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Study on low pressure evaporation of fresh water generation system model †

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Abstract

A low pressure evaporation fresh water generation system is designed for converting brackish water or seawater into fresh water by distillation in low pressure and temperature. Distillation through evaporation of feed water and subsequent vapor condensation as evaporation produced fresh water were studied; tap water was employed as feed water. The system uses the ejector as a vacuum creator of the evaporator, which is one of the most important parts in the distillation process. Hence liquid can be evaporated at a lower temperature than at normal or atmospheric conditions. Various operating conditions, i.e. temperature of feed water and different orifice diameters, were applied in the experiment to investigate the characteristics of the system. It was found that these parameters have a significant effect on the performance of fresh water generation systems with low pressure evaporation.

Keywords: Distillation; Ejector; Fresh water generation; Low pressure

1. Introduction

Human has been dependent on rivers, lakes, reservoirs and ground water for fresh water in domestic life, agriculture, and industrial activities. These sources represent only about 1% of the Earth's water while 97% of the Earth's water is in the form of seawater. Water is a basic natural resource and plays a crucial role in the overall development of the economy of any country. Some cities are unable to cope with demand for fresh water due to rapid industrialization and increasing population. Pollution of rivers, lakes and ground water due to industrial wastes and discharge of large quantities of sewage are activities that increase the scarcity of fresh water even to cities located near rivers and lakes.

The demand for water is always increasing, and to cope with this problem, some technologies to convert brackish water or seawater into potable water have been studied for many years. It is an energy-intensive process, and only viable if the source of energy is practically free, such as a celestial source, geothermal source or industrial waste heat. Various processes were developed for the conversion of seawater or brackish water into potable water, and only a few of these processes have been commercialized. Distillation, electrolysis and reverse osmosis are well documented processes and commonly used for desalination [1].

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 are processes 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 inexpensive [2, 3]. 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 for potable use. Vacuum desalination is a process by which water is vaporized at a 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 to the cost of heating to the boiling point. This study demonstrates the possible application of vacuum fresh water generation for water purification with low temperature feed water, where waste heat from the water cooling machine of a ship can be applied to heat the feed water.

Some studies of low pressure evaporation have been developed by many researchers, such as Kumar et al. [4], who designed a desalination system utilizing ocean thermal gradient. J. H. Tay et al. [5] investigated vacuum desalination applica-

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tion and showed that water can be boiled at low temperature at a corresponding low pressure. Tay et al. [6] conducted a pilot study on a laboratory-scale system and concluded that system performance depends on how efficiently the heat losses are 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 [7]. A detailed experimental study was made by Mani [8, 9] to probe the effect of water depth and slope of a single-sloped solar still. Mani et al. [10] 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. [11], and their work was validated with experimental measurements.

A single effect desalination system was developed before by Rahman et al. [12]. 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 is concerned with thermal and pressure characteristics and performance of condensed vapor yield of single effect configuration combined with thermal vapor compressor (ejector).

2. Experiment setup and procedure

The required heat energy for fresh water generation by distillation can be brought down by reducing the boiling temperature [4]. By the creation of low pressure in the evaporator, the boiling point of water can be minimized.

A pilot study, as shown in Fig. 1, was conducted in the laboratory to investigate the phenomena and feasibility of using a vacuum distillation process for water supply; tap 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. Test section dimension parameters 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.

The treatment system is designed to minimize the heat requirement. The system consists of several main pieces of equipment: pump, heater, evaporator designed to have low pressure, condenser, and ejector. Briefly, water from the tank (water tank) is pumped to the nozzle of the ejector as a motive fluid to create a low pressure region at the nozzle exit plane inside the ejector. This low pressure allows the water in the evaporator to vaporize at a low temperature. Feed water with a temperature range from 40-80℃ was pumped to the evaporator from the heater; Table 2 shows summaries of the operation condition of this experiment. Water vapor produced in the

Table 1. Test section dimension.

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

Table 2. Experiment operation condition.

Variable	Value
Feed water flow rate	200, 300, 400 [cc/min]
Orifice hole diameter	1, 1.5, 2 mm
Feed water temperature	40, 50, 60, 70, 80℃
Pressure motive of ejector	0.4 MPa
Condenser temperature	8 – 12℃
Experiment duration	15 minutes

Fig. 1. Experimental devices.

