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Preliminary investigations on an air-cooled based low temperature flash evaporation desalination system for small-scale applications

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ABSTRACT

This paper deals with the use of an air-cooled condenser in a low-temperature flash evaporation desalination system, suitable for small-scale applications. A small-scale desalination system has been designed to operate at an evaporator pressure of 0.2 bar and the performance of the system is evaluated for different inlet feed water temperatures between 70 and 90˚C and at varying flow rates using three different nozzles. It is seen that the yield of the system depends on the temperature of inlet water, nozzle diameter and flow rate. A maximum yield ratio of 2.3% is obtained at an inlet water temperature of 90˚C and at a feed water flow rate of 200 ml/min. The quality of the condensed distillate is found to be within the safe standards of drinking water making this system a feasible and viable option to meet the small-scale freshwater needs in rural and coastal areas.

Keywords: Air-cooled; Flash evaporation desalination; Low temperature; Vacuum desalination

1. Introduction

According to the World Health Organization, the permissible limit of salinity in drinking water is 500 ppm, while for special cases up to 1,000 ppm is acceptable [1]. There is a continued interest in developing desalting equipment suitable for village use that is dependable, inexpensive and commercially viable [2].

2. Review of literature

It is observed from the review of literatures [3–7] that no attempt has been made to utilize air as a cooling medium in the condenser. The motivation is due to the availability of free air that can be used for the condensation of water vapour. As the heat to be removed is considerably less in a small-scale system, the use of air-cooled condensers would eliminate the necessity of cooling water pump, cooling tower, piping, etc., making the system more compact.

3. Experimental set-up and procedure

The schematic representation of the experimental set-up is shown in Fig. 1.

The major components of the system are shown in Fig. 1. The brine prepared by mixing common salt is heated and injected into the evacuated flash vessel

