Thermal Desalination using MEMS and Salinity-Gradient Solar Pond Technology

University of Texas at El Paso
El Paso, Texas

Cooperative Agreement No. 98-FC-81-0047

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13. ABSTRACT *(Maximum 200 words)*

MEMS (multi-effect, multi-stage) flash desalination (distillation) driven by thermal energy derived from a salinity-gradient solar pond is investigated in this study for the purpose of improving the thermodynamic efficiency and economics of this technology. Three major tasks are performed: (1) a MEMS unit is tested under various operating conditions at the El Paso Solar Pond site; (2) the operation and maintenance procedures of the salinity-gradient solar pond coupled with the MEMS operation is studied; and (3) previous test data on a 24-stage, falling-film flash distillation unit (known as the Spinflash) is analyzed and compared with the performance of the MEMS unit.

The data and information obtained from this investigation is applicable to a variety of thermal desalination processes using other solar options and/or waste heat.

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Mission Statements

U.S. Department of the Interior

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to tribes.

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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1.0 EXECUTIVE SUMMARY

Multi-stage flash distillation (MSF) driven by thermal energy derived from a salinity-gradient solar pond has been studied in this research to improve the thermodynamic efficiency and economics of this technology. Three major tasks have been performed: (1) a multi-effect, multi-stage (MEMS) flash desalination (distillation) unit has been tested under various operating conditions at the El Paso Solar Pond site; (2) the operation and maintenance procedures of the salinity-gradient solar pond (SGSP) coupled with the desalination operation have been studied; and (3) previous test data on a 24-stage flash distillation unit (so-called Spinflash unit) has been further analyzed and compared with the performance of the MEMS unit.

The research provides useful data and information for improving the overall thermodynamic efficiency and economics of solar-pond-coupled MEMS desalination. The data and information obtained in this project are also very useful for thermal desalination using other solar options and/or waste heat.

2.0 BACKGROUND AND INTRODUCTION TO THE PROJECT

As water shortages become a major problem, both nationwide and globally, desalination will increasingly be required to meet growing demands for fresh water. Desalination technologies have developed rapidly during the past several decades for desalting a variety of raw waters (seawater, brackish ground water, industrial waste water). Among the desalination technologies, thermal desalination, including multi-stage flash distillation (MSF) and multi-effect distillation (MED), are the current leading desalination processes. In 1996, the total capacity of thermal desalination represented about 70 percent of the world total of seawater desalination plants. (Morton, et al., 1996) 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 water desalinated (3 percent electricity and 97 percent heat). (Mesa, et al., 1996) 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.

During the past two decades, a substantial amount of research into solar energy desalination has been undertaken (Manwell and McGowan, 1994). Thermal desalination by salinity-gradient solar ponds is one of the most promising solar desalination technologies, and has been studied in the United States, Israel, and several other countries. (Swift, 1988; Esquivel, 1992; Glueckstern, 1995) These studies have shown that for sites where conditions are favorable for salinity-gradient solar ponds, they are less costly than other solar options. Moreover, 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. 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.

Combining the salinity-gradient solar pond technology with MEMS and other desalination technologies can possibly lead to a "zero discharge" desalination process. Figure 1 shows one approach to "zero discharge." The reject concentrate from the primary desalination process, such as reverse osmosis (RO), electrodialysis (ED), or MSF, provides make-up water to the salinity-gradient solar pond (SGSP), which in turn provides feed brine to a MEMS. The highly saline brine from the MEMS will be fed to a brine concentrator and recovery system (BCRS). The BCRS is driven by the thermal energy from the SGSP, producing a near-slurry salt discharge. The salt discharge is then used to recharge the solar pond, adding to the SGSP capacity, or is processed as chemicals for use or sale. This systems approach addresses two critical environmental issues for inland desalting plants: 1) reusing the brine concentrate thereby negating the need for disposal (zero discharge); and 2) providing additional pollution-free renewable energy for the desalting process.

