

Vacuum Distillation System Aiming to Use Solar-Heat for Desalination

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Abstract: A simple vacuum distillation system has been developed for the desalination of the seawater and for the purification of contaminated well water. This system can be operated by solar heat, and the production of salt is possible in this vacuum still. Because no consumption parts are required, the system should work more than 30 years. This simple system had the thermal efficiency of 70% which is equivalent to the generation of 10 kg/m² of water per day.

Key Words: Desalination, Freshwater, Solar-distillation, Vacuum distillation

1. Introduction

In the desert area, many desalination systems are working to produce fresh water from seawater. The most cost effective desalination method is Reverse-Osmotic (RO) method using organic filters. The other is the Multi-Stage Flash (MSF) method using petroleum fuel. These methods are good for producing a large amount of fresh water (up to 470000 tons/day). However, conventional desalination systems consume a lot of fuel, electricity or filters in operation. Those systems are good for the well-progressed or oil-producing countries, but not suitable for the under-developed countries without oil fields because of the high running cost.

On the other hand, many solar-powered desalination schemes have been proposed to prevent above-mentioned disadvantages of conventional desalination systems (Qiblawey and Banat, 2008). However, these schemes have small yields, and have many difficulties in the operation such as the condensation of salt and the removal of condensed saline-water.

We wanted to develop a simple solar-powered vacuum distillation system for producing fresh water using only pipes as the main device. This system contains a evaporating pipe heated by solar-radiation and a cooling pipe cooled by air. This system only contains pipes, and no elements are consumed during operation. We have developed several variations of heating and cooling schemes, and the details are presented in this paper.

Our first priority was to develop a distillation system suitable for arid and rural areas in developing countries. For this purpose, the cost of the machine should be low enough to introduce them into the rural desert.

2. Solar Desalination Methods

2.1. Previous schemes

For reducing the energy consumption for the saline-water or contaminated water desalination, many schemes using the solar-power have been proposed (Kunze, 2001, Tanaka *et al.*, 2000). These methods were the basin types, the vacuum distillation systems, and the solar-heated tube schemes. However, the yields of water for these schemes were very small, and these systems required heavy maintenance work to operate.

As an example, a solar-heated vacuum-desalination system was proposed (Abi-Jabal *et al.*, 2001). This system used a multi-stage vacuum-distillation scheme with solar-heat, and 120 kg/day of water was obtained. However, for operating the multi-stage distillation, a complicated vacuum control was required in the large-scale vacuum system. The empty weight of the system was 5 tons, and the operating weight was 12 tons. This meant the total cost of the system was very large, and it brought difficulty for wide-spread use in the rural area.

2.2. Operation principle of new approach

The solar-distillation systems using U type tube have been proposed by many researchers in many papers (Midili and Ayhan, 2004a, 2004b) or patents^{A)B)}. This principle is very common and is very simple. However, this scheme is not found in use because of the difficulty in maintaining the systems. These schemes employed complicated heating and cooling systems, for example, multi-stage and indirect heating of saline-water. For this reason, the heating efficiency was low, and the complicated structure of heating tube provided a difficulty in cleaning of the device.

In our system, the sunlight is directly received at the boiling pipe, and boiling pipe is a simple tube. This provides high heat efficiency because the sunlight heats the heating pipe,

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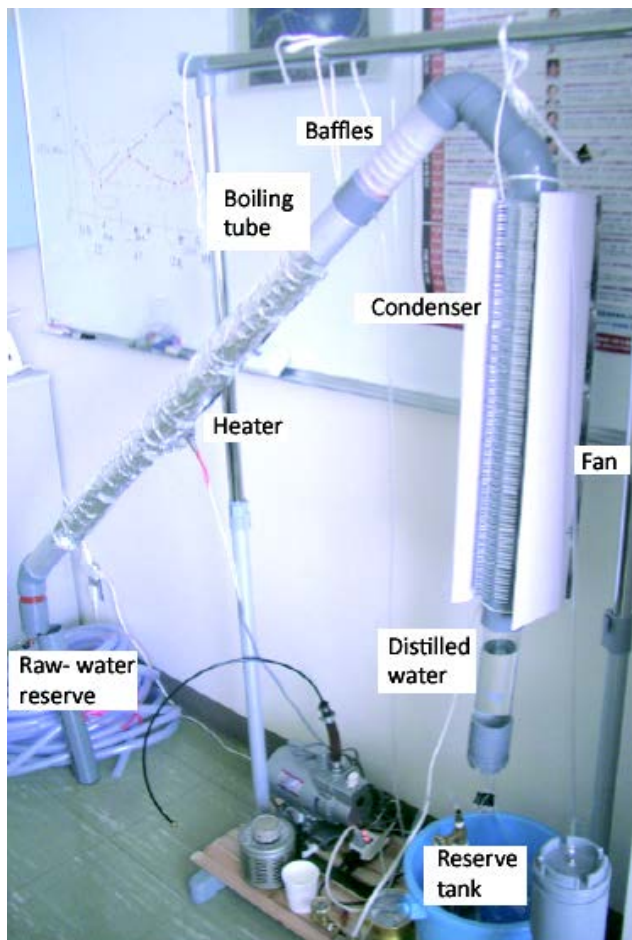


Fig. 1. Photograph of distillation system.

which is cooled by evaporation inside the pipe. This also provides a very simple structure which is easy to maintain. The cooling tube (condenser) is also a very simple pipe.

