INVESTIGATIONS ON LOW TEMPERATURE FLASH EVAPORATION DESALINATION FOR SMALL-SCALE APPLICATIONS

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***Abstract*— This paper presents the experimental study of a flash evaporation based desalination system that can cater to the small-scale fresh water needs of coastal and arid areas. The proposed small-scale system consists of an evaporator, water-cooled condenser and a vacuum pump to produce the required vacuum in the evaporator. The effect of inlet brine water temperature at various flow rate and evaporator pressure on the fresh water yield is evaluated. A maximum fresh water yield of 4 l/h is obtained at an evaporator pressure of 0.08 bar and an inlet brine temperature of 56°C when the feed water is flashed at the rate of 3.6 l/min. The quality of the desalinated water is found to be within the acceptable standards. Thus the proposed system is found to be a promising and feasible solution for addressing the small-scale fresh water needs of coastal and arid regions.**

Keyword- Flash evaporation, Low temperature, Small-scale, Vacuum desalination

I. INTRODUCTION

The radical changes in the weather patterns around the globe due to man-made activities have led to the acute shortage of vital resources like drinking water of acceptable standards. Industrialization and civilization has led the mankind to achieve great technological feats at the expense of co-existence with nature and exploiting its blessed resources. Ambitious needs of man are driving us and our future generations towards a brawling and unsafe living on this planet earth. Water resource which was once considered to be a naturally available resource has now emerged as a product that has to be manufactured with specific quality. With the intensification of the non-availability of safe drinking water, researchers and industrialists have started developing technologies like desalination to convert the abundantly available sea water to potable water to balance the need. Over the past 30 years, various desalting technologies have been well established around the world to supplement the fresh water needs on a large-scale level. But, the development of a robust technology to meet out the small-scale fresh water needs of coastal and arid areas have not progressed beyond the research level. Besides the commercially available RO based technologies, there exists a tremendous scope for development of new technologies in the small-scale market.

Thermal based desalination methods, where the saline water is evaporated and condensed to obtain drinkable water are energy-intensive, necessitating high grade energy for the conversion. Cost analysis of desalination units strongly point out that a very large proportion of the cost of desalinated water is linked with the cost of energy. The emergence of low temperature evaporation technology where the saline water is allowed to evaporate at low pressure can be sustained using waste heat or low-grade heat available from solar, turbine and engine exhaust etc., The abundant availability of solar energy makes solar-based desalination one of the promising and safe method for producing potable fresh water. In fact, the water-deprived countries where desalination is the only source of fresh water are the ones with abundant sunshine. This, is sufficient to heat water around 50-60°C with a flat plate collector working with 50% efficiency in these areas. The present work focuses on the development of a low temperature flash evaporation system to produce fresh water for the small-scale needs of coastal and arid areas.

Tay, studied the performance of a vacuum based desalination system where the brine water heated to 40-90°C by utilizing the waste heat from a steam turbine is flashed at a vacuum of 0.1-0.7 bar. This system generated potable water in the range of 0.8 to 1.46 l/h while operating in the temperature range of 62-73°C. The studies of Lourdes Garcia-Rodriguez and Carlos Gmoez-Camacho, affirmed the competency of solar energy compared to conventional energy applied to MSF distillation processes in a few climatic conditions. Joseph, developed a single stage solar desalination system using flat plate collectors that produced 8.5 liters of fresh water per day. Eames, showed the technical feasibility of producing 30 liters of fresh water per day by utilizing the heat derived from a solar panel of 4.727 m^2. Lalzad, developed a system in which a flat plate collector of area 4 m^2 produced 14-17 kg of distillate per day. Most of the works reported so far are small-scale systems based on barometric vacuum where the evaporator is placed at a height of more than 10 meters above ground level. However, the accumulation of non-condensable gases in the evaporator during the operation disturbs the vacuum and it becomes necessary to use a vacuum pump to further maintain the vacuum conditions in the evaporator. Hence, the present investigation aims at utilizing a vacuum pump to create and sustain the vacuum conditions in the evaporator during the process which will enable the system to be compact and efficient.

II. EXPERIMENTAL SET-UP

The schematic representation of the experimental set-up and its photographic view are shown in Fig. 1. and 2 respectively.