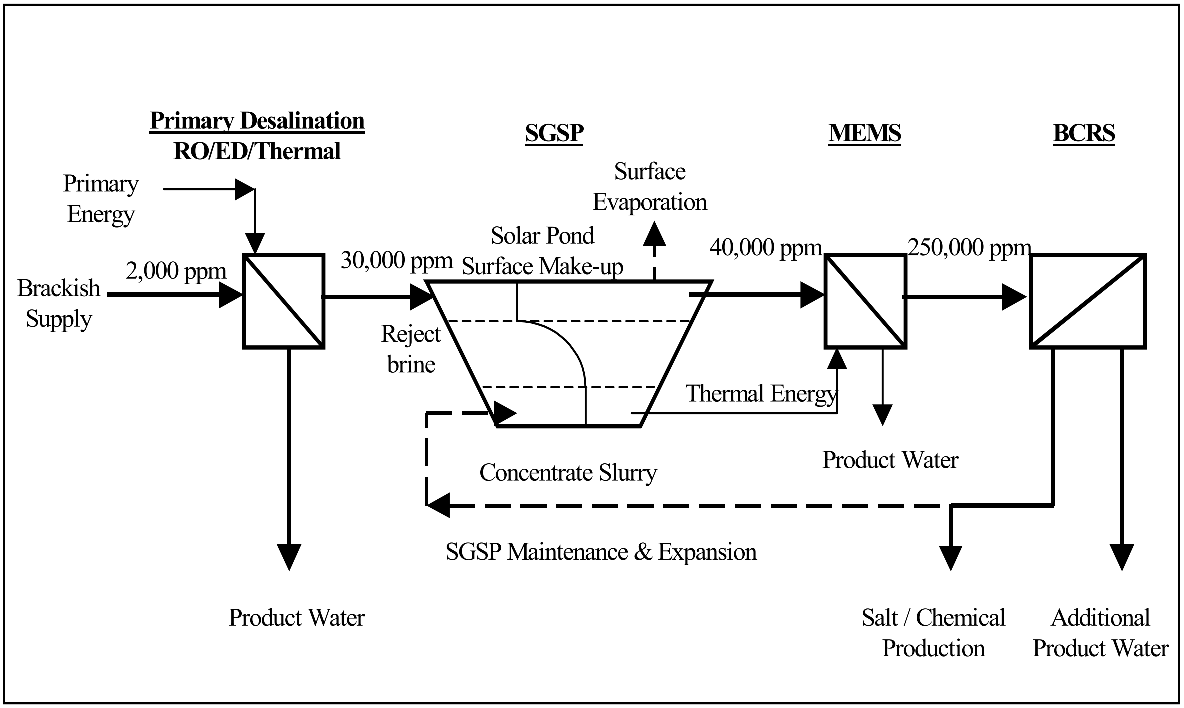

Figure 1. Schematic of Zero Discharge Desalination System

In the United States, the previous research on thermal desalination powered by salinity-solar ponds was mainly conducted at The University of Texas at El Paso (UTEP) through the support of the U.S. Bureau of Reclamation. Two falling-film, multi-stage flash (MSF) distillation units (Spinflash) were tested intermittently during the periods of 1987 to 1988 and 1990 to 1992, respectively (Kyathsandra, 1988; Li, 1992; McElroy, 1993), 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 at the El Paso Solar Pond site. These previous tests focused on the technical feasibility of thermal desalination coupled to solar ponds. The technical feasibility of desalination using thermal energy from solar ponds has been proven. However, this technology is still in the development stage, and past demonstration plants have experienced operational difficulties (Thomas, 1997). In order to demonstrate long-term reliability of this technology, and most importantly, to improve its thermodynamic efficiency and economics, to make it more cost-effective and competitive with other desalination options, additional research is needed.

The objectives of this project are to determine the thermodynamic performance and economics of multi-effect, multi-stage (MEMS) flash desalination driven by the thermal energy derived from a solar pond and to test and demonstrate the long-term reliability of this operation. The major task of this project is to operate and test a MEMS unit under different operational conditions including heat input, temperature level, and raw water sources. This MEMS unit was installed at the El Paso Solar Pond site in October 1997, but has only undergone limited testing prior to this project. In order to determine the relationship between the performance of the MEMS unit and operational conditions, extensive tests were conducted and data were collected and analyzed. In addition to the test of the MEMS unit, the solar pond operation and maintenance procedures coupled with desalination operation were also studied in order to improve and optimize overall efficiency and economics of solar-pond-coupled thermal desalination. Also, for gaining a better understanding of the solar-pond-coupled thermal desalination technologies, the previous test data on a 24-stage flash distillation unit (Spinflash unit) were further analyzed and compared with the performance of the MEMS unit.

This project made productive use of predominately existing facilities at the University of Texas at El Paso to perform research tests and to collect operational data. The research work provides definitive data and information on the economics and technical performance of solar-pond-coupled thermal desalination. These data and information are also useful for improving thermodynamic efficiency and economics for other solar and/or waste heat thermal desalination options.

This project has a positive impact on the environment for both the short term and long term. The pond utilizes solar energy thereby eliminating fossil fuel based emissions as a source of atmospheric contamination. For the long term the technology makes use of renewable solar energy and is sustainable. Therefore, the technology itself is environmentally friendly, and if implemented would serve as a sustainable energy source for the desalination of brackish waters.

3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

- The MEMS unit can be operated successfully with thermal energy derived from a salinity-gradient solar pond.

- The MEMS unit can be effectively operated at a top brine temperature range of 65 – 80 °C (149 – 176 °F). The upper limit is determined by the material used in construction of this particular unit.

- The MEMS unit can be operated with very high concentration levels, with the reject brine at near saturation. Therefore, the MEMS unit can be used for desalting higher concentration brackish water.

- The production rate of distillate for this MEMS unit ranged from 0.43 to 1.32 gallons per minute (gpm) (1.63 to 5.00 liters per minute). A statistical analysis of the test data shows that of 13 variables measured and calculated, production rate is significantly affected only by flash range, reject concentration, and first-effect water recirculation rate. Production rate increases with flash range and first-effect water recirculation rate, but decreases with reject concentration.

- The performance ratio ranged from 1.70 to 3.72 pounds of distillate per 1000 Btu of thermal energy input. A statistical analysis for performance ratio shows that of 13 variables measured and calculated, the performance ratio is significantly affected by flash range, temperature of distillate, and temperature of reject brine. Performance ratio increases with temperature of distillate and decreases with flash range and temperature of reject brine.

- 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 the distillate.

- The solar pond surface water is an effective cooling source for thermal desalination. By using the surface water as a cooling source, the electricity consumption for the cooling loop can be reduced.

- Scaling was observed in the third stage condenser during the tests. Statistical analysis of the data indicates that the observed scaling had no significant effect upon production rate and performance ratio.

- Compared with the Spinflash unit, the MEMS unit has a lower performance ratio. This is a limitation of the MEMS unit, not the technology. The performance ratio can be increased by adding more stages. The MEMS unit is much easier to operate and maintain and requires no specific pretreatment of feed.

- These tests added confidence to the thermal desalination performance data used in a previous study. Economic analysis of a salinity gradient solar-pond-coupled desalination plant using thermal desalination and reverse osmosis technology was examined. The study showed that the salinity gradient solar-pond-coupled system produced the lowest cost water when compared with evaporation ponds and deep well injection as brine concentrate disposal alternatives. Based on this research, MEMS, operated with heat from a solar pond, appears to be a viable thermal technology to treat highly saline feed water using heat from a SGSP. This is an important result in realizing the long-term potential of zero discharge desalination.

3.2 Recommendations

- The water level of both the first and fourth flash chambers should be controlled automatically. This will make the unit operate continuously at near steady state and increase its efficiency.

- Better thermal insulation is needed on the MEMS unit to reduce heat losses and increase thermal efficiency.

- Information and data on the same type, but large-scale unit, need to be gathered in order to perform a more realistic economic analysis for large-scale desalting facilities.

4.0 DESCRIPTION OF TEST FACILITIES

4.1 Salinity Gradient Solar Pond

A salinity-gradient solar pond (SGSP) is a body of water that collects and stores solar energy. Generally, it has three regions (from top to bottom): the upper convective or surface zone; the main gradient zone (MGZ); and the lower convective or storage zone. The upper convective zone (UCZ) is a homogeneous layer of low-salinity brine or fresh water, and the lower convective zone (LCZ) is a homogeneous, concentrated salt solution that can be either convecting or temperature stratified. Inbetween is the nonconvective, main gradient zone, which constitutes a thermally insulating layer in which the salinity increases with depth (Hull, et al, 1989). Insolation is absorbed and stored in the lower levels of the pond which typically operates in the range of 60 to 90 ºC. SGSPs have the potential to produce low cost thermal energy from a renewable source at large scale for industrial applications, including desalination.

