Experimental Study on the Performance of Tubular Desalination Still by Hydrophilic/Water Absorption Modification

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Abstract: A tubular desalination still is designed with surface modification by hydrophilic and wrapped absorbent material. This paper discusses the mechanism of heat and mass transfer inside the modified system, carries out the experiments of constant temperature and constant power heating, and the water yield of the tubular desalination still before and after surface hydrophilic / water absorption modification is obtained. The experimental results show that, water yield rate of the still is linearly proportional to the operation temperature. The water yield rate of the modification tubular still is up to 297 ml•h⁻¹ when temperature is 85 °C, almost 25 % higher than that of the smooth tube. When the constant power (150 W) is used to heat for 12 h, the total water yield and the Performance Ratio of the modification tubular still are 2057.7 ml and 0.72, respectively, improved by 30.9 % when compared with that of the smooth tube.

Introduction

China is among the 13 countries in the world which are in urgent shortage of fresh water, the lack of drinking water will affect the sustainable development of the country. With abundant seawater resources, the transformation of sea water into fresh water which is drinkable can effectively alleviate the problem of drinking Water shortage in China. In the field of desalination, compared with disc-type desalination device, tubular desalination device has a compact structure, good pressure and other advantages, the development potential is enormous. In 1988, Professor GN Tiwari¹¹ first proposed the idea of tubular distillation. Ahsan et al. [2,3] Established a theoretical model to predict the water production of tubular still. Experimental results verifies the consistency of the model with the theoretical one. In order to improve the efficiency of tubular still, Chen Zhili, Zheng Hongfei et al. [4,5] independently developed a multi-effect tubular desalination device, which fully utilized the latent heat of steam condensation. On the basis of the theoretical analysis, it is further proposed to increase the heat transfer by using the fins outside the condensing sleeve[6].

As to tubular still, the heat transfer tube and its surface properties are the core of the impact of water production efficiency. One of the main reasons for the low water yield per unit area of the conventional tube type desalination system is that the surface heat efficiency of the heat exchange tube is low[7]. Sujith Kumar et al. [8,9] prepared a mixed hydrophilic coating of iron-doped Al₂O₃-TiO₂ on the surface of copper heating block, found the critical heat flux and heat transfer coefficient were improved. In this paper, a tubular still was designed, which was surface-modified and encapsulated with water-absorbing material, strengthen the tube evaporation in the system, thus improving the performance of the device.
Seawater Desalination Facility and Experiment Method

Seawater Desalination Facility and Operation Principle

The Surface hydrophilic/water-absorption modified tube-type desalination facility structure is shown in Figure 1. The basic structure of the desalting device includes heat pipes, a seawater tank, a seawater overflow tank (hereinafter referred to as an overflow water tank) and a condensing sleeve, and the material is made of 304 stainless steel. The main body is made up of 2 stainless steel tubes (a seawater tank and a condensing sleeve) nested from inside to outside. In addition, the two heating tubes can play the role of the support of the internal structure of the system. The plasma sprayed zirconia was used to modify the outer wall surface of the seawater tank and wrap the glass cloth. With the same size of the structure, the evaporation area of the seawater can be increased to 0.3848 m$^2$, 3.6 times larger than the smooth tube type’s.

![Figure 1. Sketch Diagram of the Tubular Still.](image)

Heat is transfer into the seawater within the seawater tank through the heat pipes. The seawater vapor evaporates and the water vapor is condensed into fresh water along the inner wall of the condensing sleeve. The fresh water slides down to the bottom along the inner wall of the condensing sleeve, and finally flows out through the outlet and is collected, that’s the entire desalination process. With the evaporation of the water absorbed in the hydrophilic / absorbent material, the capillary force of the absorbent material can absorb the water in the overflow tank, and the evaporation water will be added in time to prevent the phenomenon of dry spots.

Experiment Method

Constant Temperature Heating Test

An electric-heated thermostatic water bath is used to control the circulating hot water temperature as an analog heat source. The simulated heat source temperature is constant at 60, 65, 70, 75, 80, 85°C, respectively. Using the peristaltic pump (BT100-2J) to fill the system. The steady-state water yield of two tubes (smooth tube and surface hydrophilic/suction modified tube) at corresponding operating temperatures can be obtained.

Constant Power Heating Test

Voltage regulator and electrically heated wire (50 Ω) was used as analog heat source. By regulating
the output voltage of the regulator, the heating experiments were carried out at 100, 150, 200 and 250 W power respectively, and continuous heating for 12 h.

