Experimental Study on Fresh Water Generation System with Low Pressure Evaporation
저압 증발기를 갖는 청수제조 장치에 관한 실험적 연구

Hanshik Chung, Supriyanto Wibowo, Gyeonghwan Lee, Yonghan Shin, Hyomin Jeong†
정한식 · 위보워 · 이경환 · 신용한 · 정효민†

(received 24 October 2010, revised 21 January 2011, accepted 07 March 2011)

Key Words : Fresh water generation, Ejector, Distillation, Low pressure

Abstract : A fresh water generation system is designed for converting brackish water or seawater into fresh water. In this paper fresh water generation by distillation process that evaporates feed water and subsequently condenses vapor as evaporation product to get fresh water was studied and city water was employed as feed water. The system uses the ejector to create a vacuum, under which liquid can be evaporated at lower temperature than it at normal or atmospheric condition, hence less energy consumption. The effect of various operating conditions i.e. temperature of feed water and different orifice diameters were studied experimentally to investigate the characteristic of the system. It was found that these parameters have significant effect in the performance of fresh water generation system with low pressure evaporation.

Nomenclature

Tbti : Inlet of boiling tube of evaporator [℃]
Tbto : Out of boiling tube of evaporator [℃]
Tfti : Bottom of flashing tube of evaporator [℃]
Tfto : Upper of flashing tube of evaporator [℃]
Tsi : Steam inlet of the condenser [℃]
Tso : Steam out of the condenser [℃]
Pbti : Boiling tube pressure at bottom [mmhg]
Pbto : Boiling tube pressure at top [mmhg]
Pft : Pressure in the flashing [mmhg]

1. Introduction

Several fresh water generation processes have been developed to use seawater as a source of water for potable water supply to cities (desalination). Membrane processes, namely microfiltration, ultrafiltration and reverse osmosis, are widely used. Solar heated membrane distillation and capillary distillation processes are developed to reduce energy consumption. It has been demonstrated that membrane distillation is a technically viable process, but only economically feasible where waste energy is available or electricity is very expensive[1~2]. Capillary distillation utilizes the effects of solid liquid interfacial molecular forces by using fractioning plates having capillary type passages. Vacuum desalination is another alternative process to convert seawater into potable use. Vacuum desalination is a process by which water is vaporized at lower temperature when subjected to vacuum pressure. The boiling point of water drops with decreasing absolute pressure. The cost of decreasing pressure is negligible in comparison with the cost of heating to the boiling point. This study demonstrates the possible application of vacuum fresh water generation for water purification using low temperature of feed water

정효민(책임저자) : 경상대학교 에너지공학과 · 해양산업연구소
E-mail : hmjeong@gnu.ac.kr, Tel : 055-646-4766
위보워,이경환,신용한 : 경상대학교 대학원 정밀기계공학과
정한식 : 경상대학교 에너지공학과 · 해양산업연구소

where the heat can be applied as waste heat from water cooling machine of ship.

Some studies of the low pressure evaporation also have been developed by many researches, such as Kumar et al.[3] designed a desalination system utilizing ocean thermal gradient, J. H. Tay et.al.[4] he investigated vacuum desalination where the water was boiled at low temperature at the corresponding low pressure. Tay et al.[5] conducted a pilot study on a laboratory scale system and concluded that the system performance depends on how efficiently the losses of heat were eliminated. Utilization of waste heat from a steam turbine for production of fresh water through a vacuum desalination process was first reported by Low and Tay.[6]

A detailed experimental study was made by Mani[7~8] to probe to the effect of water depth and slope of a single sloped solar still. Mani et al.[9] reported on the utilization of an ocean thermal gradient for production of fresh water through a vacuum desalination process and presented the design details of the system.

Simulation of the desalination system was also carried out by Kudish et al.[10], and their work was validated with experimental measurements.

A single effect desalination system was developed before by Rahman et al..[11]

Preliminary experimental studies done on the system, show that the system has good potential for application in marine desalination where the available engine cooling water temperature varies between 60 and 70℃. This study was concerned with the thermal and pressure characteristic and performance in case of condensed vapor yield of single effect configuration combined with thermal vapor compressor (ejector) Fig.1.

2. Experiment Setup and Procedure

The requirement of heat energy for fresh water generation by distillation process can be brought down by reducing the boiling temperature.[3] By the creation of low pressure in the evaporator, boiling temperature of water could be lowered to as low as possible.

