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Desalination coupled with salinity-gradient solar ponds

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Abstract

Thermal desalination by salinity-gradient solar ponds (SGSP) is one of the most promising solar desalination technologies. Solar ponds combine solar energy collection with long-term storage and can provide reliable thermal energy at temperature ranges from 50 to 90°C. Solar-pond-powered desalination has been studied since 1987 at the El Paso Solar Pond Project, El Paso, Texas. From 1987 to 1992, the research mainly focused on the technical feasibility of thermal desalination coupled with solar ponds. Since 1999, the research has focused on long-term reliability, improvement of thermodynamic efficiency, and economics. During this period, a small multi-effect, multi-stage flash distillation (MEMS) unit, a membrane distillation unit, and a brine concentration and recovery system (BCRS) were tested over a broad range of operating conditions. The most important variables for the MEMS operation were flash range, concentration level of reject brine, and circulation rate of the first effect. The brine concentration and recovery system is part of the goal of developing a systems approach combining salinity-gradient solar pond technology with multiple process desalination and brine concentration. This systems approach, called zero discharge desalination, proposes concentrating brine reject streams down to near NaCl saturated solutions and using the solution to make additional solar ponds. In addition to presenting the test results on the MEMS and BCRS units, this paper also presents a summary of solar pond operation experiences obtained from the 16-year operation at the El Paso solar pond.

Keywords: Solar desalination; Solar pond; Thermal processes; Low-temperature processes; Brine concentration; Zero discharge desalination

1. Introduction

As water shortage becomes one of the major problems worldwide, desalination will increasingly be required to meet growing demands for fresh water. Desalination technologies have been developed rapidly during the past several decades for desalting a variety of raw waters (seawater, brackish ground water, and industrial wastewater). Among the desalination technologies, thermal desalination, including multi-stage flash distillation (MSF) and multi-effect distillation

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(MED) is the current leading desalination process. In 1996, the total capacity of thermal desalination represented about 70% of the world total of seawater desalination capacity [1]. Thermal desalination is an energy-intensive process. According to some studies, thermal desalination consumes approximately 1.3 kWh electricity and 48.5 kWh heat for each m^3 of desalinated water (3% electricity and 97% heat) [2]. As costs for energy rise and carbon emission reduction is legislated, it becomes increasingly important to lower traditional energy requirements for desalination by making use of solar energy and/or low-cost waste heat. In most arid and semi-arid areas, such as the southwestern area of the United States and most of the Middle East and North Africa (MENA), there is a shortage of fresh water and an abundance of solar radiation. Solar-powered desalination can and should play an important role to help solve the water problems in these regions.

During the past two decades, a substantial amount of research into solar energy desalination has been undertaken [3,4]. Thermal desalination by salinity-gradient solar ponds (SGSP) is one of the most promising solar desalination technologies. Compared with other solar desalination technologies, solar ponds provide the most convenient and least expensive option for heat storage for daily and seasonal cycles. This is very important, both for operational and economic aspects, if steady and constant water production is required. The heat storage allows solar ponds to power desalination during cloudy days and nighttime. Twenty-four hour a day operation allows desalination units of half the size to produce water relative to other solar desalination options. Another advantage of desalination by solar ponds is that they can utilize what is often considered a waste product, namely reject brine, as a basis to build the solar pond. This is an important advantage when considering solar ponds for inland desalting for fresh water production or brine concentration for use in salinity control and environmental cleanup applications.

Desalination by salinity-gradient solar ponds and has been studied in the US, Israel, and several other countries [5–9]. In the US the previous research on thermal desalination powered by salinity-gradient solar ponds has been conducted mainly at The University of Texas at El Paso since 1987, through the support of the US Bureau of Reclamation.

2. Salinity-gradient solar pond

SGSP combine solar energy collection with long-term storage. They are simple in design and low in cost. Such ponds may be a reliable source of heat for a wide range of industrial and agricultural applications such as process heating, space heating, desalination, and electricity generation. A typical salinity-gradient solar pond has three regions. The top region is called the surface zone, or upper convective zone (UCZ). The middle region is called the main gradient zone (MGZ), or nonconvective zone (NCZ). The lower region is called the storage zone, or lower convective zone (LCZ).