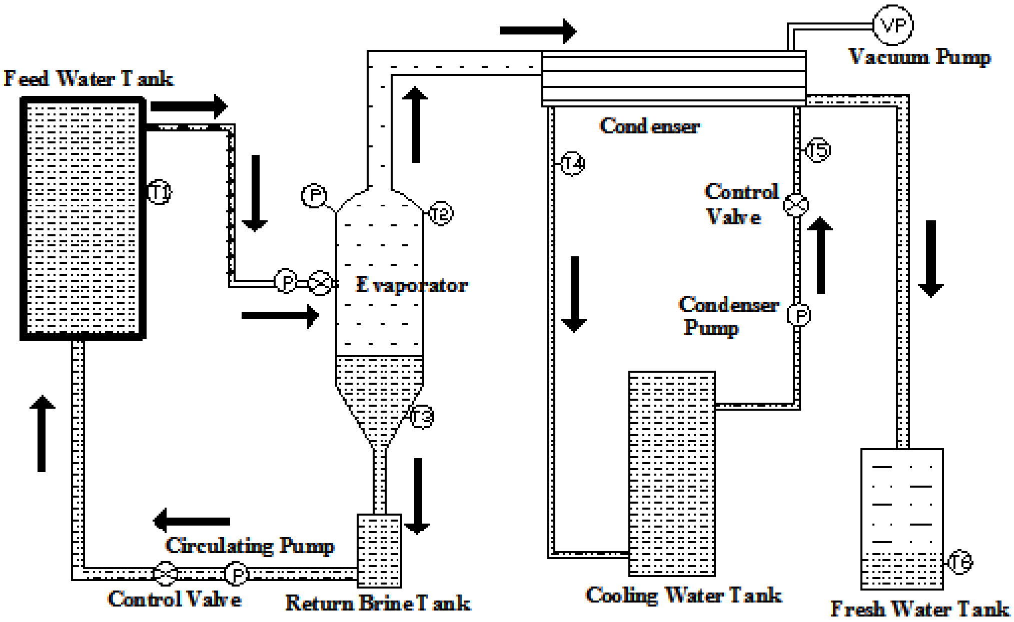

Fig. 1. Schematic representation of the experimental set-up

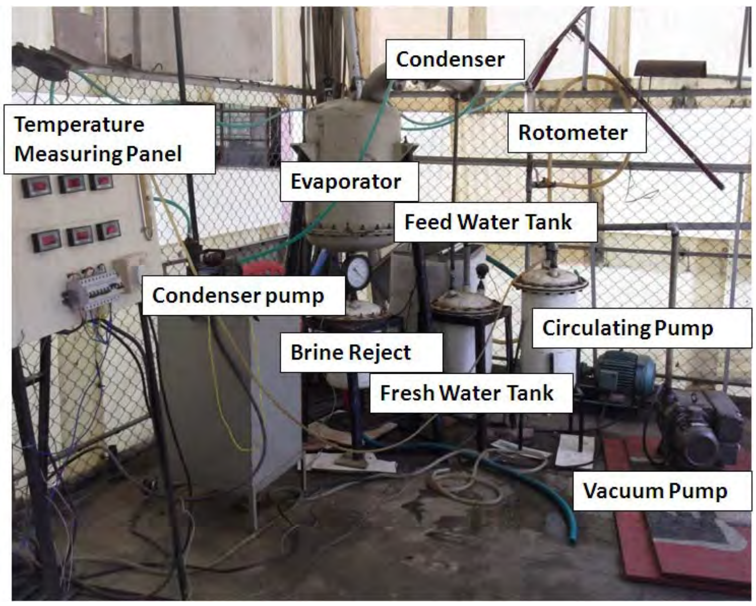

Fig. 2. Photographic view of the experimental set-up

A. Principle of Working

The brine water is prepared by mixing common salt at the rate of 35 gm/l of water so as to maintain a ppm of 35,000 which is similar to that of the sea water. The brine is heated in an insulated storage tank of 30 liters capacity with the help of an immersion heater to the required temperature of flashing. The inlet brine water is then pumped by a circulating pump through a control valve and a rotometer to the evaporator. The evaporator is maintained at vacuum using a vacuum pump. The water is sprayed as fine droplets using a nozzle so as to enhance the evaporation process. The evaporated vapour is circulated through the water cooled condenser to obtain fresh water in the fresh water tank. The brine reject from the evaporator is sent back to the storage tank through a control valve and a pump. A separate condenser pump is used to circulate water at ambient temperature through the condenser for condensing the evaporated water from the evaporator. K-type thermocouples are used to measure the temperatures at various points in the system and are recorded with the help of an electronic display. The vacuum in the evaporator is measured using a vacuum gauge.

