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A discussion of "Heat pumps as a source of heat energy for desalination of seawater"

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Abstract

The paper, "Heat pumps as a source of heat energy for desalination of seawater", was published in *Desalination* [Vol. 139, 2001]. In the paper, heat pumps using agent R12 or water and vapor were introduced to be used as a source of heat energy for desalination. The cyclic processes of heat pump were illustrated in T-S and P-H thermodynamic diagrams under the conditions of condensation temperature at 120°C and an evaporative temperature of 20°C, but there are some questions that need to be discussed. First, thermodynamic diagrams of the transcritical cycle of heat pumps using agent R12 are given. Second, the ratio between mass flows of the water vapor and agent R12 is discussed and the heat balance equations of desalination are given. Third, calculations from a 5 t/d desalination plant are given as an example.

Keywords: Discussion; Desalination; Heat pump; Seawater

1. Introduction

The supply of fresh water is a key element for all societies. Together with the supply of energy, fresh water is a fundamental need for most aspects of life. Fresh water is needed in agriculture, as drinking water, or as process water in various industries. Groundwater and/or surface water is not always sufficiently available, and the scarcity is expected to increase in the future. Seawater desalination has become a reliable method for water supply all over the world. It has already been practiced successfully for many decades, and the technical and economical feasibility is obvious. The common processes for seawater desalination are multi-effect distillation (MED), multi-stages flash (MSF), reverse osmosis (RO), and electrodialysis (ED) [1].

The most popular method is thermal desalination [2]. For distillation there are many heat sources such as steam, warm water, solar, electronic, atomic power, etc. In the paper "Heat pumps as a source of heat energy for desalination

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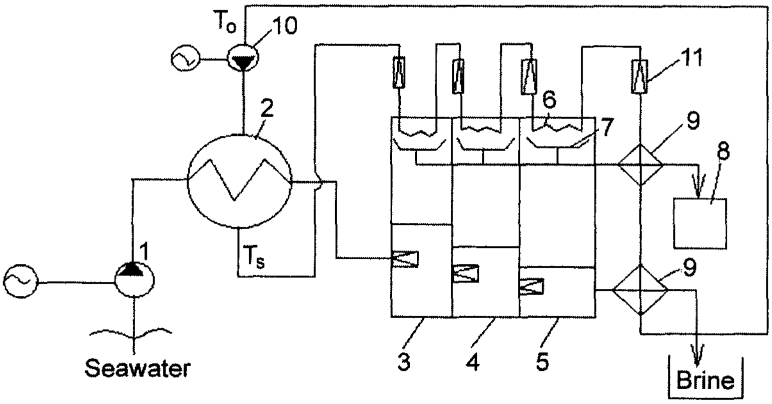

Fig. 1. Desalination plant with compression heat pump, cycle at R12. 1 pump, 2 heat pump condenser, 3–5 stages of evaporator, 6 cooler, 7 distillate storage unit, 8 tank for distillate discharge, 9 regenerative heat exchanger, 10 heat pump compressor, 11 reducer.

of seawater", the author presented heat pumps as a source of heat energy. The process of this method is shown in Fig. 1.

"The following processes take place in the plant. The seawater is fed through pump 1 into closed heater 2 where its temperature increases up to the required level. In the operation of three-stage thermal multistage evaporator (3,4,5), at the cost of reduction of pressure of heated water, it boils up. The vapor obtained from the seawater at each stage condenses on film coolers 6, collects at storage units 7 and allocates to distillate tank 8. Brine from the last stage of desalination plant is fed to regenerative heat exchanger 9 for more significant cooling before sea burial. Source of heat for desalination process is vapor of agent R12, ammonia (or other substance with low vaporization temperature) being obtained behind compressor of heat pump 10. This vapor R12 having high pressure and temperature is a heating medium in heat exchanger 2. Then vapor after reducing pressure and temperature in reducer, goes through in sequence cooler at each stage of desalination plant. The operating cycle of compression heat pump is over when at the last stage vapor R12 is heated up in regenerative heat exchangers and again directed to compressor of heat pump 10."

