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Experimental research of an integrative unit for air-conditioning and desalination

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Abstract

Desalination with a humidification–dehumidification process has proven to be an efficient means of utilization the condenser and evaporator of heat pump to product fresh water from sea water. This paper presents an integrative device of air-conditioning and desalination driven by mechanical vapor compression heat pump. There were four circuits in this system such as vapor compression, heat water, air flow and fresh water circuit. According to different combination, several function including air-conditioning, dehumidification and desalination could be realized. Compared with traditional desalination device, the system utilized the heat from condenser and cold from evaporator of heat pump adequately, and reclaimed latent heat partially. The experimental results show that it would circulate with considerably higher PER under the optimal choice of sea water flow rate, feed water temperature, the volume of sea water in box and the length of humidifier. When this system was used as dehumidification, it can regulate air temperature of outlet in a large range.

Keywords: Heat pump; Desalination; Dehumidification; Air-conditioning

1. Introduction

Water is available in abundant quantities in nature, however, there is shortage of potable Water in many countries around the world. A large proportion of the world's population do not have access to good quality drinking water, and around 80 per cent of the world's diseases are attributable to inadequate water supplies, sanitation, and water treatment [1]. As the human population of the world grows, it will become increasingly difficult to keep up with the demand for proper sanitation and water

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treatment. To meet the fresh water requirement, many techniques have been developed during the past 40–50 years, scientists and technologists are now dedicated to the innovation of various desalination processes including economic distillation processes.

There are some kinds of heat pumps such as thermal vapor compression (TVC), mechanical vapor compression (MVC), absorption vapor compression (ABVC), and adsorption vapor compression (ADVC) [2,3]. Heat pump was used to desalination in several ways, and preliminary analysis of four systems and comparison of their performance was presented by Ettouney etc [4,5]. MVC desalination was one of the most efficient thermal distillation processes. The MVC is compact and suitable for small potable unit.

In air-conditioning it is often necessary to control and regulate the air temperature and the water vapor content in air mainly by evaporator and condenser to satisfy comfort [6,7]. Sea-water desalination can be realized by heat distillation using evaporation and condensation, electro dialysis or reverse osmosis etc. according to their drive force, such as temperature, electro-potential and pressure difference [8–12]. Evaporator and condenser are both applied to heat distillation and air-conditioning, so we want to construct an integrative unit combined air-conditioning and desalination for household appliance. The construction, principle and performance obtained by experiment will be illustrated in this paper.

2. System configuration and principle description

The integrative system is diagrammatically shown in Fig. 1. It consisted of a traditional heat pump including evaporator, condenser, expansive valve and compressor, and other components such as blower, humidifier and a heat exchanger for the heat recovery. It is

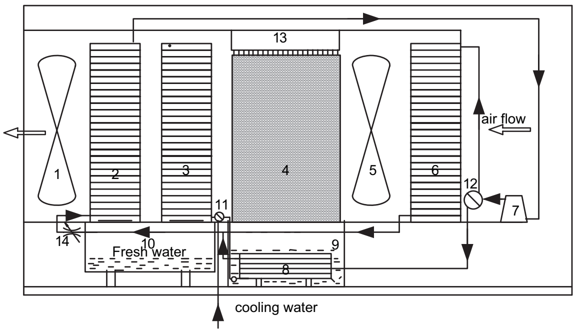

Fig. 1. Sketch of the integrative unit for air-condition and desalination. 1 and 5, blower; 2, evaporator; 3, heat exchanger; 4, humidifier; 6, air cooling condenser; 7, compressor; 8, water-cooling condenser; 9, sea water tank; 10, fresh water tank; 11 and 12, cross valve; 13, sprayer; 14, compression release valve.

interesting that there were two condensers in this unit, one using air-cooling to discharge the heat of condensation for air conditioning, another using water-cooling to heat the sea water in water-box for desalination, which can be switched each other by a cross valve. The two way blowers were used to drive the air and enhance the heat and mass transfer. The heat exchanger plays a role of humid air per-cooling to get some fresh water and feed water preheating to recover the part of latent heat. The humidifier, a honeycomb construction having enormous surface to increase the effect of the heat and mass transfer, was a key component to make the separation between water and salt.