B. System Specifications

The main components of the desalination system like evaporator, condenser is designed and the specifications are shown below.

- Evaporator : Diameter 0.5 m and height 0.7 m
- Condenser : Diameter of shell 200 mm
  No of tubes 12
  Length of tube 500 mm
  Outer diameter of tube 6.5 mm
  Inner diameter of tube 5 mm

III. EXPERIMENTAL ANALYSIS

Experiments were conducted for varying input parameters such as pressure in the evaporator, temperature of inlet brine water and the feed water flow rate. The various operating parameters of the experimental investigation are shown in Table 1.

Sl. No.	Operating Parameters	
1	Feed water flow rate	: 1.5 & 3.6 lpm
2	Inlet brine water temperatures	: 50 - 56°C
3	Pressure in Evaporator	: 0.08 & 0.1 bar
4	Condenser Temperature	: 31-34 °C
5	Experiment duration	: 8-20 mins

TABLE I. Operating Parameters

The first set of experiments were conducted by maintaining a pressure of 0.08 bar in the evaporator and flashing water at temperatures in the range of 50°C, 52°C, 54°C and 56°C at a constant flow rate of 1.5 liters/min. A series of experiments were conducted by maintaining the pressure at 0.1 bar in the evaporator. The water temperature of the evaporator chamber, the temperature of the return brine, the condenser inlet and outlet water temperatures and the fresh water temperature are recorded for all the experimental tests. The performance of the proposed system for various operating conditions is shown in Table II.

Pressure in the Evaporator (bar)	Feed water flow rate (liters/min)	Inlet Brine water Temp (T_1°C)	Evaporator Chamber Temp (T_2°C)	Return Brine Temp (T_3°C)	Condenser		Fresh water Temp (T_6°C)	Amount of fresh water Yield (ml)
					Cooling water inlet Temp (T_4°C)	Cooling water outlet Temp (T_5°C)		
0.08	1.5	50	39.42	35.4	33.74	34.86	31.43	308
		52	40.43	36.12	33.86	35.14	31.54	371
		54	41.27	36.76	34.12	35.49	32.14	470
		56	42.54	37.26	35.76	35.76	32.64	511

TABLE II. System Performance for Various Operating Conditions

The experiments were repeated by varying the flow rate of feed water and the amount of fresh water yielded for change in other parameters were recorded. The temperatures of water at various inlet and exit points were also recorded.

IV. RESULTS AND DISCUSSION

The fresh water yield was measured experimentally for different operating conditions. The pressure in the evaporator, the inlet brine water temperature and feed water flow rate are the main parameters considered in this study.

The effect of inlet brine water temperature on the fresh water yield at an evaporator pressure of 0.08 bar is shown in Fig. 3. The variation of the fresh water at various inlet brine temperatures and flow rates is shown. The fresh water yield increases with increase in the inlet brine water temperature. The fresh water yield also increases with increase in the inlet brine flow rate. The fresh water yield increases by 21% when the inlet brine temperature increases from 52°C to 54°C. However, the rate of increase in yield is around 8% between the inlet brine temperatures of 54 and 56 °C. A 5-10% increase in the fresh water yield was observed with the increase in the inlet brine water feed rate from 1.5 – 3.6 liters / min.