The lower zone is a homogeneous, concentrated salt solution that can be either convecting or temperature stratified. Above it the NCZ constitutes a thermal-insulating layer that contains a salinity gradient. This means that the water closer to the surface is always less concentrated than the water below it. The surface zone is a homogeneous layer of low-salinity brine or fresh water. If the salinity gradient is large enough, there is no convection in the gradient zone even when heat is absorbed in the lower zone because the hotter, saltier water at the bottom of the gradient remains denser than the colder, less salty water above it.

Because water is transparent to visible light but opaque to infrared radiation, the energy in the form of sunlight that reaches the lower zone and is absorbed there can escape only via conduction. The thermal conductivity of water is moderately low, and if the gradient zone has substantial thickness, heat escapes upward from the lower zone very slowly. The insulating properties of the gradient zone, combined with the high heat capacity of water and large volume of water, make the solar pond both a thermal collector and a long-term storage device.

The thermal efficiency of solar ponds, which is defined as the ratio of heat removal rate from the LCZ to solar energy incident on the pond surface, is mainly affected by clarity of pond water, pond configuration — especially the depth of the gradient zone — and temperature difference, ΔT, between the lower zone and surface zone. The greater the ΔT, the lower the thermal efficiency because of more heat losses at higher pond temperatures. For this reason, solar ponds are more efficient for medium- to low-temperature thermal applications than for electric power generation in which higher temperatures (usually above 85°C) are required for operating the generator efficiently. The thickness of the storage zone (LCZ) also has an effect on the thermal performance of the ponds. The daily temperature fluctuation in a solar pond with a thicker storage zone is smaller than with a thinner storage zone. However, the pond with a thicker storage zone will have a longer start-up time. As an example, the El Paso solar pond has a 1.2 m gradient zone and 1.35 m storage zone, and the bottom temperature increased at a rate of about 1°C per day during start-up, while the temperature fluctuation in the LCZ is 1–3°C between day and night.

Solar ponds have several advantages over other solar technologies. They have low cost per unit area of collector, inherent storage capacity, and are easily built over large areas. It has been demonstrated that salinity-gradient solar ponds can be reliable heat sources at temperature levels of 50 to 90°C.

3. Operation of the El Paso solar pond

3.1. General description

The El Paso Solar Pond is a research, development and demonstration project operated by the University of Texas at El Paso and funded by the US Bureau of Reclamation and the State of Texas. The project, which is located on the property of Bruce Foods, Inc., a food canning company, was initiated in 1983. The El Paso solar pond has been in operation since 1985. It was the first in the world to deliver industrial process heat to a commercial manufacturer in 1985, the first solar pond electric power generating facility in the US in 1986, and the nation's first experimental solar-pond-powered desalting facility in 1987. In the early years the El Paso pond sustained record-breaking near-boiling temperatures that destroyed the gradient layer. New gradient establishment and management methods have since been developed to prevent such problems. Clarity and stability control strategies were developed and helped identify an optimum stability margin for maintaining a high-performance solar pond [10].

The El Paso solar pond has a surface area of 3000 m^2 (0.75 acre) and a depth of about 3.25 m (10.7 ft). The UCZ, MGZ, and LCZ are approximately 0.7 m (2.3 ft), 1.2 m (3.9 ft), and 1.35 m (4.4 ft), respectively. The pond uses an aqueous solution of predominantly sodium chloride (NaCl). Fig. 1 shows the typical density profile of the solar pond. The LCZ contains saturated or near-saturated brine with a concentration of about 26% by weight. The concentration in the UCZ (surface zone) is normally maintained at 1–4% salt by weight (10,000–41,000 mg/l).

3.2. Pond performance

The major climate conditions of El Paso are shown in Table 1. Fig. 2 shows a typical temperature profile of the solar pond. An annual

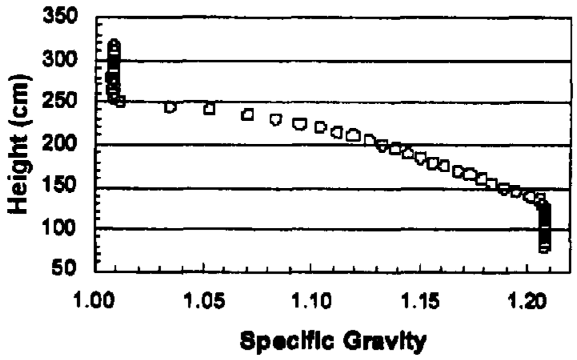

Fig. 1. Density profile of the El Paso solar pond on September 1, 1999.