The El Paso Solar Pond (Figure 2) is a research, development, and demonstration project operated by the University of Texas at El Paso and funded by the Bureau of Reclamation and the State of Texas. The project was initiated in 1983 and is located on the property of Bruce Foods, Inc., a food canning company. The El Paso Solar Pond has been operated 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 United States in 1986, and the nation's first experimental solar-pond-powered water desalting facility in 1987. The pond has a surface area of 3000 m^2 (0.75 acre) and a depth of about 3.25 meters (10.7 feet). The thicknesses of 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. Typical density and temperature profiles for the El Paso Solar Pond are shown in Figures 3, 4, and 5, respectively.

The MEMS project was delayed from March 22, 1999 until May 15, 1999 because of the loss of the gradient in the solar pond due to inadequate salt management facilities, which have since been attended to. Prior to and during the suspension, the solar pond was partially drained while new salt was purchased and dissolved. After sufficient saturated brine was obtained, the salinity gradient was created during the week of April 5-10, 1999. Figure 5 shows the temperature history of both the UCZ and LCZ of the pond through the middle of December 1999. The temperature of the lower convective zone increased at an average rate of 1 °C (1.8 °F) per day from April 6 through June 10, 1999. After reaching an operating temperature of 85 °C (185 °F) on June 10, the pond began providing heat to the MEMS unit, as well as to an organic Rankine cycle (ORC) engine for electricity generation, a thermal membrane desalting unit, and a brine concentrator.