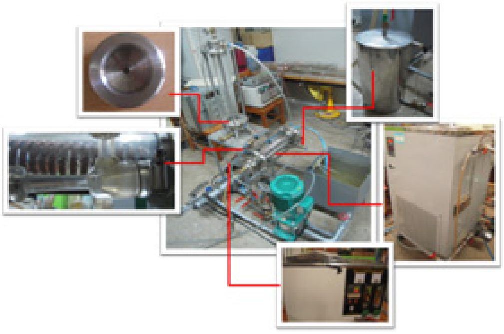

Fig. 1 Experimental devices setup

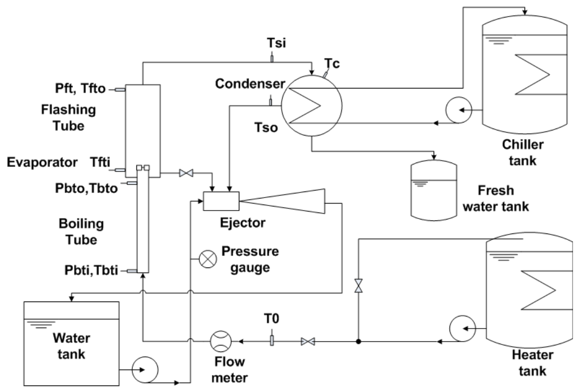

Fig. 2 Schematic diagram of experimental setup

Table 1 Test section dimension

Part	Diameter (mm)
Boiling tube of evaporator	25
Flashing tube of evaporator	70
Pipe connection	10

A pilot study was conducted in the laboratory to investigate phenomena and the feasibility of using a vacuum distillation process for water supply, city water was used as feed water to the evaporator. The schematic diagram of the laboratory experimental study is shown in Fig.2.

This fresh water generation technique involves sequence processes like pressurization of water using a pump, creation and maintenance of a vacuum using an ejector, evaporation of feed water from heater with low temperature and condensation of water vapor using cold water from chiller. Dimension parameters of Test section are summarized in table 1. The main targetable advantages of this fresh water generation system are low maintenance cost and utilization of lower grade energy.

Table 2 Operational conditions of experiment.

Variable	Value
Feed water flow rate [ml/min]	300
Orifice hole diameter [mm]	1∼2
Feed water temperature [℃]	40∼80
Pressure motive of ejector [mmHg]	3000.25
Condenser Temperature [℃]	8∼12
Experiment duration [min]	15

The treatment system was designed to minimize the heat requirement. The system consists of several main equipments there were pump, heater, evaporator which design to have low pressure, condenser, and ejector. Briefly water from tank (water tank) is pumped to the nozzle of ejector as a motive fluid to create low pressure region at the nozzle exit plane inside the ejector. This low pressure allows the water in the evaporator to vaporize at low temperature. Feed water was pumped from heater to evaporator with temperature range of 40~80℃; table 2 shows summaries of the operation condition of this experiment. Water vapor which produced in evaporator went up through the pipe to condenser, in the condenser some vapor condensed and flow to the fresh water tank, and the rest of uncondensed vapor would sucked by ejector to the water tank to complete the cycle.

3. Result and Discussion

The fresh water production performance was determined for different operation conditions.

Temperature and flow rate of feed water to evaporator and orifice diameter were the main operating variables for this experiment. Pressure and temperature distribution and condensed vapor production are the important parameters to analyze the characteristic performance of the system.

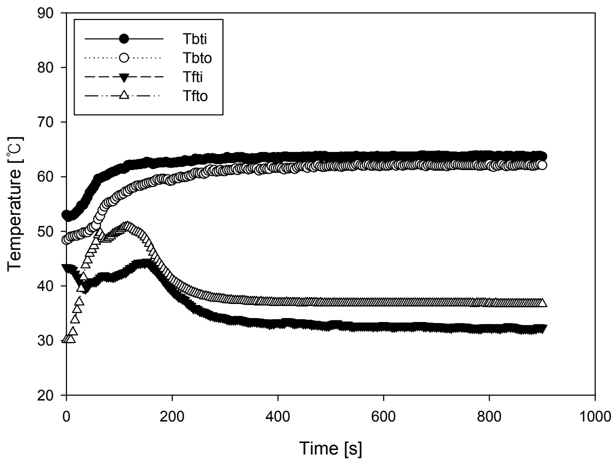

Fig. 3 Temperature distribution in evaporator during experiment.

