a M_a + p_w M_w}{R T_{av}} = \rho_a + \rho_w \tag{3}$$

where R is the universal gas constant, 8.3145 J/(mol K); R_g is gas constant, $R_g = R / M$; T_{av} is the average temperature between the evaporation

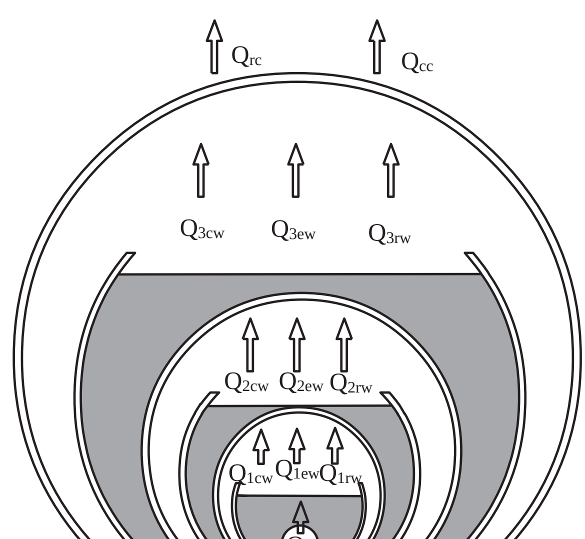

Fig. 3. Heat and mass transfer processes in the device.