"Cyclic processes of the compression heat pump which maintains desalination plants are illustrated in Fig. 2 in T-S and P-H thermodynamic diagrams. The compression heat pump cycle consists of process vapor compression in compressor 1,2, condensation process 2,3, process of throttling and heat supply in three stages of desalination plants and regenerative heat exchangers 3,4,1 [2].

2. Discussion

There are some questions in this paper that need to be raised. First, the cycle of heat pump compression using agent R12 illustrated in the T-S and P-H thermodynamic diagrams is questionable. As we well know, the critical temperature of R12 is about 111.5°C. When the condensation temperature of R12 is above this, the cyclic process of the heat pump is not under the critical temperature. It is a transcritical cycle. When the condensation temperature is 120°C, then the temperature of condensation process is changeable. As shown in Fig. 3, it is not constant, as illustrated in Fig. 2.

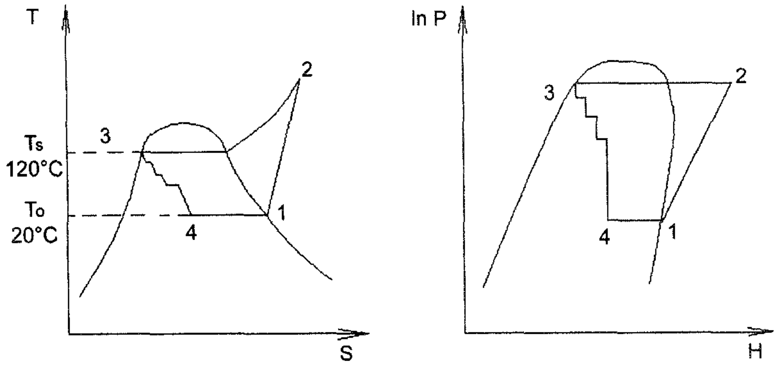

Fig. 2. Compression heat pump cycle in thermodynamic diagrams (in the original paper). 1–4 compression heat pump cycle at R12.

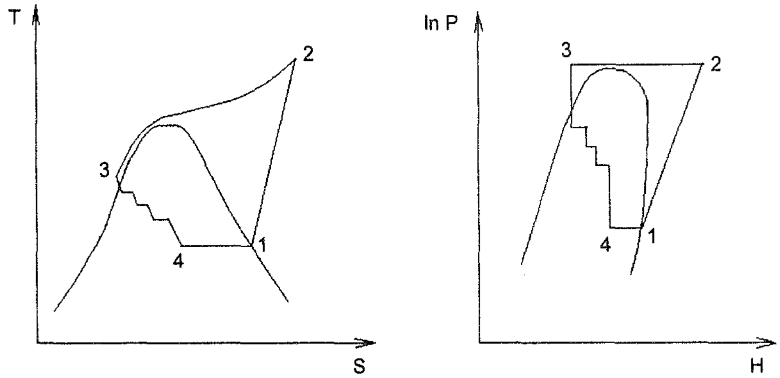

Fig. 3. Compression heat pump cycle in thermodynamic diagrams (transcritical cycle). 1–4 compression heat pump cycle at R12.

Second, as shown in Fig. 3, the cycle of the compression heat pump is not saturated. How can the point of 3 be determined? This point is determined by the pressure and temperature of R12 since pressure and temperature are two separate parameters. To get the value of H_3 from the T-S or P-H thermodynamic diagram, the value of the temperature and pressure of agent R12 should be known. Without the enthalpy of R12 at point 3, the mass flow rate of water vapor and agent R12 cannot be calculated.