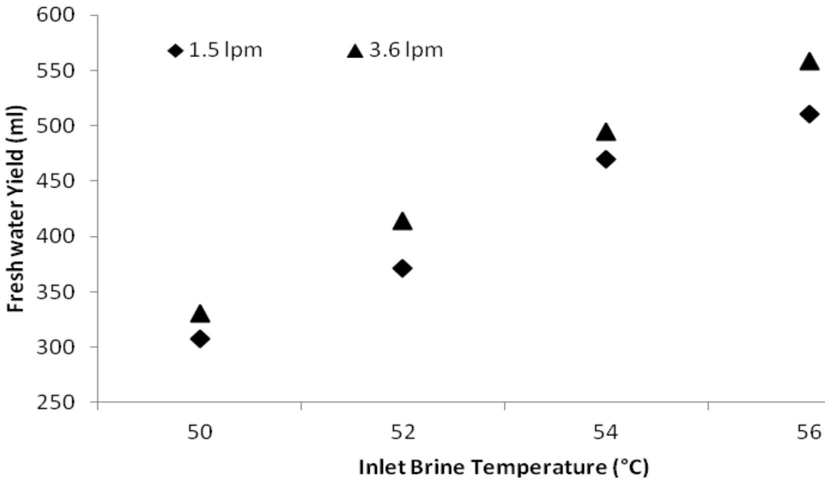

Fig. 3. Effect of Inlet Brine Temperature on Fresh Water Yield at 0.08 bar

Fig. 4. Shows the effect of inlet brine water temperature on the fresh water yield at an evaporator pressure of 0.1 bar. The variation of the fresh water at various inlet brine temperatures and flow rates is shown. Similar to the results obtained with 0.08 bar, the fresh water yield increases with increase in the inlet brine water temperature and also with the increase in the inlet brine flow rate. The fresh water yield increases by 35% when the inlet brine temperature increases from 50°C to 52°C and by 20% when the inlet brine temperature increases from 54 to 56 °C. An average increase in 10% of fresh water yield was observed with the increase in the inlet brine water feed rate from 1.5 – 3.6 liters / min.

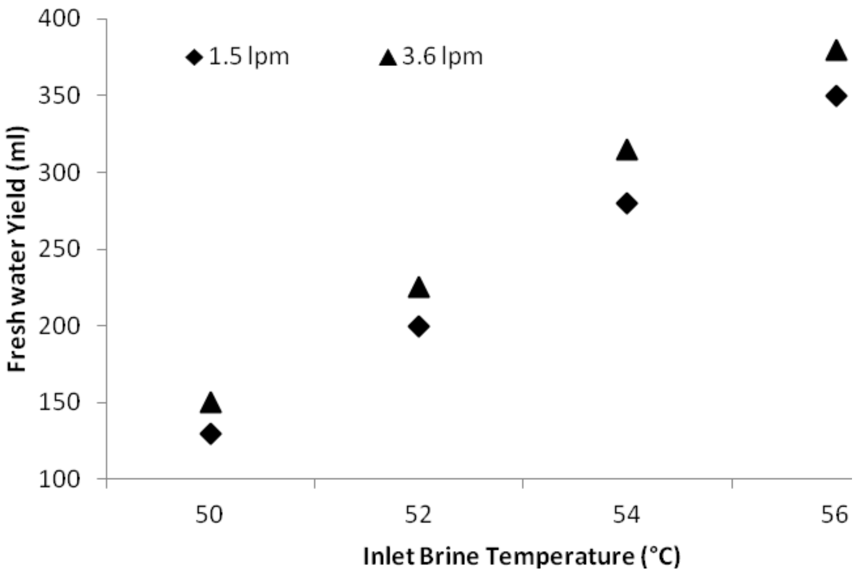

Fig. 4. Effect of Inlet Brine Temperature on Fresh Water Yield at 0.1 bar

The variation of the inlet brine water temperature on the fresh water yield at an evaporator pressure of 0.08 bar and 0.1 bar is shown in Fig. 5. It is seen that the fresh yield increases with decrease in the evaporator pressure. At an inlet brine temperature of 56°C and flow at the rate of 3.6 lpm, the fresh water yield at the evaporator pressure of 0.1 bar is 380 ml and at the evaporator pressure of 0.08 bar is 558 ml.