Temperature distribution inside evaporator at 70℃, 300 ml/min and 1 mm, for feed water temperature, flow rate and orifice size respectively, is shown in Fig.3. Temperature was increasing for some times and would remain constant at about 200 seconds after starting the experiment. Temperature in upper of flashing tube of evaporator (Tfto) was higher than it at bottom of flashing tube (Tfti), this phenomenon is indicating that evaporation occurred inside the evaporator.

Pressure distribution in evaporator during

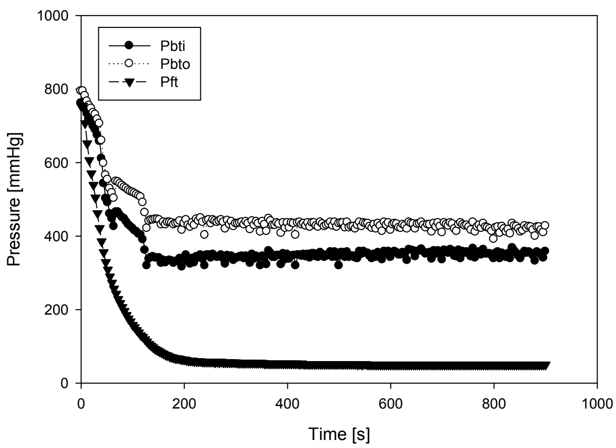

Fig. 4 Pressure distribution inside evaporator during experiment.

experiment is showed in Fig. 4. It shows the pressure in the boiling tube was higher than it in flashing tube of evaporator. Pressure in flashing tube of evaporator was around 50 mmHg while pressure inside boiling tube were around 350 mmHg and 432 mmHg at boiling tube inlet and outlet respectively.

Detail pressure distribution in the boiling tube and flashing tube evaporation with vary of feed water temperature is shown in Fig.5. The pressures in the flashing tube (Pft) were varied from 29.25 to 57.98 mmHg. Boiling tube pressure at the bottom (Pbti) was above that of the top of the boiling tube (Pbto). At the feed water rate of 300 ml/min the pressure at the bottom and top were 340.47～350.92 mmHg and 324.49～459.89 mmHg. The pressure inside the boiling tube having feed water temperature from 50℃ to 60℃ was decreasing then slightly increase again when feed water temperature is increasing up to 80℃. This phenomenon happened because of partial evaporation of feed water in the pipe before reaching the boiling tube has occurred as the effect of low pressure created in evaporator by ejector and the amount of partial evaporation was increasing significantly when temperature of feed water changed from 50℃ to 60℃. The pressure inside the boiling tube of evaporator increased, when the feed water temperature is increased. Pressures inside the flashing tube were always

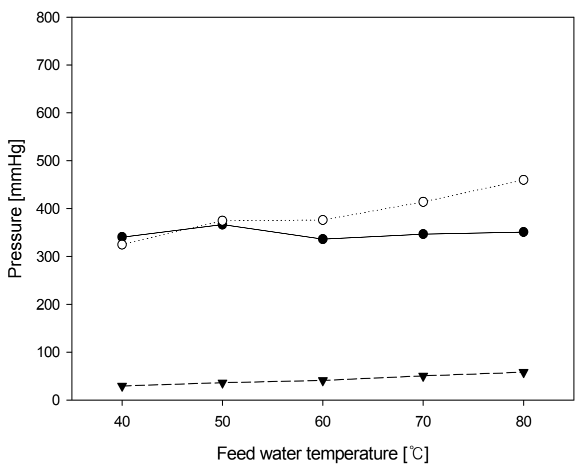

Fig. 5 Pressure distribution in the evaporation in different of feed water temperature

lower than the pressures in the boiling tube of evaporator.

Temperature distribution in the evaporator was tending to increase with the increasing of feed water temperature as shown in Fig.6.

This figure shows temperature distribution inside evaporator with the increasing of feed water temperature and 1 mm of orifice diameter was used. Boiling tube bottom varied temperature from 37.9～72.24℃ and the top temperature followed the same trends but below this line 37.08～70.03℃. Flash tube bottom temperature line was at upper position than the top temperature.