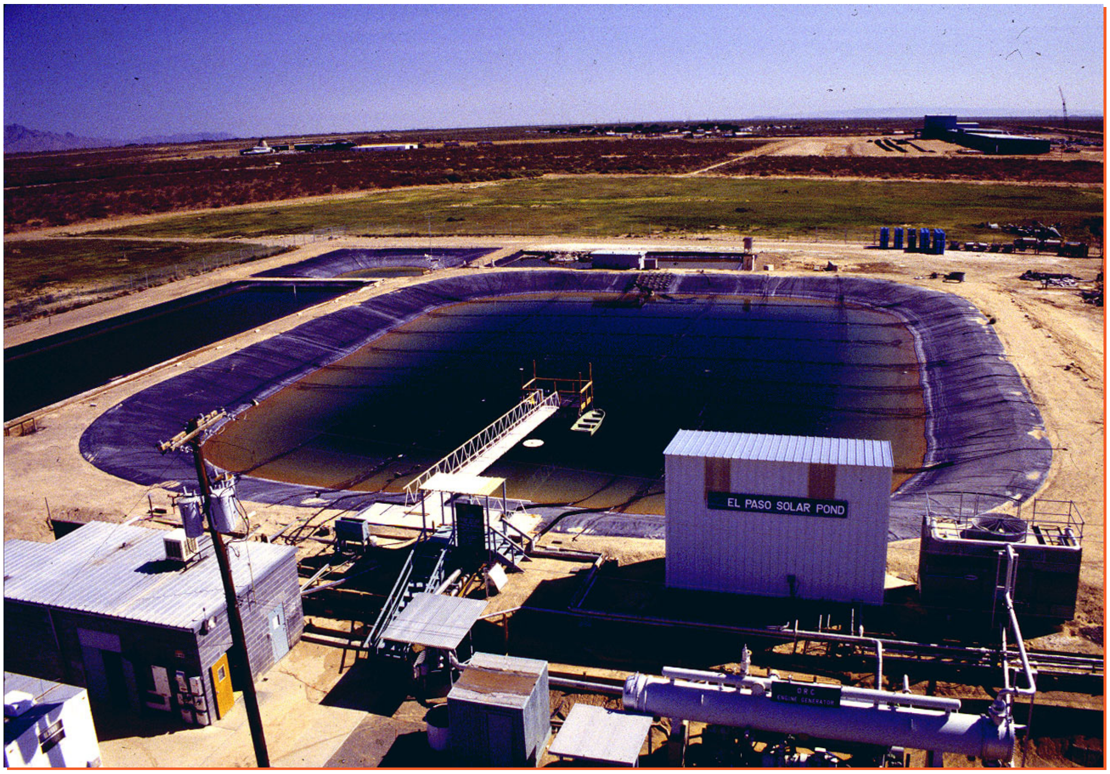

Figure 2. Picture of the El Paso Solar Pond

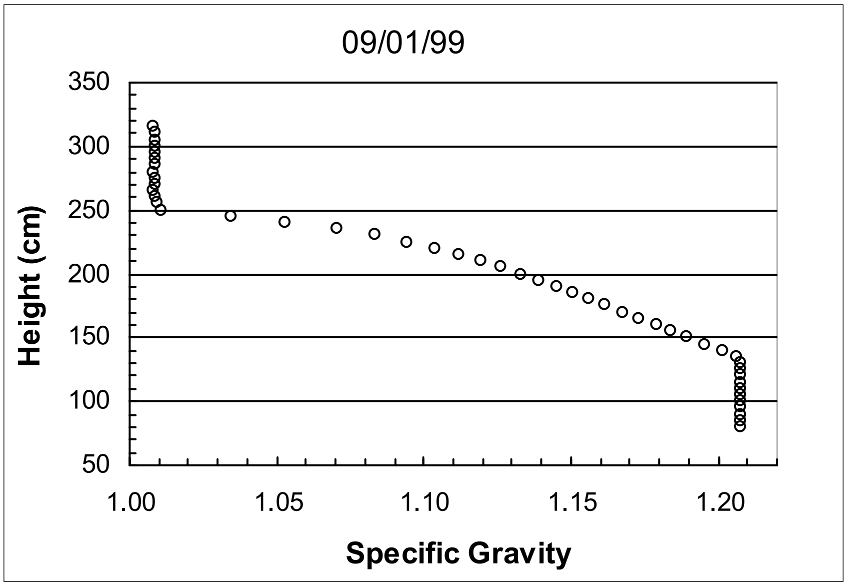

Figure 3. Specific Gravity Profile of the Solar Pond

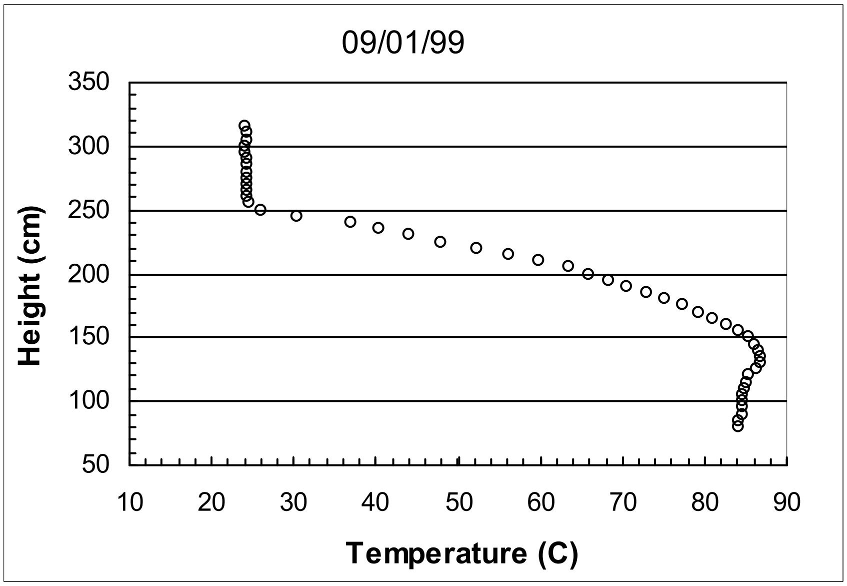

Figure 4. Temperature Profile of the Solar Pond

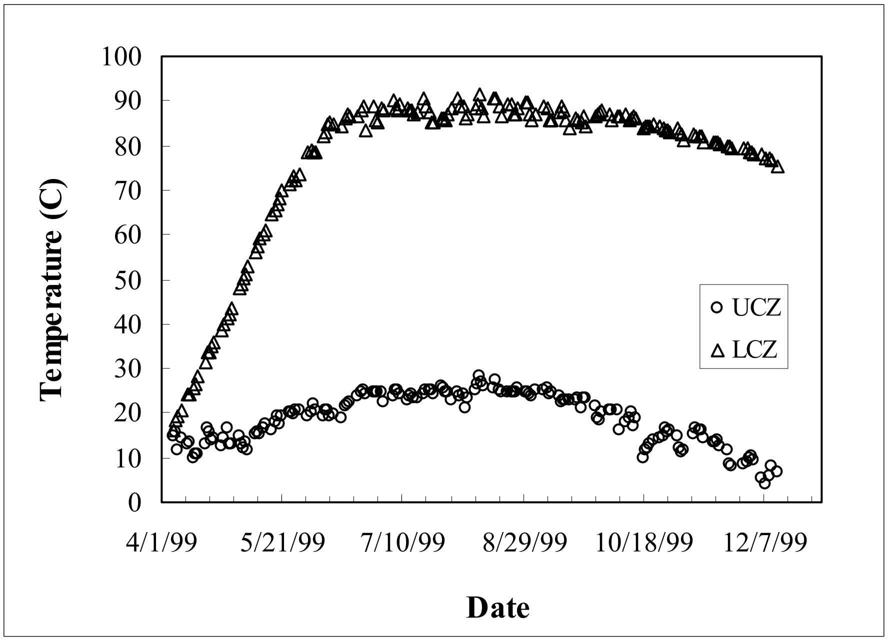

Figure 5. Temperature Development of the El Paso Solar Pond

4.2 MEMS Unit

4.2.1 Equipment Description

The multi-stage flash distillation (MSF) process makes use of the fact that water boils at progressively lower temperatures as it is subjected to progressively lower pressures. The feed water (brackish or seawater) is heated and then introduced into a chamber (so-called flash chamber) where the pressure is sufficiently low to cause some of the water to boil instantly, or "flash" into steam. Vaporization of some of the water results in lowering the temperature of the remaining brine. The brine then flows into the next flash chamber where the pressure is lower than the previous chamber, more of the water flashes into steam, and the temperature is again reduced. In order to reduce energy requirements and obtain efficiency in the recovery of thermal energy, multi-effect, multi-stage distillation (MEMS) technology has been developed. A MEMS distillation system may be considered as a series of several single-effect, multi-stage (SEMS) distillation systems with proper arrangements for the recycle loops. Each component of the SEMS system is called an effect. The water vapor evolved in an effect can then be used to heat another effect boiling at a still lower temperature and pressure. The MEMS flash distillation process appears to have several advantages over the SEMS flash distillation process in increasing the steam economy (Williamson, et. al., 1965; Cadwallader, E.A., 1964; Silver, R.S., 1966; and Fan, et. al., 1968).

The MEMS unit tested in this project is similar to the one tested in 1992, except without the vapor compression unit. It is a 3-effect, 4-stage flash distillation unit which was originally designed by W. R. Williamson and manufactured by Licon, Inc. in Pensacola, Florida for producing high quality distilled water from saline or brackish water at the rate of about one gallon per minute. 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 eductors (jet-pumps) 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. Eductors 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 an effort 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.

Figure 6 shows a picture of the MEMS unit, and Figure 7 shows its schematic and piping system. As shown in these figures, there are four flash chambers with corresponding condensing bundles in the MEMS unit. The first and second chambers make up the first effect, the third chamber is the second effect, and the fourth chamber is the third effect.