It should be operated in the different way to realize the different functions.

2.1. Air-conditioning and dehumidification

When the system used as air-conditioning, it circulated as a traditional water-cooling heat pump.

The thermodynamic process of the refrigeration is shown in Fig. 2. The saturated refrigerant liquid at point 4 flows through an expansion valve and becomes wet refrigerant vapor at point 5,

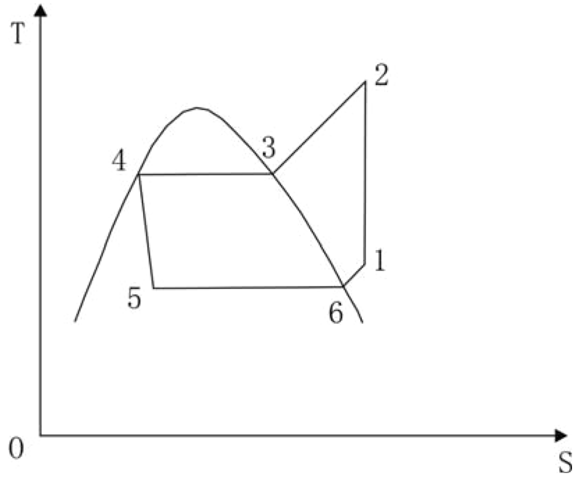

Fig. 2. T-s diagram of the refrigeration system.

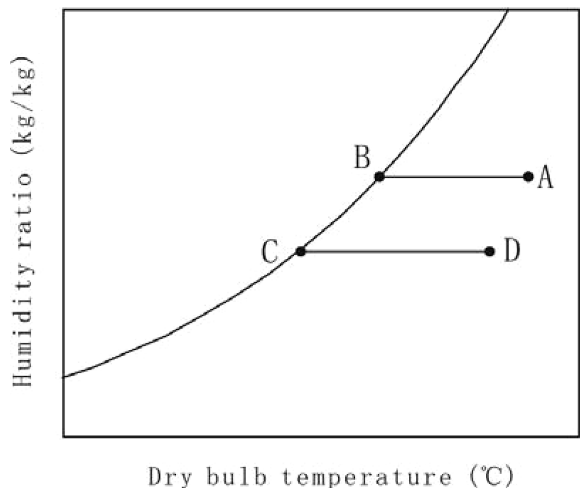

Fig. 3. Psychrometrics of the air dehumidification.

then it evaporates in the evaporator to the point 6 and superheats to the point 1. The superheated refrigerant vapor enters the mechanical compressor, in which it would be pumped to point 2, and a higher pressure and temperature will be reached. This superheated vapor is then cooled and condensed to a saturated liquid of state 4 through point 3 in the condenser. Then, it is throttled through the expansion valve to a mixture of liquid and vapor, and enters into the evaporator.

When the refrigerant liquid evaporated, it absorbs the heat from the air flow. In this process, the latent and sensible load is treated in a coupled way, and the air is chilled and dehumidified. As shown in Fig. 3, the air flow at state A is chilled to saturated state B at the constant humidity, and then it is continuously chilled and dehumidified to state C.

If the air temperature at the outlet is very low, and cannot be supplied to the environment directly. Using the exchanger regulated by the water flow rate, the air temperature will be increased to state D.

At the same time, when the refrigerant vapor condensed, its latent heat is released to heat the water in the tank for other domestic use.

The primary energy ratio (PER) of this system can be defined as follows:

$$\mathrm{PER} = \frac{\text{useful energy}}{\text{primary energy input}} \tag{1}$$

Primary energy input equals the sum of power required by compressor, fans and pump, and useful energy is the sum of heat from condenser and cold from evaporator. Generally speaking, as the mode of heat pump, PER is very high.

