Desalination 399 (2016) 29–33

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

The effect of the inject pressure on the distilled water by vacuum heat pump

LiuBin [a,*], LiQinqin [a], ZhouZhiyong [a], M. Sajid [b]

[a] Tianjin Key Lab of Refrigeration Technology, Tianjin University of Commerce, Tianjin, 300134, PR China
[b] School of Mechanical & Manufacturing Engineering (SMME), National University of Sciences & Technology (NUST), Islamabad, Pakistan

HIGHLIGHTS

- The effect of three ejector nozzles on distilled water in vacuum heat pump distillation is studied.
- The negative pressure produced by the ejector reaches a minimum of −0.085 MPa at the spreading ratio of 0.0156.
- The amount of distilled water produced by per kilowatt hour is above 4.7 kg with an energy efficiency of 3.13.
- The design proposed represents a feasible and viable option for the production of distilled water.

ARTICLE INFO

Article history:
Received 28 February 2016
Received in revised form 14 July 2016
Accepted 26 July 2016
Available online xxxx

Keywords:
Ejector
Simulate
The ratio of ejector
Distilled water

ABSTRACT

A new machine to produce distilled water was provided, which includes a heat pump system and a vacuum system (DWVHP). In the vacuum system, the ejector is the key component. Three kinds of ejectors were studied by using FLUENT software to simulate their parameters. The performance characteristics of ejectors, including the distributions of pressure and velocity in the mixtures were observed. The simulation results showed that a vacuum is formed in the ejector throat, where the speed also reached its maximum value. When degree of vacuum is lower, the boiling point of water will also be lower and the evaporation speed will be faster. The optimized ratio between the area of the throat and that of the mixing section can be obtained according to theoretical calculations. The ejector with the ratio 0.0156 can be used to prepare distilled water and the experimental results show that the energy consumption of 1 kilogram distilled water is lower than 0.3 kWh.

1. Introduction

With the development of economy, the problems of water resources shortage and energy shortages appeared in more and more countries and regions. At the same time, people also have increasing demands on the quality and quantity of water, so the research of water treatment and purification has never been stopped.

Scholars have done a lot of the work on water purification and other aspects, but the principle of the method is not the same and new methods and new technologies continue to emerge. For example, Surajbhan Sevda et al. [1] used microbial respiration to purify the water, and they have made the single seawater desalination room volume increase from 3 mL to 15 L. There are also a lot of traditional researches on the distilled water by evaporation pipe, such as Ahmed Hegazy [2] collected the water through a vacuum evaporator to collect steam condensation, and the energy consumption is about 1.8 kWh/kg; Khamid Mahkamov [3] studied a new type of small and dynamic solar desalination device, where the piston converter was driven by solar energy and with periodic changes in volume and pressure, in which the purified water can be collected in evaporation tube. There are also many scholars who used membrane technology to produce distilled water. For example, Akshay Deshmukh et al. [4] studied the desalination by forward osmosis, and they summed up quantitative results between the structure parameters of the support layer with reduced film area in a certain range, thereby saving cost. In the direct contact membrane distillation process, Hung C. Duong [5] optimized the thermal efficiency of the brine, so that the water recycling rate ranges from 20% to 60%, and the energy consumption can be reduced by more than half. A. Khalifa [6] and other studies have used air gap membrane distillation to produce distilled water, and the influence of feed temperature and air gap width on the system performance was obtained. In addition, solar energy as a clean energy was also widely used to produce distilled water, such as H. Reif John and Wadee Alhalabi [7] used solar energy for desalination. Comparing with the conversion of

* Corresponding author.
E-mail address: lbtjcu@tjcu.edu.cn (B. Liu).

http://dx.doi.org/10.1016/j.desal.2016.07.040
0011-9164/

solar energy into electricity, they pointed out that it was more effective and attractive for the system to be converted into heat energy. U. Sahoo [8] and others used solar energy for desalination of sea water and polygeneration, reducing the cost and greenhouse gas emissions. Combination of distilled water and refrigeration system has been researched in-depth by scholars. For example, Yongqing Wang [9] studied a high-efficiency combined desalination and refrigeration system based on the LiBr–H2O absorption cycle, getting more high energy utilization rate and lower operating costs. S.A. Nada et al. [10] studied the water production rate of distilled water in the process of desiccant air conditioning. Houa Shaobo et al. [11] used simulation method to verify the feasibility of marine cooling system with seawater cooling and seawater desalination. C.·Chiranjeevi [12] studied the combination of the two-stage seawater desalination and refrigeration system to improve the energy utilization coefficient. Scholars have studied other methods for producing distilled water, such as Alexandra Rommerskirchen [13] produced distilled water by using the single module electrode capacitor. Compared to the traditional capacitive deionized, it can produce distilled water continuously. Ruijun Zhang [14] studied the influence of salt, anionic polyacrylamide and crude oil on the membrane fouling in the process of polymer flooding. Comparing with the effect of silica gel and AQSOA-Z02 on distilled water, Peter G. Youssef [15] summed up the effect of different cooling water temperature on the two kinds of materials. Ebrahimi Khosrow [16] studied the use of low grade heat source for seawater desalination.

Although the principle of the method for producing distilled water is various, the study on the distilled water by vacuum heat pump is relatively rare. In this paper, the effect of the pressure of the ejector pressure on the production of distilled water is studied.

2. System structure

The vacuum heat pump system is shown in Fig. 1.