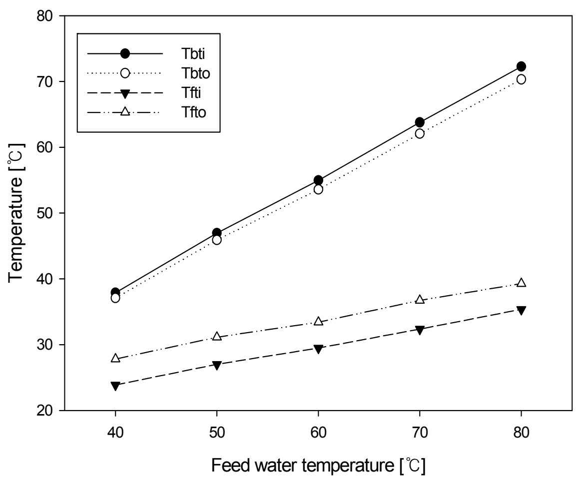

Fig. 6 Temperature distribution inside the evaporator with various feed water temperature

Flashing tube temperature shows straight line (23.87～35.34℃ for bottom flashing tube, 27.8～39.27℃ for upper flashing tube). Feed water temperature inside evaporator increases the temperature inside the evaporator. It shows also that the temperature inside the flashing tube always lower than it inside boiling tube.

Fig. 7 shows the pressure in the flashing tube when different size of orifices were used. There were increasing trends of flashing tube pressure with the feed water temperature. The minimum pressures was 21.5 mmHg when 2 mm orifice was applied at 40℃ of feed water and reach maximum at 59.5 mmHg with 1 mm orifice at 80℃. There were effects of those orifice sizes by increasing the pressure from 21.5 to 43.5 mmHg when feed water temperature was 40℃.

Steam temperature before entering the condenser increases sharper than it at the outlet of condenser when feed water temperature increases from 40～80℃. Inlet steam temperature line was always above the outlet steam temperature line with temperature different range 10.9～17.2℃ for 300 ml/min feed rate of the 1 mm orifice as can be seen in Fig. 8. This graph shows that the temperature different between temperature steam inlet and outlet of the condenser is increasing when temperature of feed water increases.

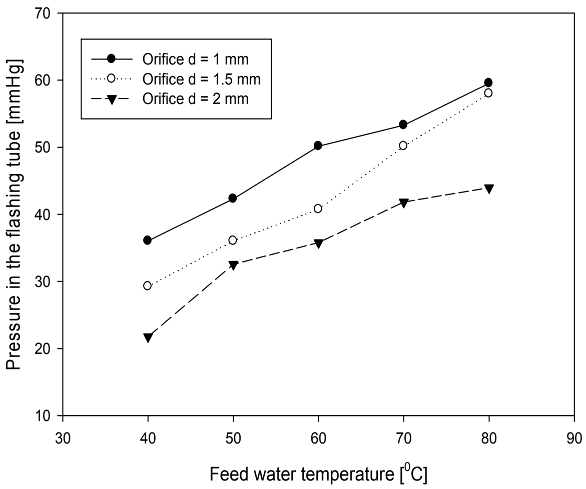

Fig. 7 Distribution of pressure inside the flashing tube of evaporator with increasing for feed water temperature.

The effect of feed water temperature difference on yield of condensed vapor while other parameters such as motive pressure of ejector, flow rates of water through condenser, and evaporator were maintained constant as shown in Fig. 9. When temperature of feed water rate and temperature was increased, condensed vapor produced from the experiment were also increased. It was because the higher temperature of feed water the more steam produce in evaporator. Condensed vapor will decrease when the diameter of orifice hole decreases. On the flow rate of 300 ml/min showed bubbles flowed through it. This bubbles created because of vacuum effect in the evaporator which created feed waters partially vapor.

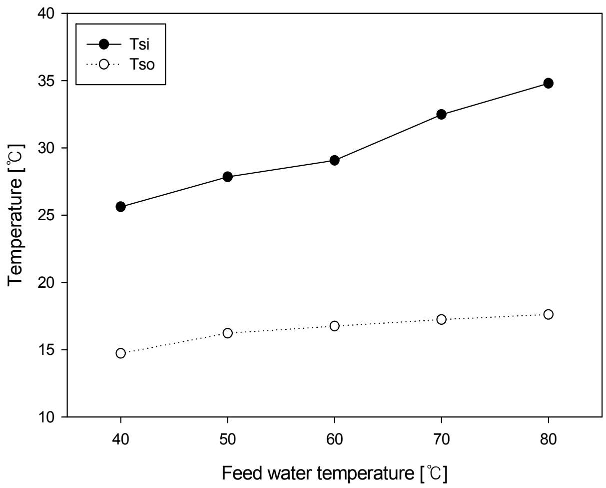

Fig. 8 Temperature steam inlet and outlet of the condenser in different feed water temperature