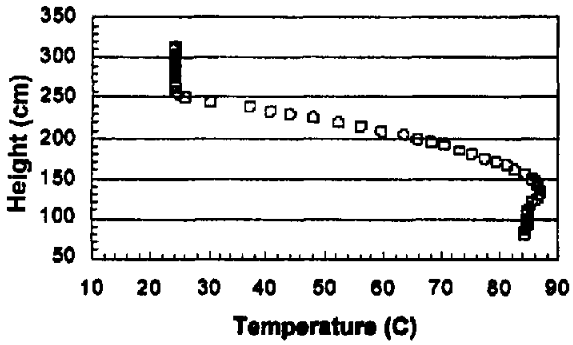

Fig. 2. Temperature profile of the El Paso solar pond (with heat extraction) on September 1, 1999.

Table 1
Climate conditions of El Paso, Texas

Month	Solar radiation, kWh/m²/d	Ambient temp., °C	Relative humidity, %	Wind speed, m/s
January	3.5	6.0	51	3.2
February	4.5	8.9	42	3.5
March	5.9	12.8	32	4.4
April	7.1	17.4	27	4.4
May	7.8	22.1	27	4.1
June	8.0	26.9	30	3.5
July	7.4	27.9	44	3.2
August	6.8	26.7	48	3.0
September	5.9	23.6	51	2.9
October	4.9	17.8	47	2.8
November	3.8	11.3	47	3.1
December	3.2	6.7	52	3.0
Average	5.7	17.3	42	3.4

temperature plot for both LCZ and UCZ is shown in Fig. 3, based on the years 1991–1993. The operation temperature of the pond ranged from 70°C in winter to 90°C in early fall. The highest temperature observed at the El Paso solar pond during these years was 93°C, and the maximum temperature difference between the LCZ and UCZ was well above 70°C. The observed temperatures in the storage zone at the bottom of the pond were influenced by ambient conditions and periodic heat removal to operate testing equipment and generate electricity. During the summer months heat is specifically removed from the solar pond, usually by generating electricity in order to maintain the stability of the gradient zone and to prevent boiling. For comparison, the average ambient temperature is also shown in Fig. 3. It can be seen that the pond surface temperature is quite close to the ambient temperature for most of the year, except for the

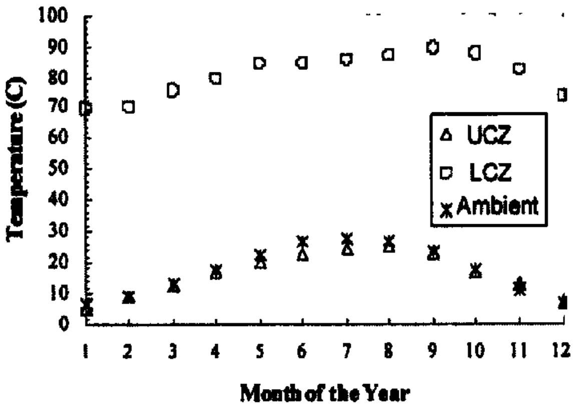

Fig. 3. Temperature development in the solar pond. UCZ, LCZ, upper and lower convective zones, respectively.

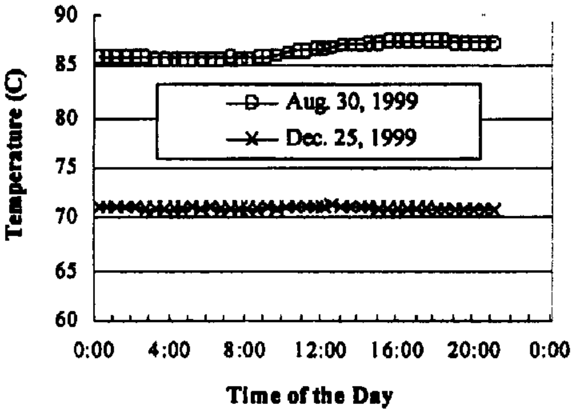

Fig. 4. Temperature variation in the LCZ of the El Paso solar pond during a day.

summer months. Then the surface temperature is several degrees lower than the ambient temperature. For this reason, the solar pond surface can be used as a cooling source for the thermal desalting processes.