Figure 6. Picture of the MEMS Unit

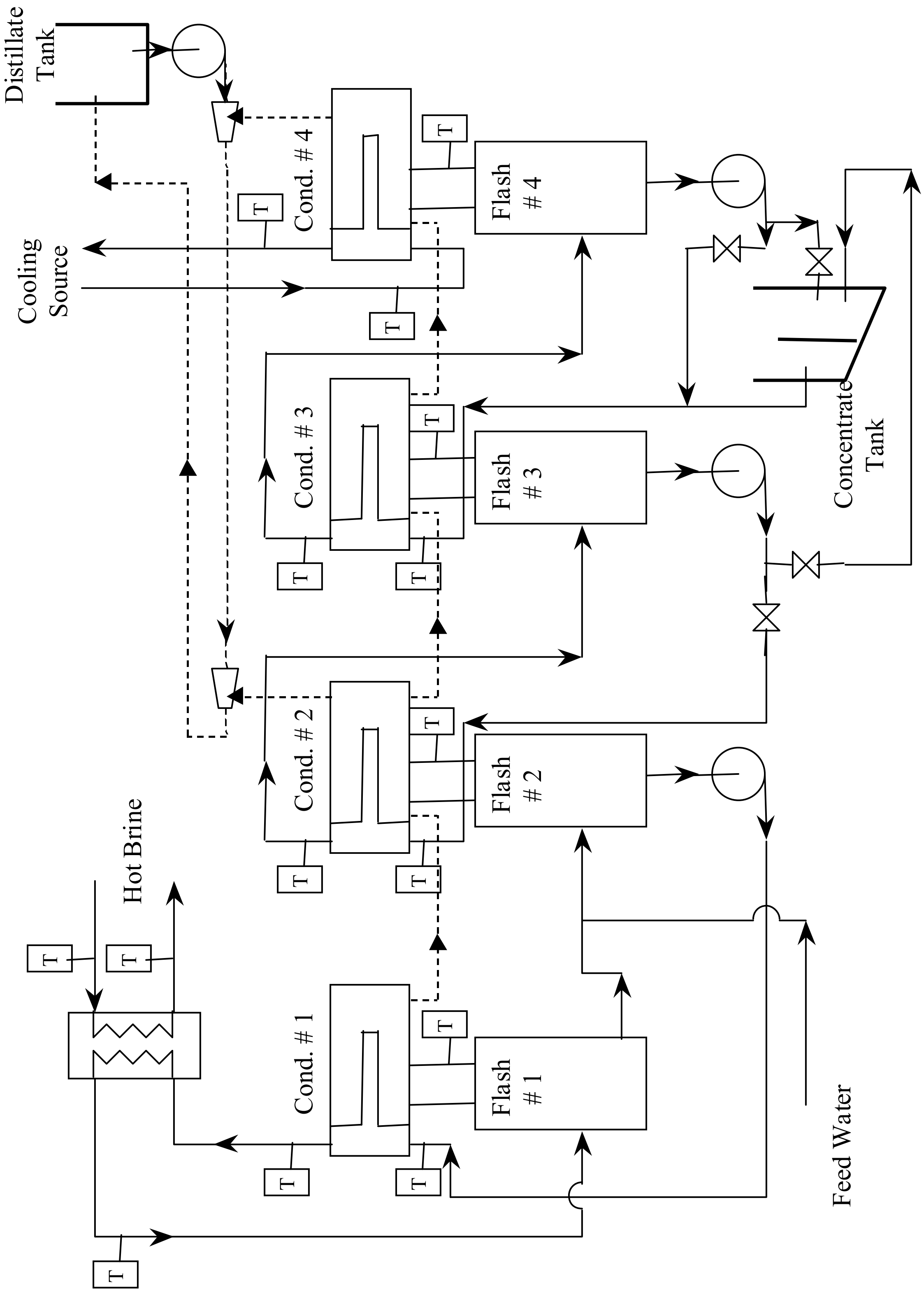

Figure 7. Schematic of the MEMS Unit and Piping System

The flash chambers (Figure 8) are fiberglass cylinders that increase progressively in diameter from 8 to 12 inches (20.3 to 30.5 cm). The diameter of each is dictated by the constraints of the separator mesh. The mesh allows vapor to cross at velocities from 18 to 25 ft/s (5.5 to 7.6 m/s). Each chamber in the series is at a lower pressure. This increases the volumetric flow rate and requires larger chambers to keep velocity within range (Barron, 1992).

Each of the four flash chambers has a corresponding condensing bundle connected by a steam duct constructed of CPVC pipe. The first stage condenser is a single pass bayonet-augmented heat exchanger, as shown in Figure 9. Although the bundle configuration pertaining to the second flash chamber is different than that of the third and fourth chambers, the three condensers are, in general, bayonet-augmented heat exchangers, but of a double-pass design. The condenser design for the second stage is shown in Figure 10, and the condenser design for third and fourth stages is shown in Figure 11. The cylindrical shells of all the condensers are constructed of 2-inch thick fiberglass and embody flanges used to assemble the bayonet configuration, as required by the design. On one or both ends of the vessel, the design provides for sight windows that are used for visual inspection of either corrosion or scaling. The condensing tube bundles used in this MEMS unit use titanium as the contact material and polypropylene as the bayoneted material. The condensers are arranged to conserve space and to allow the produced distillate to be gravity fed (in addition to vacuum dragged) from one shell to the next, see Figure 12. For more detail description about this MEMS unit, see Barron (1992).

The MEMS unit has one concentrate tank, made of polypropylene, which can withstand temperatures in excess of 180 °F (82 °C). The tank, as shown in Figure 13, is separated into two sides by a V-notch weir. The weir measures flow rate. The concentrate flows over the V-weir and through a course strainer, where it is vacuum-dragged out of the left side and into its corresponding flash chamber. A calm area is created on the right side of the tank to allow for sedimentation of crystallized solids.