2.2. Desalination

Desalination is a process which extracts fresh water from sea water. In this system, it is based on a humidification–dehumidification process.

The refrigeration cycle is common to the above paragraph. The condenser was used to heat the sea water, and the evaporator was used to cool the humid air and produce fresh water.

The water in the tank was heated by the latent heat of refrigerant vapor condensation. The hot water leaving the tank was sprayed on the humidifier, in which the mass and heat transfer between the air flow and the hot water were completed. Part of the sea water evaporated and the air flow was humidified. The concentrated sea water would back to the sea water tank. When the concentration of the sea water reached the stipulation value, it was released, and the fresh cold sea water would be supplemented.

The thermodynamic process of air stream in this mode is shown in Fig. 4. The air flow under the state 1 was forced through the humidifier, its temperature and humidity increased, and reached the state 2. Then it flowed through the pre-cooling exchanger, the temperature and the humidity decreased to the state 3′ through the point 3, and a little fresh water would be produced. The cold air from the pre-cooling exchanger entered the evaporator, and was cooled further to have more fresh water. The outlet air flow would reach the state 4.

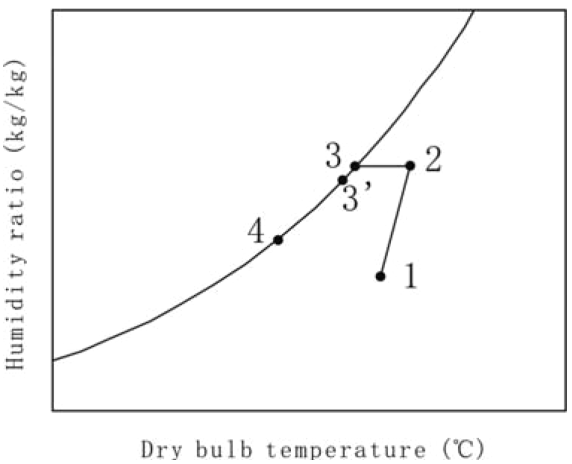

Fig. 4. Psychrometrics of the air humidification and dehumidification.

3. Experimental results and discussions

The schematic diagram and related parameters of the experimental unit are respectively shown in Fig. 1 and Table 1.

The system PER of desalination is the same as Eq. (1), but useful energy is the fresh water production multiplied by latent heat. The primary energy input was about 500 W. If the fresh water production was 2.5 (kg/h), useful energy was about 1700 W, so PER of desalination would be 3.4.

In Fig. 5, the effect of the feed water flow rate on the fresh water production is shown. It shows that the fresh water production increased when the feed water flow rate increased, and dry area appeared on the humidifier surface when the feed water flow rate reduced. It is also can be seen that the effect of feed water flow rate was large near the small flow rate. With the increasing of the flow rate, the fresh water production would reach to a peak value, and maintain constantly.

The effect of feed water temperature on the fresh water production is shown in Fig. 6. The water temperature had a great effect on the fresh production. Five different water temperatures were selected respectively, and the feed water flow rate was fixed at 235 L/h. As indicated, the fresh water production increased with the feed water temperature increasing, and the increasing rate would slow down with the temperature increasing.

Table 1
Scale and relative parameters of the experimental unit

Blower	Compressor	Water flow	COP of heat pump	Humidifier (mm)
Power 37 W Flux 19 L/s	Rated power 450 W Refrigerant R 22	Tank volume 35 L Water pump 15 W	3.0	$280 \times 280 \times 80$

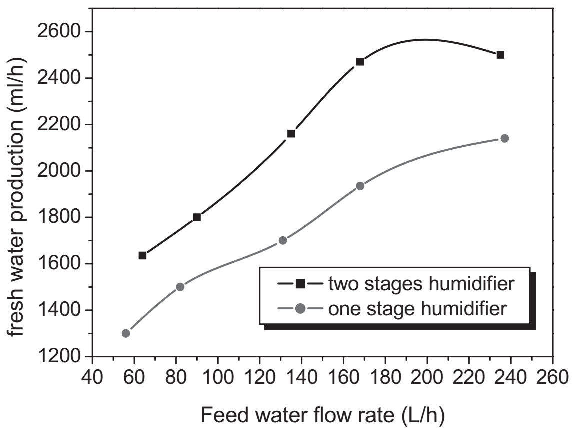

Fig. 5. Effect of the feed water flow rate on the fresh water production (feed water temperature 45°C).