The temperature of the LCZ varies seasonally, as shown in Fig. 3. However, its variation between day and night is about 1–3°C due to the thermal storage capacity in the pond. As examples, two daily temperature plots (August 30, 1999, and December 25, 1999) are shown in Fig. 4. This is a very important factor for providing a steady heat supply to the thermal desalination processes. During a typical day in the summer (Fig. 4), the storage zone temperature starts to increase at about 8 AM and stops increasing at about 8 PM. The bottom temperature can increase up to 3°C a day during the spring heating season if no heat is extracted. More generally, the rate of heating of the storage zone is proportional to the incoming solar radiation and inversely proportional to the thickness of the storage zone. The thickness of the storage zone can be increased to increase the storage capacity or decreased to increase the temperature response.

The salinity gradient was built by utilizing the scanning injection technology which was developed by the El Paso Solar Pond Project. The procedure consists of partially filling the pond with saturated brine and injecting fresh water in a scanning step-by-step fashion through a diffuser that is immersed within the existing solution. With these new techniques, the salinity gradient was built with great ease, was less labor-intensive and less time-consuming. Most importantly, the achieved salinity profile was much smoother and matched well with the desired profile. It took 4 days to build the gradient. A transient temperature gradient became established immediately after the salinity gradient was established, and the bottom temperature of the pond increased at an average rate of about 1°C per day. In about 2 months, the bottom temperature reached 80°C [11].

The heat from a solar pond is usually extracted in one of two ways. The first method is to pump the hot brine from the storage zone of the pond to a heat exchanger located near the pond. The second method is to pump a heat exchanger fluid, usually fresh water, through a heat exchanger located within the LCZ of the pond. Both have advantages, but pumping the hot brine to an out-of-pond heat exchanger tends to be the most cost-effective and trouble-free system. At the El Paso solar pond, brine withdrawal is the method used for heat extraction, and this method has been shown to be effective. Hot brine is pumped from the storage zone by means of a diffuser (extraction diffuser) mounted in the storage zone, passed through an external heat exchanger, then returned to the bottom of the pond through another diffuser (return diffuser). The extraction diffuser can be moved to the height of maximum temperature in the storage zone and the return diffuser is placed at the pond bottom. This method allows placement for both the extraction and return diffusers near the point of use, reducing pipe cost. Also, this method insures that the cooler brine is returned to the bottom, reducing ground losses, and that the piping can be easily removed for inspection and repair.

Both suction and return diffusers are double-plate diffusers. The suction diffuser is mounted under the deck of the instrumentation tower, among the four columns, and 20 cm below the lower boundary (see Fig. 2). The lower plate of the suction diffuser is circular, 76 cm (30") in diameter, and the upper plate is a square of 102 cm × 102 cm (40" × 40"). The two plates are spaced at 15 cm (6") apart. The opening of the diffuser is covered with stainless steel screen to prevent the piping system from sucking in debris.

The return diffuser is placed at the pond bottom about 15 m (50') away from the instrumentation tower, on a gravel bed. The gravel bed is about 10 cm (4") thick, and below the gravel lies a piece of 10-mil polypropylene which covers the sand and prevents it from being washed away by the brine exiting the diffuser. Both upper and lower plates of the diffuser are circular, 122 cm (48") in diameter. The gap between the two plates is also 15 cm (6"). The maximum withdrawal flow rate for this design is 2.3 m^3/min (600 gpm), and at this flow rate the exiting velocity is less than 7 cm/s.

4. Desalination research at the El Paso Solar Pond Project

4.1. Brief history

From 1987 to 1992, the research was mainly focused on the technical feasibility of thermal desalination coupled with solar ponds. During this time, two falling-film, multi-stage, flash (MSF) distillation units (Spin-flash) were tested intermittently during the periods of 1987 to 1988 and 1990 to 1992, respectively [12–15], and a multi-effect, multi-stage (MEMS) distillation unit (Licon unit) with a vapor compression unit was tested for a short period of time in 1992 [16].