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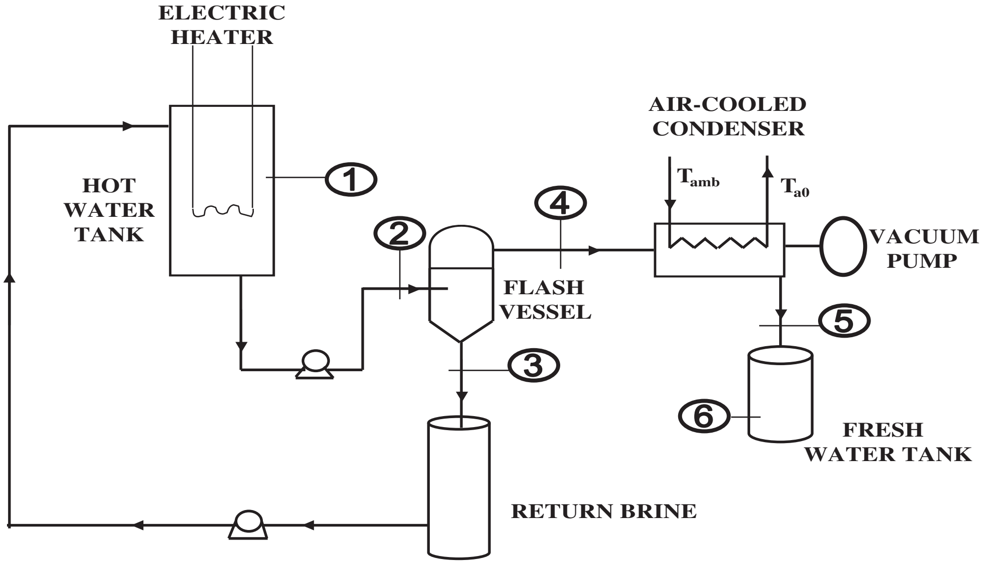
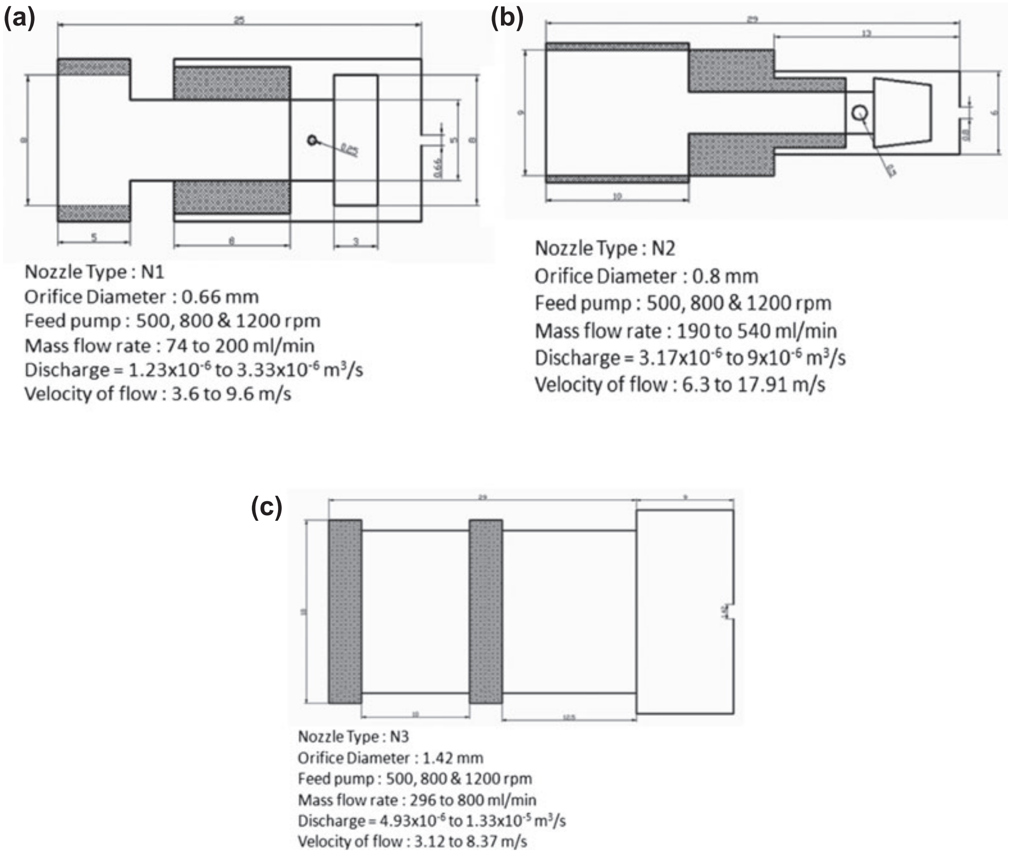


Fig. 1. Schematic diagram of the experimental set-up.



Nozzle Type : N1
Orifice Diameter : 0.66 mm
Feed pump : 500, 800 & 1200 rpm
Mass flow rate : 74 to 200 ml/min
Discharge = 1.23×10^{-6} to 3.33×10^{-6} m^3/s
Velocity of flow : 3.6 to 9.6 m/s

Nozzle Type : N2
Orifice Diameter : 0.8 mm
Feed pump : 500, 800 & 1200 rpm
Mass flow rate : 190 to 540 ml/min
Discharge = 3.17×10^{-6} to 9×10^{-6} m^3/s
Velocity of flow : 6.3 to 17.91 m/s

Nozzle Type : N3
Orifice Diameter : 1.42 mm
Feed pump : 500, 800 & 1200 rpm
Mass flow rate : 296 to 800 ml/min
Discharge = 4.93×10^{-6} to 1.33×10^{-5} m^3/s
Velocity of flow : 3.12 to 8.37 m/s

Fig. 2. Specification of nozzles used in the study. (a) Nozzle N1, (b) Nozzle N2 and (c) Nozzle N3.

Table 1
Details of uncertainties

Measured/estimated parameter	Uncertainty
Temperature	1.66%
High pressure	±1.6% of span
Vacuum pressure	±1% of span
Air velocity	±2%
Condenser heat load	2.6%
Yield	1.92%

maintained at a low pressure of 0.2 bar. The evaporated brine is condensed in an air-cooled condenser and the distillate is collected in the distillate tank. The return brine is pumped to the hot water tank and heated again to the preset temperature. The specifications of the nozzles used in the study are shown in Fig. 2.