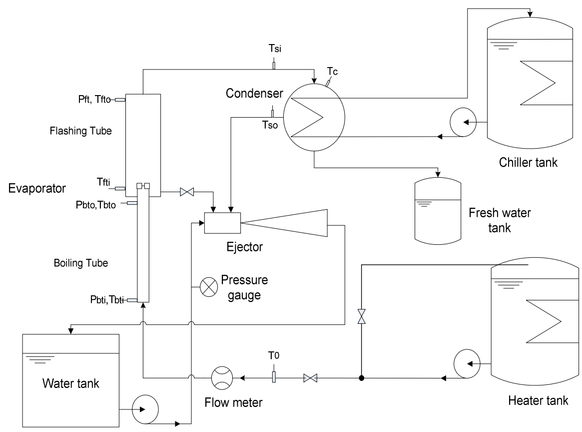

Fig. 2. Schematic diagram of experimental setup.

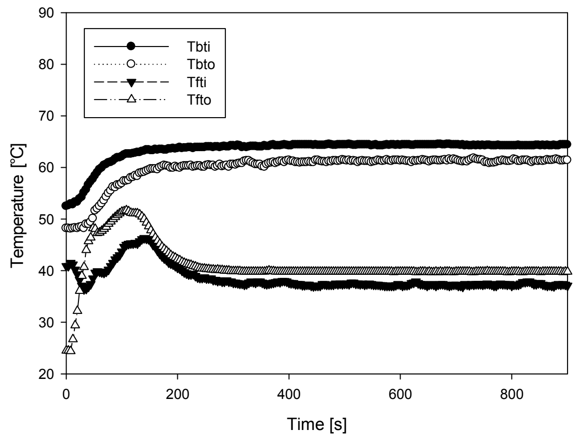

Fig. 3. Temperaturedistribution in evaporator during experiment.

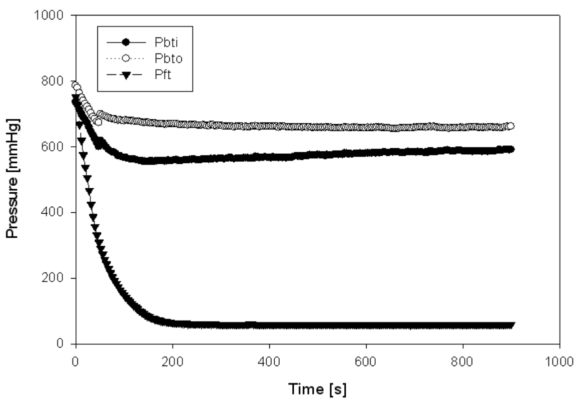

Fig. 4. Pressure distribution inside the evaporator during experiment.

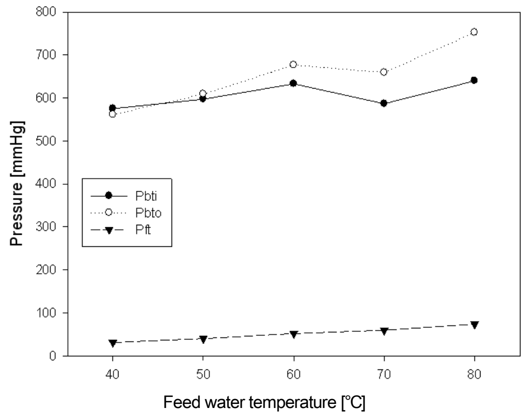

Fig. 5. Pressure distribution in the evaporation in different of feed water temperature.

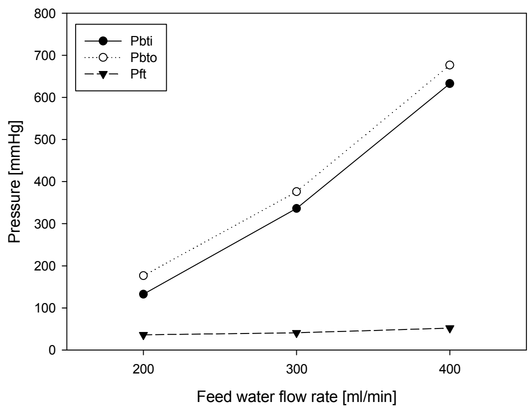

Fig. 6. Pressure distributions inside evaporator with the different of feed water flow rate.

evaporator travels up through the pipe to the condenser. In the condenser, some vapor condenses and flows to the fresh water tank, and the rest of uncondensed vapor will be sucked by the ejector to the water tank to complete the cycle.