Since 1999, the research has been focused on long-term reliability of this technology and the improvement of its thermodynamic efficiency and economics in order to make it more cost-effective and competitive with other desalination options. During this time, a small multi-effect, multi-stage flash distillation (MEMS) unit and a thermal membrane distillation unit were tested over a broad range of operating conditions, including feed water source, operating temperature, and concentration of reject brine.

Currently, a brine concentration and recovery system (BCRS) is under testing at the El Paso solar pond. The BCRS is driven by the thermal energy from the solar pond, producing a near-slurry salt discharge. The salt discharge is then used to recharge the solar pond. The goal of this test is to develop a “zero discharge desalination system” by combining the salinity-gradient solar pond technology with multiple process desalination and brine concentration. This systems approach addresses two critical environmental issues for desalting plants, especially for inland locations: (1) reusing the brine concentrate, thereby negating the need for disposal (zero discharge); and (2) providing additional pollution-free renewable energy for the desalting processes [17].

4.2. Testing of MEMS unit

The MEMS unit tested in this project is a three-effect, four-stage flash distillation unit which was originally designed for producing high-quality distilled water from saline or brackish water at the rate of about 1 gal/min. The advantages of the MEMS unit are multi-stage operation, use of low-quality heat energy, and robust design. Unlike conventional evaporators that use vacuum pumps, this unit employs jet-pumps (eductors) to produce evacuation. The eductors work by converting pressure head in the entraining stream to velocity head in the suction chamber. In the parallel section velocity head is converted back to pressure head and the suction stream entrained. Jet pumps have an advantage over vacuum pumps in having no moving parts. The evaporator and condenser shells are constructed of fiberglass materials, which are strongly resistant to corrosion. In efforts to further minimize corrosion, the tube heat exchanger bundles are constructed of stainless steel and titanium alloys. Such features help to lower maintenance and assist trouble-free operation, consequently leading to a longer unit life and lower operation and maintenance costs. It must be mentioned that the unit being tested at the El Paso Solar Pond is a small unit designed for testing the technology; it does not have the capacity or performance ratio of a full-scale system.

The performance tests were conducted during the period of August through December 1999. The MEMS was tested with five different feed waters: (1) solar pond surface brine, (2) underground water at the solar pond site, (3) brine with similar salinity as seawater, (4) Rio Grande water, and (5) underground water from east El Paso, TX. As an example, Table 2 shows the chemical analysis of a feed water sample (solar pond surface water).

Table 2
Chemical analysis of feed water

Parameter, mg/l	Solar pond surface water
Total hardness as $CaCO_3$	1,250
Calcium as $CaCO_3$	1,000
Total solids	17,300
Total dissolved solids	17,100
Suspended solids	120
Chloride	13,000
sulfate	180
Sodium	6,670

The tests were conducted at various operating conditions, mainly different salinity of the concentrate (therefore different recovery ratios), and different temperature levels (therefore different heat input to the unit). Two cooling modes were used in the tests: a cooling tower and the solar pond surface brine. The major operating parameters are summarized in Table 3.

Distillate production rate ranged from 1.63 to 5.0 l/min (0.43 to 1.32 gal/min). The MEMS unit contains a conductivity probe that automatically controls the quality of distillate. Distillate is not produced by the unit until the quality is above the set limit. For all the test results shown the quality switch was set at 100 μS (~50 mg/l TDS). Once the set minimum quality is reached, MEMS begins producing water, typically with a quality of <2 mg/l TDS. Because of the high quality of the distillate, MEMS production rates could be increased substantially by blending.