In the paper, a value of the $m = Gs/Gc$ ratio between mass flows of water vapor and agent R12 was given. The equation for the heat balance of exchanger 2 was also given.

$$m = (H_2 - H_3) / C_s (T_s - T_0)$$

Here m is not the ratio between mass flows of water vapor and agent R12, but rather it is the ratio between mass flows of feed water and agent R12. For the principle of flash desalination of seawater, only a small part of the feed water evaporates; the large part of the feed water cannot evaporate, and it remains in a saturated liquid state. The cycle of the heat pump using agent R12 with a condensation temperature of 100°C was calculated. The cycle is saturated. If the mass flow rate of water steam is 0.058 kg/s (5 t/d), temperature of seawater is 20°C, and there is only a one-stage evaporator, the pressure of steam in the evaporator is 1 bar. The mass and energy balance equations are as follows:

$$M_w \times C_{pw} \times (T_s - T_0) = M_r \times (H_2 - H_3) \qquad (1)$$

$$M_r(H_1 - H_3) = M_s \times \lambda_s + M_s \times C_{pd} \times (373 - T_1) + (M_w - M_s) \times C_{pb}(373 - T_1) \quad (2)$$

$$M_w \times H_s = (M_w - M_s) \times H_{bw} + M_s \times H_{bs} \quad (3)$$

where M_s is the mass flow rate of water vapor, kg/s; λ_s is the latent heat of steam, kJ/kg; M_w is the mass flow rate of feed water, kg/s; C_{pd}, C_{pb}, and C_{pw} are the heat capacity of fresh water, brine and seawater, kJ/kg.k, respectively; H_1, H_2, and H_3 are enthalpy of R12 before and after compressor and behind condenser of compression heat pump, respectively; M_r is the mass flow rate of R12, kg/s; H_s is the enthalpy of water at temperature T_s, kJ/kg; H_{bw} is the enthalpy of brine in the evaporator, kJ/kg; H_{bs} is the enthalpy of steam in the evaporator, kJ/kg; and T_0, T_1, and T_s are the temperature of seawater before exchanger 2, discharge fresh water and brine, and seawater after exchanger 2, respectively.

Through calculations, it is shown that although the production of water is 0.058 kg/s, the mass flow rate of agent R12 is about 15.1 kg/s. This means that to produce 5 t/d of fresh water, a large volume compressor is needed. Compared with other methods of desalination such as RO and ED, the efficiency is too low.

The equations of mass and heat balance of desalination using water and vapor as the heat pump agent are as follows:

$$M_r \times (H_2 - H_3) = M_w \times C_{pw} \times (T_s - T_1) \quad (4)$$

$$M_s \times (373 - T_2) = M_{w1} \times C_{pw} \times (T_1 - 298) \quad (5)$$

$$(M_w - M_s) \times C_{pb} \times (373 - T_2) = M_{w2} \times C_{ps} \times (T_1 - 298) \quad (6)$$

$$M_{w1} + M_{w2} = M_w \quad (7)$$

$$M_r \times (H_1 - H_3) = M_s \times \lambda_s \quad (8)$$

$$M_w \times H_s = M_s \times H_{bs} + (M_w - M_s) \times H_{bw} \quad (9)$$

Here M_s is also 0.058 kg/s (5 t/d), T_s is 140°C, and T_0 is 100°C.

By calculations, the mass flow of water and vapor is 0.0628 kg/s, and the mass flow of feed seawater is 0.62 kg/s; the temperature of seawater before heat exchanger 2 is 82.6°C, and power consumption is about 17 kW.

3. Conclusions

By analysis of heat pumps as a heat source of energy for the desalination of seawater, heat pumps using agent R12 are not feasible. When a heat pump using agent water and vapor is used as the heat source of energy for desalination, it is feasible. The heat pump cycle is under the critical temperature (374°C).

We have calculated the cycle of heat pumps using agent water and vapor at the evaporation temperature of 100°C and the condensation temperature at 140°C. It was shown that power consumption is lower than electronic compression desalination, as illustrated in Table 1.

The conclusion was reached that the efficiency of heat pumps as an energy source for desali-

Table 1
Comparison of power consumption for different kinds of desalination

Type	Production of fresh water, t/d	Power consumption, kW
Heat pump type	5	17
Electronic compression vapor type	5	36
Electronic heating type	5	150

nation is higher than the other two types, but there are still many questions such as reducing the volume, lubrication, etc., which need to be researched for a compressor using agent water and vapor.

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