3. Result and discussion

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

Temperature distribution inside the evaporator, at 70℃, 400 ml/min and 1 mm, for feed water temperature, flow rate and orifice size, respectively, is shown in Fig. 3. Temperature increased for some time and remained constant at about 200 seconds after the start of the experiment. Temperature in the upper part of flashing tube of the evaporator (Tfto) had a higher temperature compared to the bottom of the flashing tube (Tfti). This phenomenon indicates that evaporation occurred inside the evaporator. Pressure distribution in the evaporator during the experiment is shown in Fig. 4. This shows that the pressure in the boiling tube is higher than in the flashing tube of the evaporator. The pressure in the flashing tube of the evaporator is around 59.56 mmHg while the pressure inside the boiling tube is around 586.43 mmHg and 658.99 mmHg at boiling tube inlet and outlet, respectively.

Detail pressure distribution in the boiling tube and flashing tube evaporation with variation of feed water temperature is shown in Fig. 5. The pressures in the flashing tube (Pft) were varied from 31 to 73.65 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 400 ml/min, the pressure at the bottom and top of the boiling tube were 574.91 – 639.73 mmHg and 560.9 – 752.35 mmHg. The pressure inside the boiling tube from 40–70℃ of feed water temperature decreased then slightly increased again when feed water temperature increased up to 80℃. This phenomenon happened because of partial evaporation of feed water in the pipe before reaching the boiling tube. This occurred as the effect of low pressure created in the evaporator by the ejector and the amount of partial evaporation increased significantly when the temperature of feed water changed from 40℃ to 70℃.

When water feeding rate increased, pressure also increased as shown in Fig. 6. This graphic was taken at feed water tem-

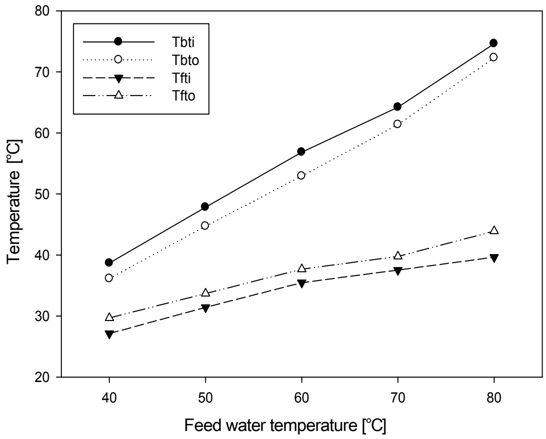

Fig. 7. Temperature distribution inside the evaporator with various feed water temperature.

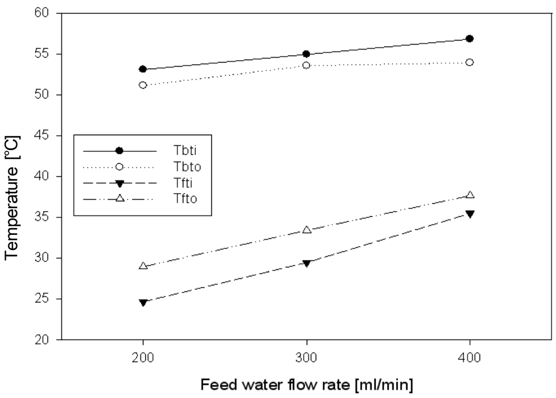

Fig. 8. Temperature distribution inside the evaporator with different flow rate of feed water.