The relationship between distillate production rate and operating conditions was analyzed statistically with JMP software, developed by the SAS Institute, Inc. A model was built to predict production rate from the measured independent variables. Of the 13 independent variables, three were found to be statistically significant at the 95% confidence level. The significant variables are: flash range, concentration level of reject

Table 3
Major operating parameters

Parameter	Test range
Heat source (solar pond brine):	
Temp., °C	77–87
Flow rate, l/min	15–2,470
Cooling:	
Inlet temp., °C	11–36
Flow rate, l/min	30–130
Feed water:	
TDS, mg/l	1,400–58,000
Temp., °C	12–28
Reject concentrate:	
TDS, mg/l	3,000–311,000
Temp., °C	35–51
Distillate product:	
TDS, mg/l	2–14
Temp., °C	24–43
Top brine temp., °C	63–80
Flash range, °C	16–37
Vacuum, mm of Hg	560–610

Table 4
Major factors

Parameter	Production rate	Performance ratio
Solar pond brine temp.	O	O
Solar pond brine flow rate	O	O
Top brine temp.	O	O
Flash range	X	X
Feed water TDS	O	O
Feed water temp.	O	O
Reject brine TDS	X	O
Reject brine temp.	O	O
Cooling water temp.	O	X
Distillate TDS	O	O
Distillate temp.	O	X
Water circulation rate of 1st effect	X	O
Vacuum level	O	O

X = significant effect.
O = no significant effect.

brine, and circulation rate of the first effect. (See Table 4.)

Based on this model, the production rate can be expressed as the equation below:

$$PD = -0.964353 + 0.0688765*(FR) - 0.000002*(COR) + 0.02679032*(CS1)$$

where PD is the production rate, (l/min), FR the flash range, (°C), COR the concentration of reject brine, (mg/l), and $CS1$ is the circulation rate of brine in the first stage (l/min).

The relationship between performance ratio (PR), which is defined as the pounds of distillate produced per 1000 Btu of thermal energy input, and operating conditions, was also analyzed statistically with the JMP software. A model was built to predict performance ratio from the measured independent variables. Of the 13 independent variables three were found to be statistically significant at the 95% confidence level. The significant variables are: flash range, temperature of reject brine, and temperature of distillate. There are no significant effects by other factors. (See Table 4.)

Based on this model, the performance ratio, can be expressed as the equation below:

$$PR = 6.81729121 - 0.0696854*(FR) + 0.12534092*(TOD) - 0.1545689*(TOR)$$

where FR is the flash range, (°C), TOD the temperature of distillate, (°C), and TOR is the temperature of reject brine, (°C).

The MEMS produced high-quality distillate. For most cases, the TDS level of the distillate was less than 5 mg/l TDS. It was also found that operating conditions did not significantly influence the quality of distillate product. This is consistent with the result obtained from the testing in 1992 [16].

Scaling and corrosion are major concerns for long-term operation of the equipment. The

MEMS unit was designed with features such as the eductors, fiberglass evaporators, stainless steel and titanium alloy heat exchanger bundles in order to minimize scaling and corrosion problems. Low-temperature operation is known to minimize scaling [18, 19].

Visual observations (white color deposit in the third-stage condensing bundle) indicated that some scaling occurred. In order to examine the effect of scaling on performance, time of operation was used as one of the independent variables in the statistical analysis. Presumably scaling should increase over time; thus time of operation can be used as a statistical analog for scaling. The statistical analysis indicated that time of operation (scaling) was not a significant factor for both production rate and performance ratio. This indicates that the limited scaling that occurred during operations did not significantly affect performance of the unit.

The tests demonstrated that the solar pond surface water is an effective cooling source for the MEMS operation. Cooling with the pond surface water has some advantages over the cooling tower. First of all, it can reduce electricity consumption. In this test the electricity consumption was reduced about 10% by cooling with pond surface water. Secondly, using the pond surface water can get a better cooling effect since the pond surface has a lower temperature than the cooling tower water during summer months. During the test in August 1999, the cooling tower water was well above 35°C (95°F). However, during the same period of time the pond surface temperature was below 30°C (86°F). With a lower cooling temperature, the flash range will increase. This effect will improve both the production rate and performance ratio, as indicated by the statistical models.