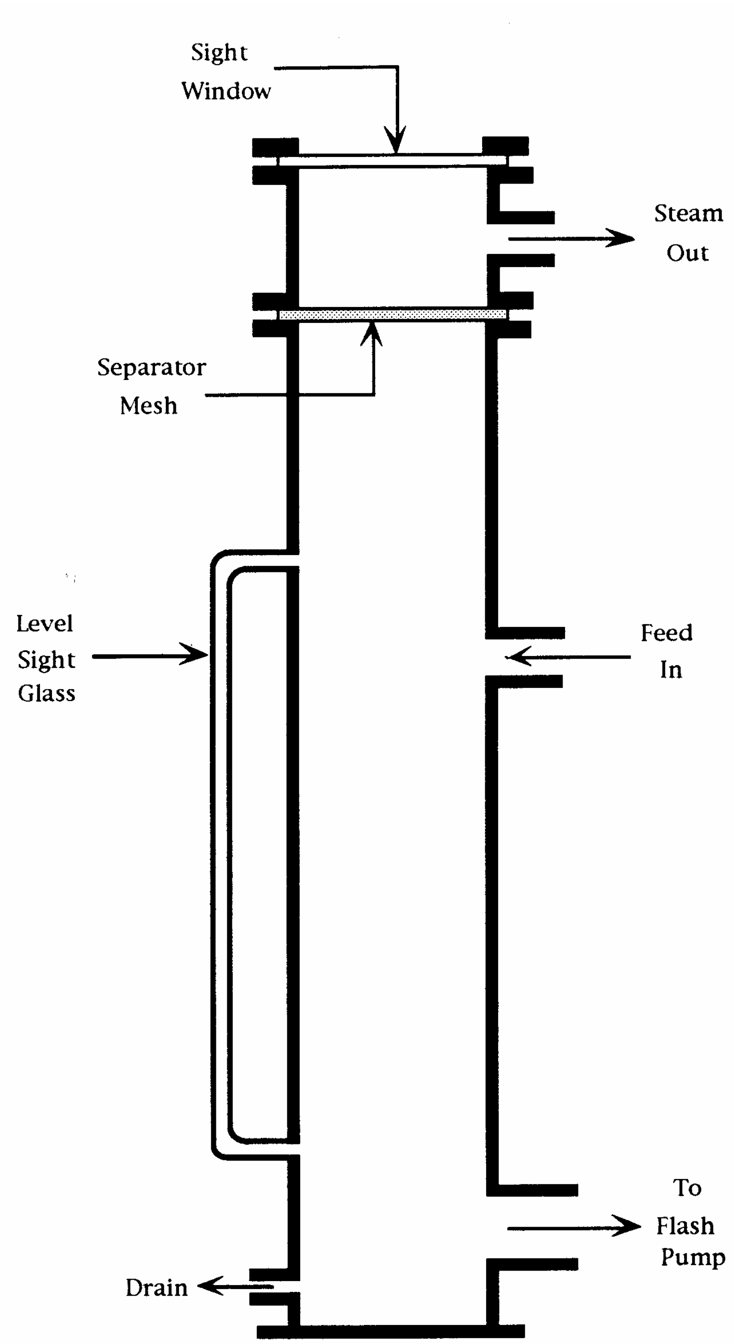

Figure 8. General Configuration of a Flash Chamber

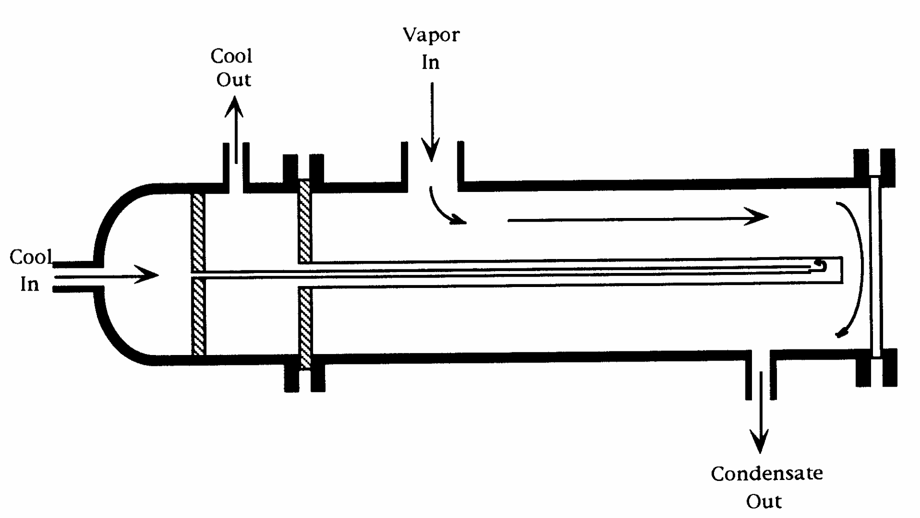

Figure 9. First Stage Condenser Configuration

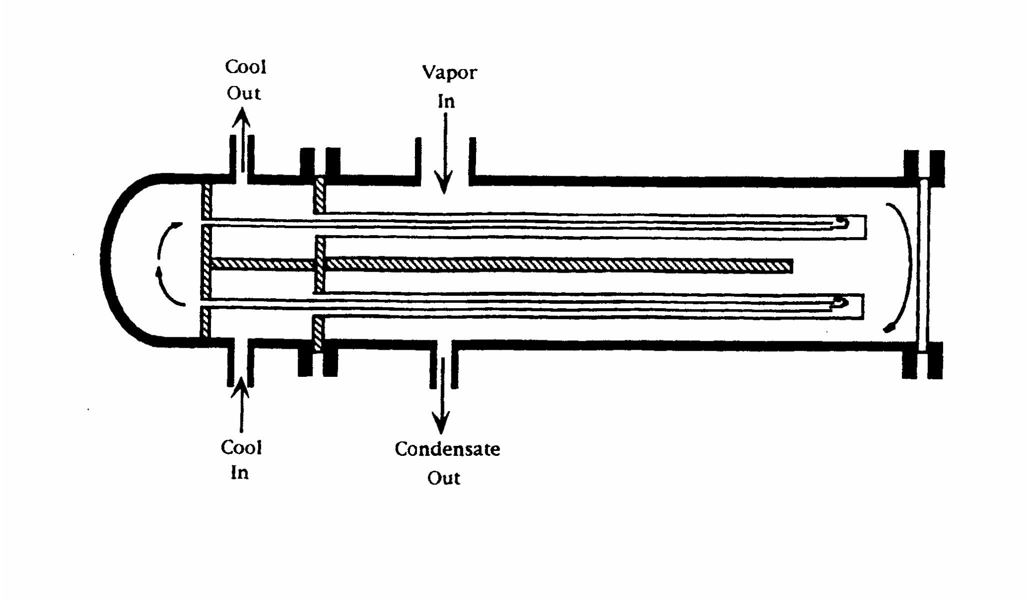

Figure 10. Second Stage Condenser Configuration

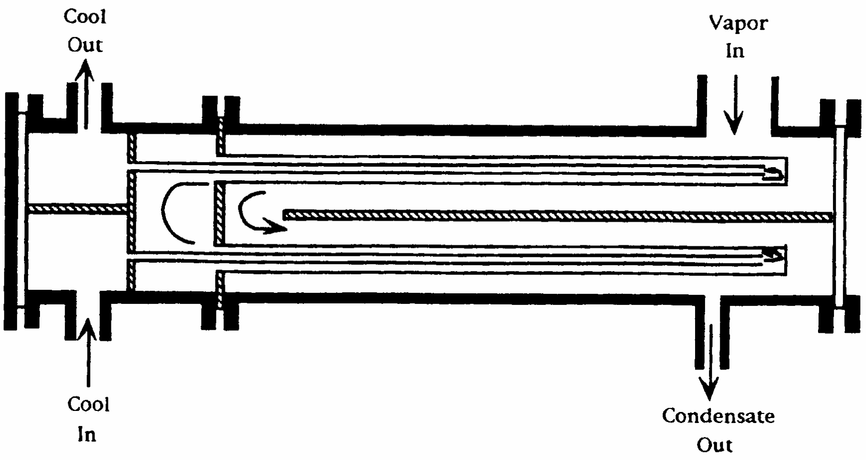

Figure 11. Third and Fourth Stage Condenser Configuration

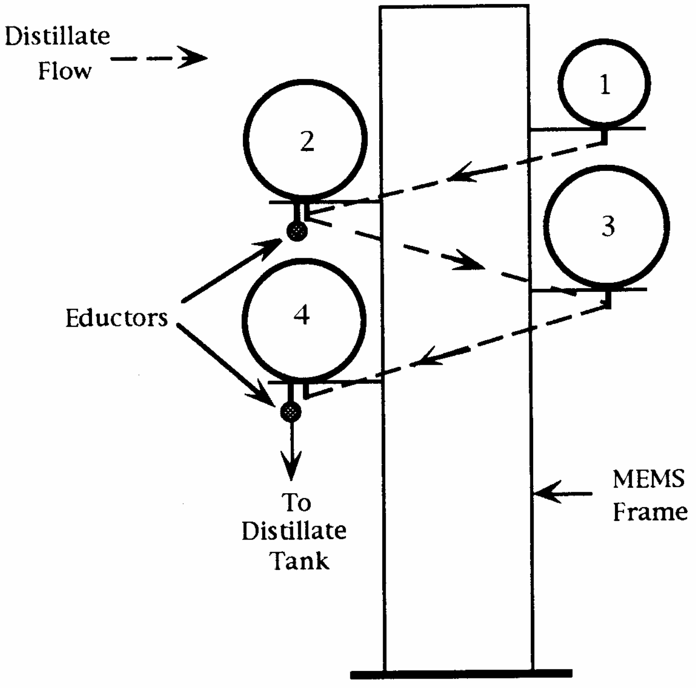

Figure 12. Staggered Condenser Configuration

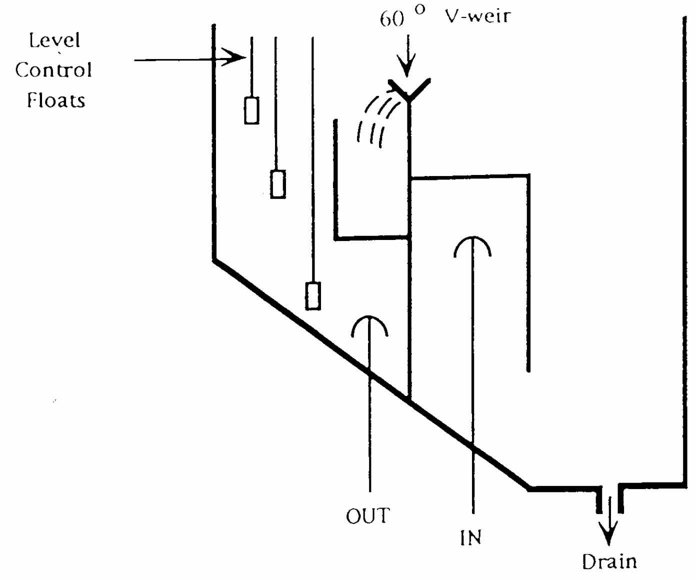

Figure 13. Concentrate Tank Configuration

4.2.2 Process Description

The MEMS unit tested in this project is a low temperature, vertical tube, flash evaporator. The classification of high temperature and low temperature is dictated by top brine temperature (TBT). High temperature is any temperature greater than 90 °C (194 °F) and low temperature is less than 90 °C (194 °F). (Al-Shammiri and Safar, 1999) The process of the MEMS unit is shown in Figure . The first step in starting up the unit is to evacuate the condensers and the flash chambers. This is accomplished by running the distillate pump, which circulates the water in the distillate network. The water flows through two in-line eductors, one connected to the second condensing bundle and the other to the fourth condensing bundle. The flowing distillate also serves as a coolant for the flash pumps. Once the appropriate vacuum is reached, the flash pumps that circulate the concentrate within the system can be energized accordingly. The concentrate will be both vacuum-dragged and pumped into each of the flash chambers. Upon entering the flash chamber, the concentrate enters tangentially on the inner chamber wall, causing the feed to form a cyclone. Once the entering concentrate reaches a certain temperature, the presence of a vacuum inside the chambers causes some of the water to be flashed. The vapor rises through a separator mesh (see Figure for chamber configuration), continuously flowing as