The operation principle is simple, and the system works as a conventional vacuum distillation device used in chemical processes, namely a combination of the boiling flask and condenser. The heating pipe contains saline-water inside, and generated water vapor is transmitted to the condenser. The water vapor is cooled in the condenser to produce water.

For the purpose of continuous operation, a 10 m of water column can be used for taking out the distilled water from the vacuum. However, this scheme is also an old idea reported previously (Al-Kharabsheh and Goswami, 2003a, 2003b).

2.3. Details of the experimental device

The photograph of system is shown in **Figure 1**. This system is using an electric heater of 500W. This heating part will be replaced with a solar heater in the actual device. The condenser is cooled by electric fans of 50W. Between the boiling pipe and the condenser, a set of combined baffles is inserted to preventing the surge of boiling saline-water. Both the boiling pipe and condenser have reserve pipes for saline-water and distilled water. An additional reserve tank is

added to the condenser for long term operation.

At the beginning of the operation, this tube is evacuated to 1/100 atmosphere with a vacuum pump, and the device is used in seal-off condition. The vacuum pump is used only once for a whole day of operation.

After the evacuation, the saline-water or contaminated water is supplied to the boiling pipe. Then, the electric heater and cooling fans are operated for the distillation. During the operation, the raw-water is supplied to the boiling pipe for maintaining the water level in the boiling pipe. The distilled water is also removed from the condenser to the additional reserve tank. In actual distillation, condensed saline-water should be removed from the boiling pipe for preventing deposition of too much salt. These operations are simply done by opening valves of the inlet and the outlet ports of this distillation system.

3. Experimental Results

3.1. Fresh-water distillation

The system was first tested with the freshwater as the raw-water. The tap-water colored by watercolor (orange color) was used to see the contamination of raw-water to distilled water. The heat efficiency was measured by the production rate of distilled water, and the measured value was higher than 80%. Without good baffles, raw-water is easily surged into the distilled water. Multi-stage baffles are found effective to prevent this surge. This baffles worked perfectly.

3.2. Saline-water distillation

Because the final application of this system is the distillation of seawater, we must know the applicability of this system to seawater. Unfortunately, the actual seawater is difficult to obtain, saline-water for the tropical fish was used at the 3.5% concentration. For observing the problem in high condensation situations, the system was operated to a very high concentration (35%). The average heat efficiency was about 70% because of higher operating temperature at the most condensed condition. The boiling temperature was increased up to 70 degree Celsius. After the experiment, a lot of salt powder was observed at the bottom of the boiling tube. The contamination of distilled water was also not observed in this experiment.

3.3. Distillation of CaCl₂ solution

Instead of the saline-water, the Calcium chloride (CaCl₂) solution, which was used as a desiccant of the home closet, was distilled to obtaining water from the air. In this experiment, the distillation was done normally with somewhat higher temperature. This means we can obtain water from

the air even in the most arid area without any kind of water.

4. Discussion

A very simple distillation system has been demonstrated the ability of distillation using electric heater. The proof experiment with solar-heat is not performed as yet, but the principle is the same with the achieved experiment. Because of the cost of this scheme is very cheap, this scheme seems to adaptable to the very rural area of the arid countries. This method is applicable to making drinking water, and the water production for the agriculture with the drip irrigation. Using this method, we can grow *Jatropha* or *Pongamia* tree for the production of botanical oil for the bio-diesel-fuel in the very arid rural area such as Somalia in Africa.

Since this method is distillation, this scheme is also useful for purifying drinking water in the contaminated well water area. In India and Bangladesh, many wells are contaminated with Arsenic, and the measure to remove this contamination is urgently required^{C)}. We strongly believe our method should be used in such cases.

The amount of water production of this system is not large as conventional methods (MSF or RO), but this scheme requires almost no running cost for more than 30 years. The size of 30 kg/ day system should be 3 (L) × 1 (W) × 1.5 (H) m. This size machine is very suitable for home use in the arid areas.

If the system is operated in parallel, we can obtain 1~10 ton water per day. This water should be enough to maintain a few hundreds meter square orchard of *Jatropha* or *Pongamia* tree. This provides a large amount of employments for rural areas.

Finally we want to mention our system is freely modified in the case of application. If we have electricity, the cooling should be done using electric fan because it provides a very small system. If we have no electricity, we can construct a system without the electric fan. In this case, cooling fins should be large as compared to the fan-type system. If the

maintenance for the vacuum system is difficult, we can construct the distilling system at atmospheric pressure, but it requires high boiling temperature (100°C) causing lower heat efficiency.

We are now planning to perform the solar-heat experiment, and it will be reported soon.

Notes

A) R. E. Snyder: US Patent 2490659 (1949).

B) H. A. Wilson: US Patent 5552022 (1996).

C) <http://www.daiwa.jp/water/index.html>

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