The condenser is cross-flow finned type with 10 tubes arranged perpendicular to the air flow. The pipes are of 10-mm diameter and the spacing between them being 18 mm. The total effective heat transfer area is 0.56 m^2. The flow rate of the brine in the evaporator is varied using a variable speed controller to vary the speed of the motor driving the pump. A series of experiments are conducted with the feed water temperature varying in the range of 70–90˚C and flashed at an evaporator pressure of 0.2 bar through nozzles N1, N2 and N3 and the yield, condenser load are estimated.

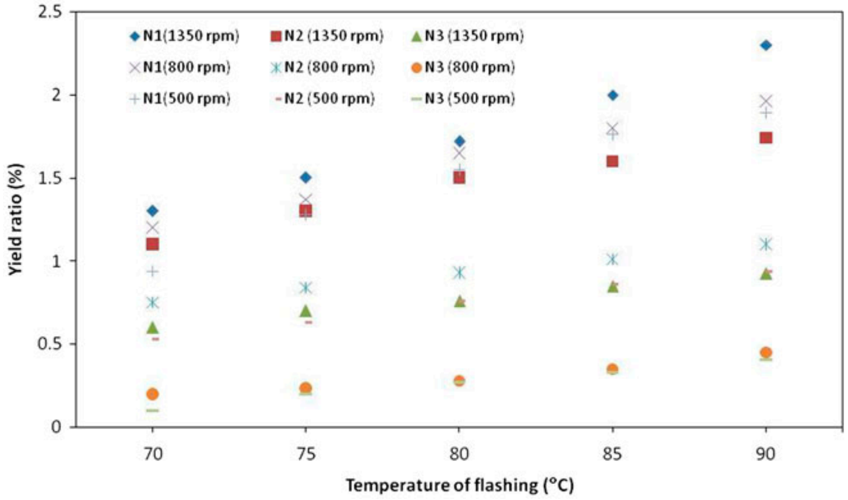


Fig. 3. Variation of yield ratio of various nozzles with change in inlet brine temperatures at various flow rates.

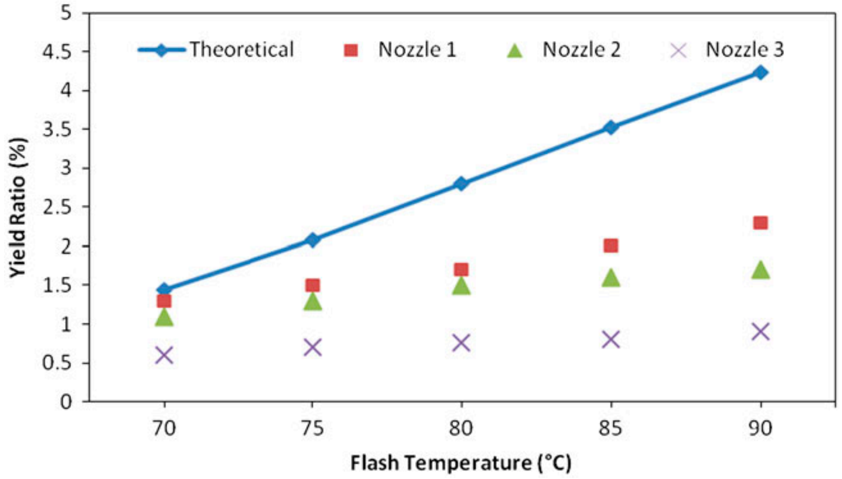


Fig. 4. Comparison of theoretical and experimental yield ratios at various inlet brine temperatures.