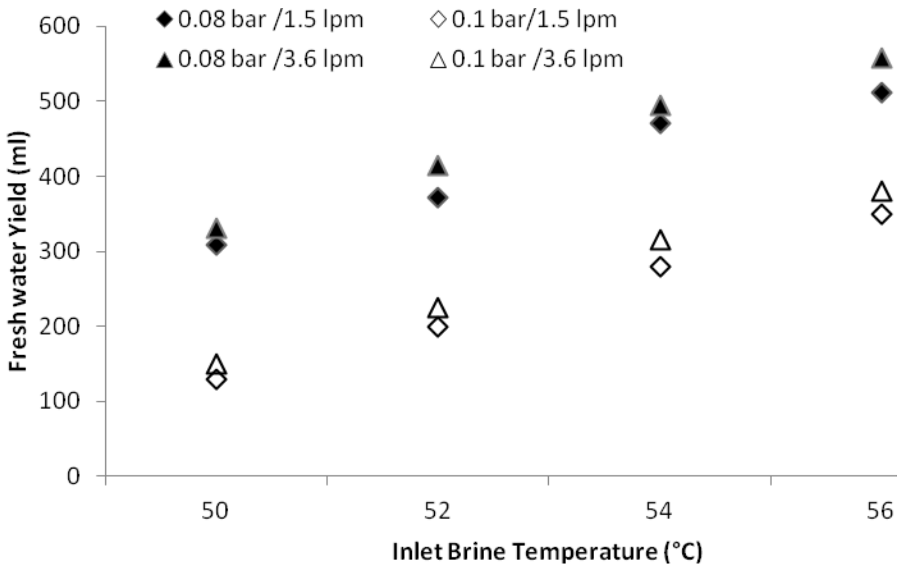

Fig. 5. Effect of Inlet Brine Temperature on Fresh Water Yield at Various Evaporator Pressures

Fig. 6. Shows the variation of the evaporator temperature, return brine temperature, inlet and outlet water temperatures in the condenser and the fresh water temperature during the operation of the system at various brine inlet temperatures and a constant evaporator pressure of 0.08 bar. The return brine temperature while the inlet brine water is injected at 56°C is around 35.76 °C and the fresh water temperature is 32.64°C. The return brine temperature can be improved by insulating the evaporator and reducing the lossed to the ambient atmosphere. The increase in this energy recovery will improve the efficiency of the system under continous operation.

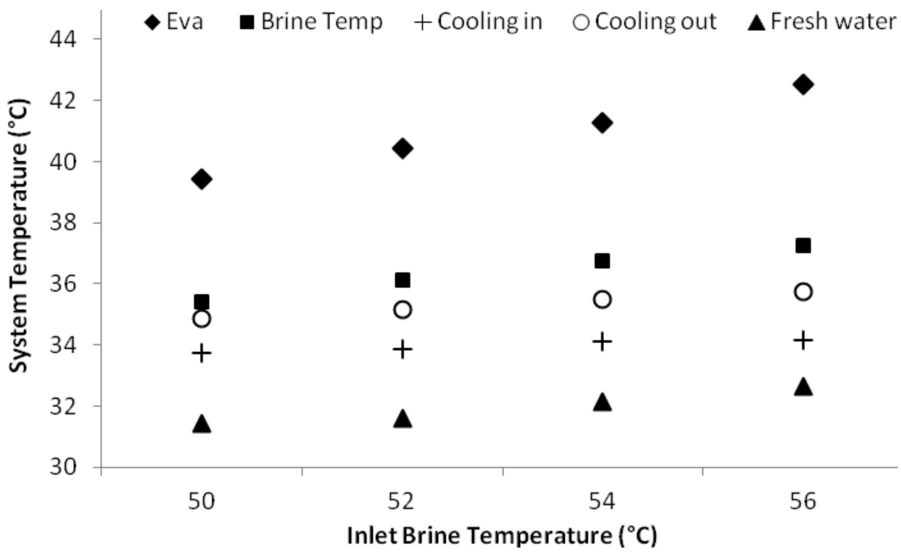

Fig. 6. Effect of Inlet Brine Temperature on other System Temperatures

The variation of the yield ratio at various inlet brine water temperatures for an evaporator pressure of 0.08 and 0.1 bar when the inlet feed water flow rate is 1.5 liters/min is shown in Fig. 7. For the same feed water flow rate, the yield ratio increases by 31-57% when the evaporation pressure is decreased from 0.1 bar to 0.08 bar depending on the inlet brine temperature.