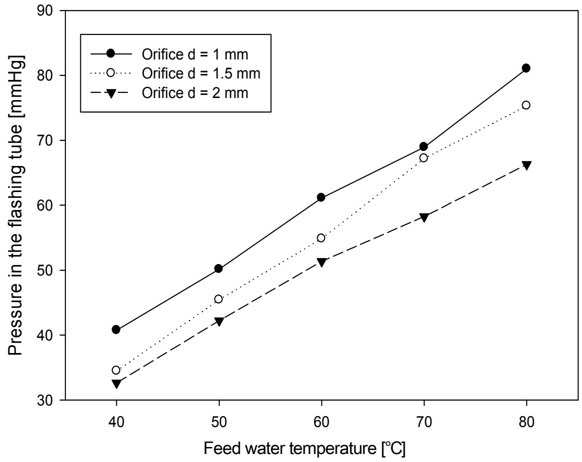

Fig. 9. Distribution of pressure inside the flashing tube of evaporator with the increasing feed water temperature.

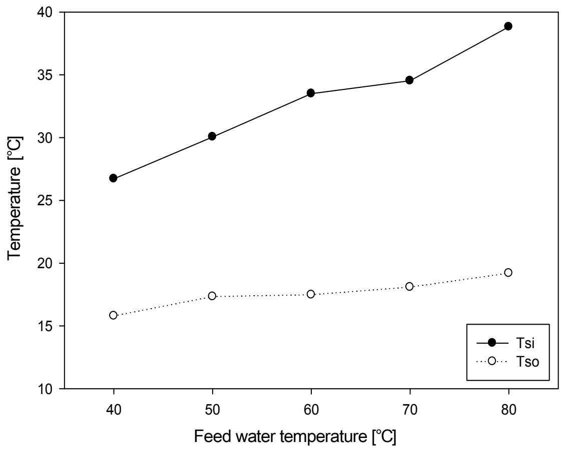

Fig. 10. Temperature steam inlet and outlet of the condenser in different feed water temperature.

perature 60℃ and orifice size 1 mm. The pressures at the flashing tube for different feed rates slightly increased from 36.04 – 56.31 mmHg. The pressure inside the boiling tube of the evaporator significantly increases when the feed water flow rate is increased.

Distribution of temperature in the evaporator tends to increase along with the increasing of feed water temperature, as shown in Fig. 7. This figure shows temperature distribution inside the evaporator with increasing feed water temperature. The orifice diameter was 1mm. The boiling tube bottom varied from 36.15–72.31℃ and the top temperature followed the same trends but below this line from 38.68 to 74.6℃. The minimum flash tube temperature line is at a higher position than that of the top temperature. Flashing tube temperature has a range of 27.14–39.63℃ for bottom flashing tube and 29.63–43.9℃ for upper flashing tube. Feed water temperature inside the evaporator increases the temperature inside the evaporator. It shows also that the temperature inside the flashing tube is always lower compared to the temperature inside boiling tube. Temperature in the evaporator, both in the boiling and flashing tubes, increased when the flow rate of feed water increased from 200 to 400 ml/min, Fig. 8.

Fig. 9 shows the pressure in the flashing tube when different size orifices were used. There were increasing trends of flashing tube pressure with the feed water temperature. The minimum and maximum pressures at a rate of 400 ml/min of feed water were 32.6 and 66.27 mmHg when a 2 mm orifice was applied. Increasing orifice sizes decreased the pressure from 61.11 to 51.34 mmHg when feed water temperature was 60℃.

Steam temperature before entering the condenser increased to significantly than what it was at the outlet of the condenser when feed water temperature was increased from 40-80℃. Inlet steam temperature line was always above the outlet steam temperature line by 26.7–38.8℃ while the outlet temperature ranged from 15.8–19.2℃ for 400 ml/min feed rate of the 1 mm orifice, as can be seen in Fig. 10. This graph showed that the temperature difference between temperature steam inlet and outlet of the condenser increased when temperature of feed water increased.

Fig. 11 shows that steam temperature at the inlet increased when the flow rate of feed water was increased. This tempera-

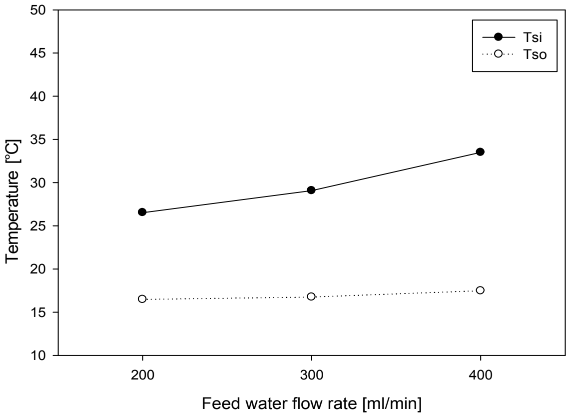

Fig. 11. Temperature steam inlet and outlet of the condenser in different feed water flow rate.