4.3. Testing of BCRS unit

The brine concentration and recovery system tested in this project is a unit that was reconstructed and revised from a brine concentrator designed by Frontier AquaDynamic and EIG [20]. The unit consists of an approximately 12 m (40') long spray evaporation chamber supporting a 9 m (30') high condenser tower for condensate water recovery. The brine concentrator was originally designed to use moderate temperature thermal energy to drive evaporative concentration of saline waste streams. In addition, the BCRS incorporates a condensation tower to recover some fresh water. One of the major technical problems in attempting to concentrate high total dissolved solids (TDS) brines is scale build-up and equipment fouling. In order to minimize the tendency for concentrates to foul heat exchanger surfaces, the BCRS maintains low thermal gradients, low temperatures, and evaporates water droplets in the air rather than on a surface. This causes the nucleation crystals, generally in the 80–120 micron size range, to form in solution rather than on surfaces. Low temperatures are made possible by the utilization of large quantities of airflow through the system. The BCRS obtains the thermal energy for evaporation both through heat exchangers from the solar pond and by direct contact with the ambient air. As such, the BCRS lies intermediately between evaporation ponds and the traditional mechanical evaporators used in industry. The advantage of the system is that it is designed to process very high concentration brines using no chemicals, other than pH control.

Air enters from two sides of the unit — the warm side and the cold side. The warm side receives the initial brine to be evaporated and added thermal energy from the solar pond. Lower air flow rate, lower salinity, and higher temperature all act to increase the vapor pressure of water on this side of the unit as compared to the cold side. The warm side air exits up a plenum in the center of the top stack.

The cold side receives brine by gravity feed from the warm side. No heat exchangers are present in the cold side, providing a simple geometry to avoid fouling problems. This side acts like an evaporative cooler. The cold side air exits on the outside of the central stack, warm air plenum.

Condensation occurs in the warmed air stream as heat is transferred through the plenum walls to the cold air and as recycled condensate is cooled to the temperature of the cold side. Theoretically a high fraction of the water evaporated on the warm side can be recovered. The theoretical recovery rate for water evaporated on the warm side is good when the temperature difference between warm and cold sides is high.

A preliminary test of the BCRS was conducted in November and December 1998. In 1999 and 2000, some modifications were made to the unit to improve fresh water recovery and instrumentation. Additional tests are being conducted during the fall of 2000. The operating conditions for the current tests are listed in Table 5. In completed tests, the evaporation rates have ranged from 450 to 2270 l (120–600 gal) per hour, depending mainly upon the weather conditions. The fresh water recovery rate has been about 190 l (50 gal) per hour. Slurry salt is produced in the cold side of the unit and pumped into the solar pond bottom along with saturated brine. The testing of the BCRS unit is still in progress, and more data will be gathered and analyzed.

Table 5
Operating conditions of the BCRS unit

Parameter	Test range
Temp. of solar pond hot brine, °C	65–82
Ambient condition:	
Temp., °C	21–30
Relative humidity, %	7–50
TDS of feed water, mg/l	3,000–300,000
Brine temp. of the warm side, °C	32–41
Brine temp. of the cold side, °C	15–27

5. Conclusions

Research at the El Paso solar pond has demonstrated that a salinity-gradient solar pond can be a reliable and environmentally friendly heat and cooling source for thermal desalination and brine concentration processes.

A MEMS thermal desalination unit, operated with heat from a solar pond, appears to be a viable thermal technology to treat highly saline feed water, although full-scale operation would require units designed for greater performance ratios. The BCRS can efficiently concentrate brine to slurry or dry salt stage. The slurry is recharged into the solar pond bottom, and it is important for salinity-gradient maintenance of the solar pond. Additional water is recovered from the brine concentrate rather than becoming part of the waste-stream. Since potable water recovery from brackish water is the reason the concentrate is produced, increased production of potable water is advantageous. These results are important in realizing the long-term potential of zero discharge desalination.

The MEMS unit can be effectively operated at a first stage vapor temperature range of 60–75°C (140–167°F), and at a very high concentration ratio with the reject brine at near saturation conditions. Therefore, it can be used for desalting higher concentration brackish water, such as reverse osmosis concentrates.

The temperature level has significant effect on both production rate and performance ratio of the MEMS unit. The production rate increases, but the performance ratio decreases with both increased temperature and increased temperature difference between the first and fourth stages.

The MEMS produces high quality distillate. The total dissolved solid level of the product is about 2–3 mg/l. There is no significant influence of operating conditions on the quality of distillate.

This research provided important information and results in realizing the long-term goal of zero discharge desalination.

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