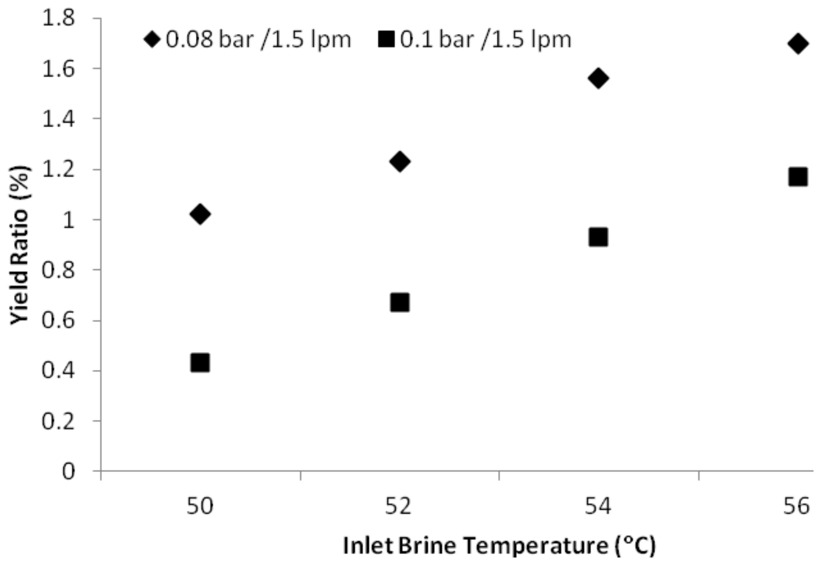

Fig. 7. Effect of Inlet Brine Temperature on Yield Ratio at Various Evaporator Pressures

Fig. 8. Shows the variation of the yield ratio at various inlet brine water temperatures for an evaporator pressure of 0.08 and 0.1 bar when the inlet feed water flow rate is 3.6 liters/min. For the same feed water flow rate, the yield ratio increases by 32-54% when the evaporation pressure is decreased from 0.1 bar to 0.08 bar depending on the inlet brine temperature.

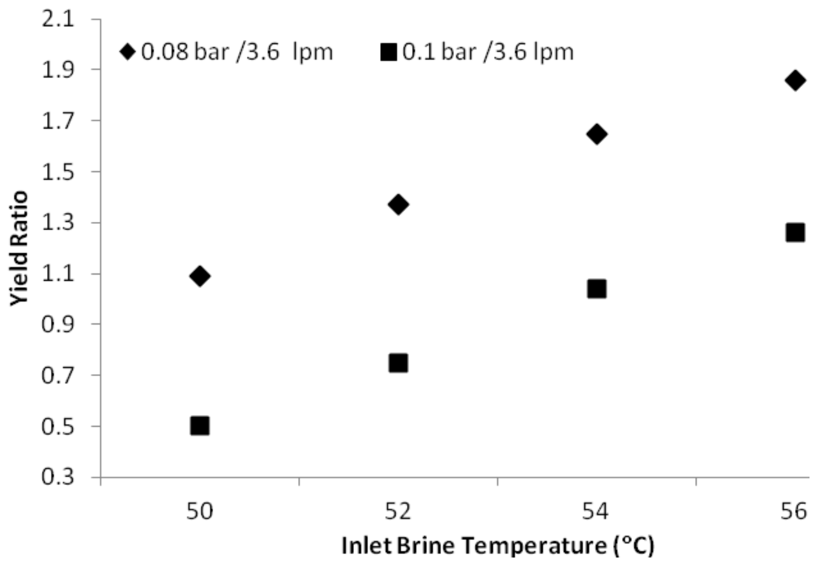

Fig. 8. Effect of Inlet Brine Temperature on Yield Ratio at Same Flow Rate

The fresh water produced was tested for its salinity and pH to determine its conformity with the safety standards of drinking. The salinity of the fresh water was measured using a flame photometer of measurement accuracy of 1 ppm and the pH ranged from 200-400 ppm. The pH of the fresh water generated ranged between 6.9 -7.2 when measured with a pH meter of measurement accuracy 0.01. The quality of fresh water is within the acceptable standards of safe drinking water making the fresh water produced a suitable for drinking.

V. CONCLUSIONS

The performance of a single stage solar desalination system based on input parameters such as vacuum pressure in the evaporator, inlet brine water temperature and feed water flow rate is experimentally analyzed. The results show that the system is capable of producing 4 l/h of fresh water at an evaporator pressure of 0.08 bar. The fresh water yield increased by 30-50 % with decrease in pressure in the evaporator and an increase in 20-35% when the inlet brine water temperature is increased. Also a 10% increase in yield is seen by increasing the inlet feed water flow rate. The quality of the fresh water is well within the acceptable standards of drinking which shows the feasibility of this small-scale system in the generation of potable drinking water in coastal and arid areas.

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