**Data logging and Processing**

1) Temperature record: Temperature recorder (RC-4HC) was used. A temperature measuring point is arranged at the upper end of the outer wall of the condensing sleeve to record the temperature of the outer wall; a temperature measuring point is arranged near the inlet of the sea flume to record the water temperature in the seawater tank; the temperature of the laboratory is constant at 20 °C.

2) Water yield measurement: Because it is fresh water, the volume of distilled water of 1 g is about 1 ml, so each weighing the same can be measured in milliliters.

3) Determination of steady state: In the constant temperature heating test, after the operation of the desalting machine, the water yield is measured every 20 min. When the water yield of the continuous 6 times is changed slightly, the steady state is determined, and the average value is obtained, taken as the steady state water production rate under the corresponding operating conditions.

**Results and Discussion**

**Constant Temperature Heating Test**

Heating experiments were carried out for two types of tube by controlling the water bath temperature. The variation of water yield at different operating temperatures is shown in figure 2.

As can be seen from Figure 2, the water yield rate of the two types of still increase with the increase of temperature, and a positive linear relationship exists. In the range of operation temperature, the maximum water yield of the surface modification type tube and smooth type tube desalination devices appeared at 85 degrees centigrade, 243.6 ml·h⁻¹ and 297 ml·h⁻¹, respectively. This is because the tubular desalination device is hydrophilic / absorbent modified, which makes the seawater rapidly spread evenly on the outer surface of the seawater tank so as to promote evaporation, and at the same time increase the evaporation area of the seawater. In addition, the increase rate of water yield rate increases with the increase of temperature, and increases by about 25% when the temperature is 85. As the temperature increases, the evaporation effect of the modified part increases too.
Constant Power Heating Test

The PR (the Performance Ratio) is another important index to evaluate the water production performance of the still, which reflects the energy utilization ratio of the device. The higher the PR is, the higher the utilization rate of energy is. It can be calculated by the following formula:

\[
\eta_{PR} = \frac{m \times h_{lg} - m \times h_{lg}}{Q} = \frac{m \times h_{lg}}{P \times t}
\]

(1)

In the formula, \(m\) — the total water yield (12 h), L; \(h_{lg}\) — evaporation latent heat under standard atmospheric pressure; 2257.6 kJ·L\(^{-1}\); \(P\) — heating power; kW; \(t\) — heating time, 12 h.

When the constant power is heated, the total water yield and the PR of the desalination unit for 12 hours are shown in Table 1. The analysis shows that with the increase of heating power, the total water yield of the tubular has been improved, but the PR is not necessarily improved. It shows that although the input energy increases, the energy utilization rate varies little. At the same energy efficiency, the input energy increases, and the energy loss increases as well. Therefore, it is not adaptable to one-sided pursuit the water production by constantly improve the energy input, An optimal input power should be taken into consideration in terms of water yield and coefficient of performance, and the optimal operation state of the desalination plant can be obtained.

Table 1 also shows that the cumulative water yield and the PR of the hydrophilic/water absorption tube are higher than that of the smooth tube when the input power is constant. At 150 W, the PR of the hydrophilic/water absorbing tube is improved by 30.9 % compared to the smooth tube. Therefore, the hydrophilic/water absorption modification of the device not only improves the water yield of the desalting unit, but also strengthens the utilization ratio of the energy.

<table>
<thead>
<tr>
<th>Power (W)</th>
<th>Smooth type</th>
<th>Hydrophilic/water-absorption modification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total water yield/(ml)</td>
<td>(\eta_{PR})</td>
</tr>
<tr>
<td>100</td>
<td>1026.6</td>
<td>0.54</td>
</tr>
<tr>
<td>150</td>
<td>1587.5</td>
<td>0.55</td>
</tr>
<tr>
<td>200</td>
<td>2607.9</td>
<td>0.68</td>
</tr>
<tr>
<td>250</td>
<td>3179.2</td>
<td>0.66</td>
</tr>
</tbody>
</table>

Summary

1) In the constant temperature heating test, the water yield of the still is positive linear with the operation temperature. At the same operating temperature, the water yield of the hydrophilic/water absorption tube is greater than that of the smooth tube. When the operating temperature is 85°C, their water yield is 243.6 and 297 ml·h\(^{-1}\), respectively, and the yield of the hydrophilic/water absorption tube increases by about 25%.

2) In the constant power heating test, with the increase of heating power, the accumulated water yield of the desalination device increases, but the PR does not necessarily increase. At 150 W, the cumulative water yield of the hydrophilic/suction and smooth tubes is 2057.7 and 1587.5 ml, respectively. Compared with the smooth tubes, the PR of the hydrophilic/water absorbing tubes increased by 30.9%.

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References