steam through a steam duct and into a condensing bundle. The concentrate that is not flashed is pumped through the condensing bundle of the previous effect to pick up the heat of the condensed steam. The steam that is produced in the last effect is condensed with the aid of an external cooling source, such as a cooling tower or solar pond surface water.

Since a partial amount of concentrate is constantly being flashed and condensed into distillate, the concentrate level is periodically replenished. The feeding takes place in the pipe that connects the first flash chamber with the second flash chamber as shown in Figure . At this point, the feed water enters the system. The amount of feed is regulated by a solenoid valve located in the feed line, which is controlled by an ultrasonic level indicator that monitors and controls the water level in the first and second chambers.

5.0 WORK PERFORMED

5.1 Set Up and Refurbishment of the MEMS System

In order to test the MEMS over a wide range of operating conditions and to obtain information about its performance, the MEMS unit was refurbished, the piping system modified and rebuilt, and a data acquisition system installed as outlined below:

- Refurbished the piping system and fixed water leaks and vacuum leaks.
- Replaced some broken parts on the MEMS unit.
- Fixed the baffle plates in the second and third stage condensers.
- Installed a 3000-gallon tank for feed water supply, and installed a level control system in the tank.
- Rebuilt feed water supply system and installed a circulation pump, a fill pump, and a pressure tank.
- Installed a pH monitoring and adjusting system for feed water supply.
- Installed thermocouples, vacuum gauges, and flow meters on the MEMS unit.
- Installed a data acquisition system and set up a shelter for it.
- Constructed the cooling system for use with pond surface water.

Preliminary testing was performed in June and July 1999 prior to the start of the performance test.