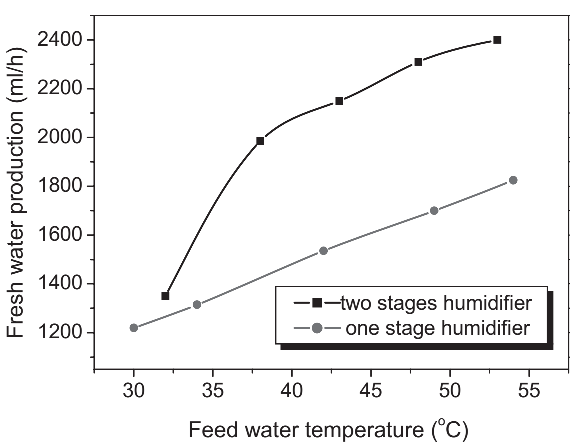

Fig. 6. Effect of feed water temperature on the fresh water production (feed water flow rate 235 L/h).

As shown in Figs. 5 and 6, the effect of feed water flow rate and water temperature on the fresh water production was tested under the one and two stages of humidifiers, and the length of one stage of humidifier was 80 mm. From this figure, the effect of humidifier length was remarkable, and the difference increased with the water flow rate and temperature increasing, because the length of humidifier stood for the area of heat and mass transfer.

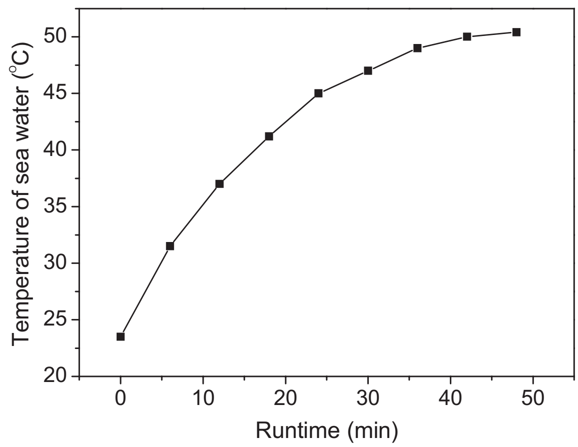

Fig. 7. Sea water temperature changed with the runtime of system.

In Fig. 7, the sea water temperature in the tank was measured at a fixed water flow rate, and the tank volume was 35 L. It can be seen that the sea water temperature was faster increased at the beginning of the system running, and with the system running the temperature would reach a balance and retain a constant. The water volume in the tank was the main factor of the temperature variation. The effect of temperature on the fresh water production was remarkable, so it was important to control the water volume in the tank, which influenced the water spray temperature at the beginning of operation.

When this unit used as air-conditioning or dehumidification, the airflow through the evaporator was chilled and dehumidified. Experimental results show that the outlet air temperature can be regulated from 10 to 28°C in summer.

4. Conclusions

In this study, an integrative unit for air-conditioning and desalination was introduced, and the effect of water temperature, water flow rate, length of humidifier and water volume on the fresh water production were investigated experimentally. The fresh water production increased with the water temperature and water flow rate increasing. The effect of length of humidifier was remarkable, and the influence was increased with the water flow rate and temperature increasing. Water volume in the tank would effect on the system performance at the beginning. Experimental results show that when the system was used as an air conditioner, it can regulate outlet air temperature from 10 to 28°C in summer. When the system used as desalination unit and air-conditioning, the PER can reached 3.6 and 6.0 respectively. This research provides a useful guide for the design and operation for this kind of integrative unit.

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