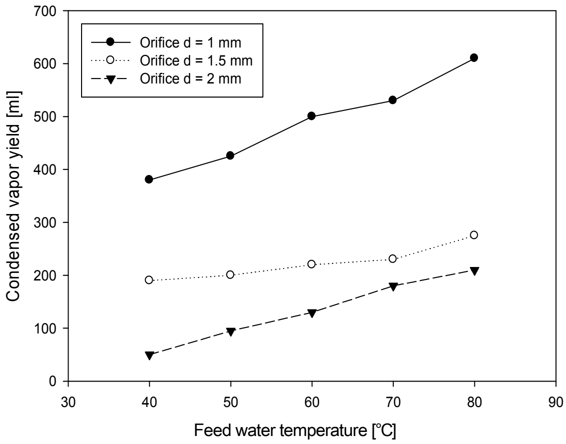

Fig. 12. Yield of condensed vapor collected from the experiment at various feed water temperature.

ture gradient increases as the flow rate increases from 200 to 400 ml/min. But outlet temperature showed a slightly decreasing trend with varying feed water. Those results were taken with a feed water temperature of 60℃ and maintained temperatures between 8-12℃ in the condenser.

The effect of feed water temperature differences 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 is shown in Fig. 12. When feed water rate and temperature were increased, the condensed vapor produced from the experiment also increased. This was because the higher the temperature of feed water, the more steam produced in the evaporator. The amount of condensed vapor decreased when the larger diameter of the orifice was decreased. With the increasing of feed water temperature, after some temperature bubbles started to flow through the pipe which was connected to the evaporator from the feed water tank. These bubbles existed because of the vacuum effect in the evaporator which made the feed water partially vaporized. In the experiment, at 40-80℃ of feed water temperature, the orifice diameters were 1, 1.5, and 2 mm, while

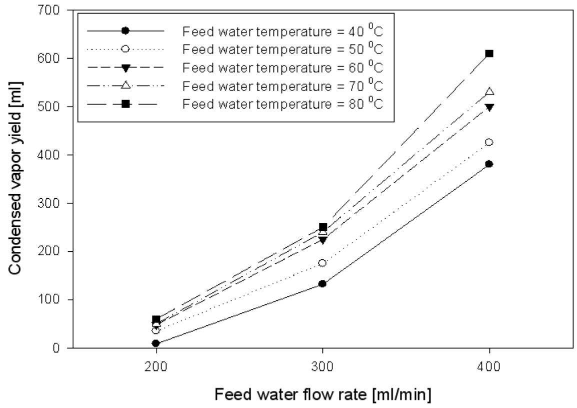

Fig. 13. Condensed vapor yield with increasing feed water flow rate and temperature.

the condensation rates were 380 – 610 ml, 190 – 275 ml, and 50 – 210 ml, respectively. When feed water flow rate and temperature were increased, the amount of condensed vapor produced from the experiment also increased, as shown in Fig. 13. Because of the higher temperature of feed water, the more steam was produced in the evaporator.

4. Conclusions

Experiments on low pressure evaporation of fresh water generator were conducted to reveal the phenomena of the system. From this experiment, it was found that water would evaporate within a temperature range of 40℃ to 80℃ in a low pressure evaporator. The amount of condensed vapor collected in the experiment was affected by feed water flow rate, temperature, and orifice diameters. The amount of condensed vapor increased with increases in evaporator flow rate and temperature and decreased with increasing orifice diameters. Maximum yield of condensed vapor in the experiment was reached at feed water temperature 80℃ and a feed rate of 400 ml/min, with a 1mm diameter orifice.

The experiments show that vacuum desalination is feasible and has its advantages: water can be boiled at lower temperature.

Acknowledgement

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