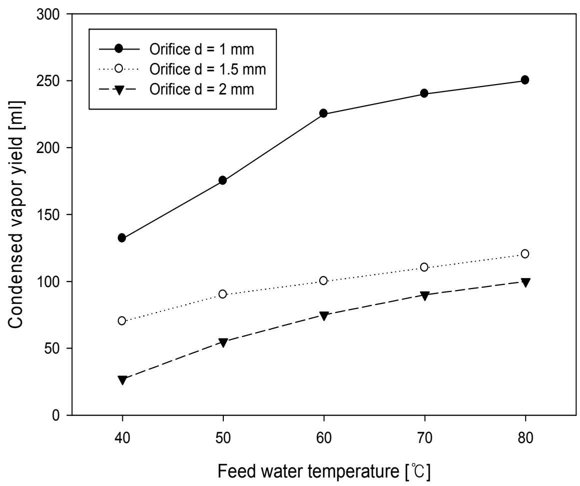

Fig. 9 Yield of condensed vapor collected from the experiment at various feed water temperature.

For 1 mm, 1.5 mm and 2 mm orifice the amount of fresh water generation were in increasing trend with distinct difference as 220 ml, 90 ml, and 60 ml for 300 ml/min feed rate and 60℃ temperature. At 40～80℃ of feed water temperature with orifice diameter 1, 1.5, and 2 mm in this experiment the condensation rate were 132～250 ml, 70～120 ml, and 27～100 ml respectively.

4. Conclusions

The experimental of fresh water generator evaporates the water by flash evaporation and subsequent condensation to get fresh water.

From this experiment, it was found that water could evaporate with temperature range 40℃ to 80℃ in a low pressure condition of evaporator.

The amount of condensed vapor collected in experiment was affected by feed water temperature and orifice diameters. Condensed vapor increased with the increasing of evaporator temperature and decreased with bigger diameter size of orifice from 1∼2 mm.

Minimum condensed vapor yield was 27 ml at 40℃ of feed water temperature with 2 mm orifice size and maximum yield was 250 ml at 80℃ with 1mm of orifice size.

The experimental study shows that a vacuum desalination is feasible and has some advantages, water can be boiled at lower temperature.

Acknowledgement

This research was financially supported by Industrial Core Technology Development, Regional Strategy Planning Technology Development of KEIT (Korea Evaluation Institute of Industrial Technology) and the National Research Foundation of Korea Grant funded by the Korean Government (NRF 2010 013 D00007).

References

1. K. Schneider and T.S. Van Gassel, 1984, Chem. Ing. Tech., Vol. 7, p. 514.
2. R.W. Schofield, A.G. Fane and C.J.D. Fell, 1987, Desalination 64 : 23 1.
3. Senthil Kumar, R., Mani, A., Kumaraswamy, 2007, "S. Experimental studies on desalination system for ocean thermal energy utilization", Desalination 207 : 1 - 8.
4. J.H. Tay, S.C Low, S. Jeyaseelan, 1996, "Vacuum desalination for water purification using waste heat". Desalination, pp. 131-135.
5. S.C. Low and J.H. Tay, 1991, "Vacuum desalination using waste heat from a steam turbine", Desalination 106, pp. 321-331.
6. J.H. Tay, S.C. Low and S. Jeyaseelan, 1996, "Vacuum desalination for water purification using waste heat", Desalination 106, pp. 131-135.
7. A. Mani, 1982, "Studies on single sloped solar still", National Solar Energy Convention, I.I.T., New Delhi, pp. 17.4-17.7.
8. A. Mani, Experimental studies on single sloped solar still, M.Teeh Thesis, liT, Madras, 1982.
9. A. Mani., S. Kumaraswamy and R. Senthil Kumar, 2002, "Utilisation of ocean thermal energy for desalination of brackish water, Technical Report", National Insti tute of Technology, Chennai.
10. A.I. Kudish, E.G. Evseev, G. Walter and T. Priebe, 2003, "Simulation study on a solar desalination system utilizing an evaporator/condenser chamber", Energy Conv. Manage., Vol. 44, pp. 1653-1670.
11. H. Rahman, M.N.A. Hawlader and M. Malek, 2003, "An experiment with single effect submerged vertical etube evaporator in multieffect desalination", Desalination 156, pp. 91-100