The structure of system is divided into two parts: the refrigeration cycle system and the water cycle system.

The principle of refrigeration cycle system is that the high temperature and high pressure gas from compressor release heat when it enters into the vapor generator and auxiliary condenser, and then the gas turn into low temperature and low pressure liquid when it flows through the capillary. The liquid will get in the condensate absorber to transfer heat with water vapor. At the end, the low pressure gas will be back to the

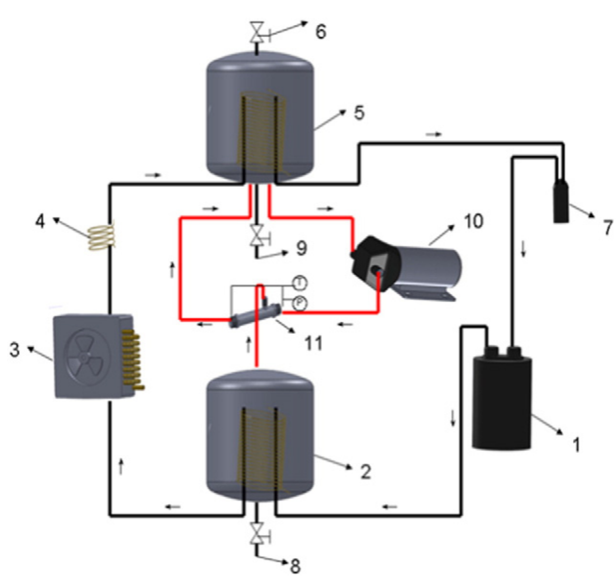

Fig. 1. System structure of distilled water. 1—compressor, 2—vapor generator, 3—auxiliary condenser, 4—capillary, 5—condensate absorber, 6—vent valve, 7—gas-liquid separator, 8—water intake, 9—water outlet, 10—high-pressure diaphragm pump, 11—ejector.

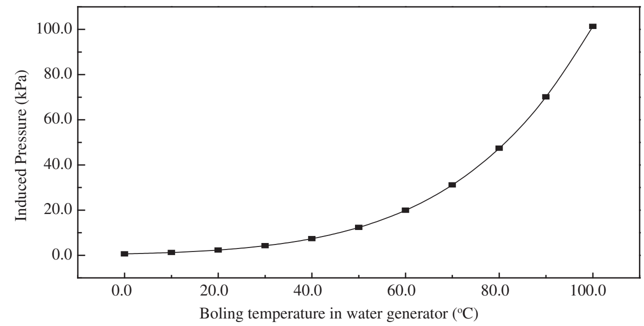

Fig. 2. Induced pressure vs. boiling temperature in vapor generator.

compressor after the liquid passing through the gas-liquid separator. In this cycle, the condensing heat of refrigerant is used to produce water vapor by vapor generator, and the evaporative cooling is used to capture water vapor and produce distilled water in condensate absorber.

The work principle of water cycle system is that the water from condensate absorber is sucked by high-pressure diaphragm pump into the ejector, and then the water will be mixed with the vapor sucked by ejector entrainment from vapor generator. After ejector diffuser, the mixture of the vapor and the water returns to the condensate absorber, where the vapor is cooled into distilled water.

From the working principle of the vacuum heat pump to produce the distilled water, we can find that the function of ejector is of vital importance in this system. The pressure of vapor generator is determined by the sucking pressure resulted from the injecting pressure and velocity of the water. When the injecting pressure is lower, the temperature of the vapor generator is low, so the condensation temperature of the refrigeration system will be reduced and the system efficiency is improved. While the temperature of the condensate absorber is higher, which means a higher temperature of the evaporation temperature of the refrigeration system, it also provides a higher performance of the refrigeration system. Fig. 2 shows the relationship between the water boiling temperature in vapor generator and induced pressure

It can be seen from Fig. 2, if a lower water vapor temperature is needed, the lower the induced pressure is. When the temperature of water vapor is 30 °C, the pressure is 4.25 kPa, and the induced pressure is 7.38 kPa at 40 °C, which means a very low pressure in vapor generator, so a very good ejector is necessary to obtain an excellent performance of the vacuum heat pump.

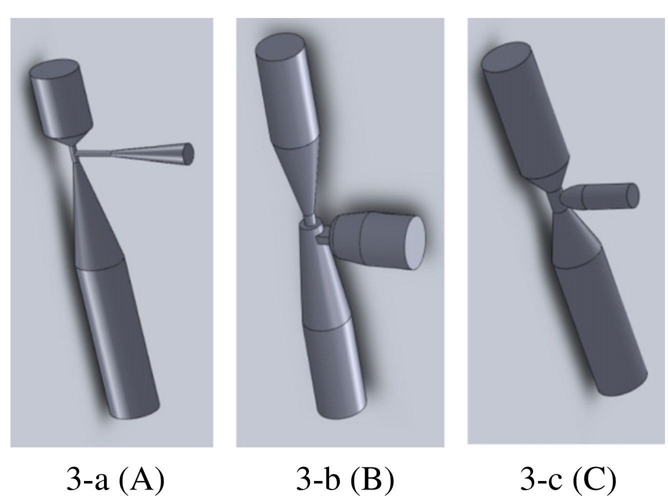

Fig. 3. Physical structure of three different ejectors. 3-a: SR = 0.0156, D_t = 1.5 mm; 3-b: SR = 0.0532, D_t = 3 mm; 3-c: SR = 0.0946, D_t = 4 mm.