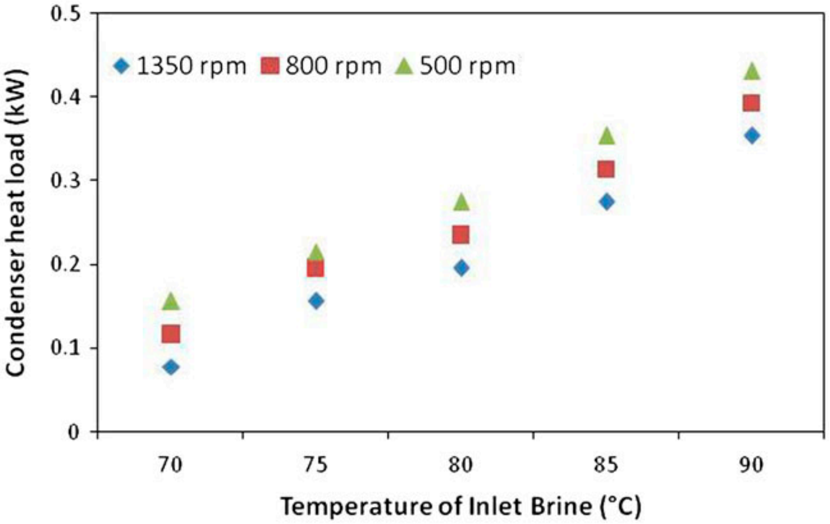


Fig. 5. Condenser heat load with nozzle N1 at various flow rates.

Table 2
Comparison of quality of distillate and feed water

Parameter	Feed water	Distillate	Desirable limits
Salinity (ppm)	33,000–35,000	352–429	<500
Electrical conductivity (μS/cm)	51,600–54,700	550–670	<750
pH	7.4–7.6	6.5–6.6	6.5–8.5

4. Uncertainty analysis

The details of uncertainties in the measurement of various parameters during the experimental analysis are shown in Table 1.

5. Results and discussion

The freshwater yield and condenser heat load are estimated for various operating conditions using the small-scale experimental set-up. The yield ratio of the system while using three different nozzles and motor speeds is shown in Fig. 3.

The yield ratio increased as the temperature of flash increased irrespective of the nozzle. The yield ratio obtained was in a range between 0.94–2.3%, 0.53–1.74% and 0.1–0.92% for nozzles N1, N2 and N3, respectively, for the temperature of flash ranging from 70–90˚C and varying flow rates. At a motor speed of 1,350 rpm, a maximum yield ratio of 2.3% is obtained with nozzle N1 for an inlet brine temperature of 90˚C. It is observed that for the same injection pressure, the yield ratio was more for nozzle N1 with an orifice diameter of 0.66 mm when compared to nozzle N2 of diameter 0.8 mm and nozzle N3 of diameter 1.42 mm.

The yield ratio of nozzle N1 is found to be the highest and the variation with respect to motor speed is less. The yield ratio is 2.3% at 1,350 rpm, 1.96% at 800 rpm and 1.83% at 500 rpm for a flash temperature of 90˚C. The diameter of the nozzle is found to influence the yield ratio more than other parameters. The small orifice diameter of N1 produces fine droplets that enhances the evaporation rate in the low-pressure flash vessel. The yield ratios of N2 and N3 reduced drastically when the injection pressure decreased which resulted in poor atomization of the brine.

The comparison of theoretical and experimental yield ratios at various inlet brine temperatures is shown in Fig. 4.

The heat load of the air-cooled condenser is estimated by observing the change in temperature of the outlet and inlet air temperatures and the velocity of air moving over the tubes using an anemometer. The heat removed by the air-cooled condenser with nozzle N1 and various flow rates is shown in Fig. 5. It is observed that the heat removed by the condenser increases as the flash temperature increases, while the yield of the system also increases. A maximum condenser heat load of 0.432 kW was obtained for an air velocity of 5 m/s.

The condenser heat load was found to vary between 0.432 and 0.078 kW for nozzle N1 at various flow rates and temperatures. It was seen that the air-cooled condenser used in the system effectively removed heat to condense the distillate. The quality of the distillate obtained was tested for pH, salinity and electrical conductivity and found to be suitable for drinking. The range of these values is shown in Table 2.

6. Conclusions

The performance of a single-stage air-cooled low-temperature flash evaporation desalination system suitable for small-scale application is studied. A maximum yield ratio of 2.3% is obtained at an inlet water temperature of 90˚C and at a feed water flow rate of 200 ml/min. Further, the yield ratio increases with decrease in orifice diameter and with increase in feed water flow rate. The heat of condensation is effectively removed by the air-cooled condenser to obtain a reasonable quality of distillate suitable for drinking. This small-scale system can help us in solving the freshwater needs of isolated villages, arid, semi-arid and coastal communities using the locally available thermal energy like solar energy.

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