5.2 Performance Testing

Performance tests were conducted during the period August through December 1999. The MEMS was tested with five different feed stocks: 1) solar pond surface brine; 2) well water at the solar pond site; 3) brine with similar salinity as seawater; 4) Rio Grande water; and 5) ground water from east El Paso, TX. Among these waters, the total dissolved solids (TDS) level ranged from 1000 mg/l for the Rio Grande water to 58,000 mg/l for the "seawater." Table 1 shows the chemical analysis of a typical feed water sample.

Table 1. Chemical Analysis of Feed Water (Solar Pond Surface Water)

Parameter	Total Dissolved Solids (mg/l)
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 salinities of the concentrate (therefore different recovery ratios), and different temperature levels (therefore different heat input to the unit). The TDS level of the concentrate brine ranged from 3000 to over 260,000 mg/l. The first stage vapor temperature, which is the highest one among the four stages, ranged from 60 to 70 °C. Also, two cooling modes were used in the tests: a cooling tower and solar pond surface brine. The cooling tower was used for most of the tests; solar pond surface water was used for the other tests to assess its feasibility and to compare the overall thermal efficiency of the two modes. The test conditions are summarized in Table 2. It should be noted that the actual operating conditions of the tests are somewhat different from the values listed in the table, because there are many variables and it is difficult to control the operating conditions precisely for each run. The tests with Rio Grande water and east El Paso ground water were only conducted at low salinity of concentrate due to the limitation of water availability.

Table 2. Test Conditions

Source of Feed Water	TDS of Feed Water (mg/l)	Concentrate		Vapor Temperature of Stage 1 (°C)	Cooling Mode
		Salinity (percent)	TDS (mg/l)		
Solar Pond Surface Brine	17,000	10	100,000	60, 65, 70	Clg Tower
	17,000	15	160,000	60, 65, 70	Clg Tower
	17,000	20	245,000	60, 65, 70	Clg Tower
Well Water	1,650	8	83,000	60, 65, 70	Clg Tower
	1,650	12	135,000	70	Clg Tower
"Seawater"	43,000	15	160,000	60, 65, 70	Clg Tower
	43,000	21	261,000	60, 65, 70	Clg Tower
	43,000	26	310,000	70	Clg Tower
	54,000	22	260,000	60, 65, 70	S-Pond Surface
Rio Grande Water	1,400	7	75,000	60, 65, 70	S-Pond Surface
East El Paso Ground Water	2,200	1	5,000	60, 65	S-Pond Surface

5.3 Data Collection

During the tests, the following parameters were collected automatically at a time interval of six minutes:

- Temperature and flow rate of hot brine from the solar pond
- Vapor temperature of each stage of the MEMS unit
- Inlet and outlet temperatures of each condenser
- Vacuum of each flash chamber
- Temperature of feed water
- Temperatures of the cooling loop
- Temperature of distillate
- Conductivity of distillate

The following data were collected manually and periodically during the tests:

- Conductivity, specific gravity, and pH of feed stock
- Conductivity, specific gravity, and pH of concentrate
- Conductivity and pH of distillate
- Flow rate of cooling loop
- Quantity of feed in to the MEMS unit
- Quantity of distillate production
- Quantity of concentrate blow down

The following data were measured periodically during the tests:

- Characteristics of raw water: chemical composition and total dissolved solids (TDS) level
- Quality of production water (distillate): chemical composition and TDS level

5.4 Data Analysis

Based on the data collected, the following parameters were calculated:

- Production rate of distillate
- Heat input from the solar pond
- Energy (both thermal and electrical) consumption rate
- Performance ratio, defined as the pounds of distillate produced per 1000 Btu of thermal energy input (i.e., energy required to evaporate distillate / energy used)
- Recovery ratio defined as the volumetric ratio of distillate produced to the feed in (i.e., volume of distillate produced / volume of feed)

The production rate of distillate is calculated by using the equation:

$$\text{Production Rate} = \frac{\text{Total Volume of Production}}{\text{Total Operation Time}}$$

The heat input from the solar pond, Q_{in}, is calculated as follows:

$$Q_{in} = \rho\, V\, C_p\, \Delta T$$

Where:

$\rho = 1.2$ kg/l (10.01 lb/gal) is the density of the saturated brine of the solar pond

V is the volumetric flow rate of the hot brine through the heat exchanger

C_p is the specific heat of the brine

ΔT is the temperature difference of the hot brine between the inlet and outlet of the heat exchanger.

According to data from the Office of Saline Water (1971), C_p = 0.80 Btu/lbm (3.349 kJ/kg°C).for a saturated aqueous sodium chloride solution (26 percent NaCl by weight) in the temperature range of 160 to 180 °F (71 to 82 °C).

The heat input from the solar pond, Q_{in}, was used as the thermal energy input in the calculation of performance ratio. Since the Q_{in} is the total heat input which includes both the heat used for distillation and the heat losses through the process, the calculated values for performance ratio should be conservative.

The recovery ratio was calculated based on the mass balance of both water and salts. The equation is as follows:

$$V_{feed} * C_{feed} = V_{dist} * C_{dist} + V_{con} * C_{con}$$

where, V_{feed}, V_{dist} and V_{con} are the volumes of feed water, distillate production, and concentrated brine, respectively, and C_{feed} , C_{dist} ,and C_{con} are the concentrations of total dissolved solids (TDS) in the feed water, distillate, and concentrate, respectively.

For steady state,

$$V_{feed} = V_{dist} + V_{con}$$

Therefore, the recovery ratio is

$$V_{dist} / V_{feed} = (C_{con} - C_{feed})/(C_{con} - C_{dist})$$

5.5 Comparison with Previous Tests with Spinflash Unit

A comparison of operation and economics of the MEMS and Spinflash was made. The Spinflash (24-stage, falling-film flash distillation unit) was tested at the El Paso Solar Pond site intermittently during the period 1987 through 1992, and useful data and information were gathered. These data and information were reviewed and compared with the results of the MEMS test. The comparison focused on performance and operation and maintenance. Results of the comparison are discussed in Section 6.7.

5.6 Solar Pond Operation and Maintenance

The solar pond was the sole thermal energy source for the MEMS test. In order to ensure the pond operated at the best condition and provides sufficient heat to the MEMS unit, as well as other facilities, the pond was monitored and maintained carefully. During the period of this project, the salinity gradient was maintained mainly by lowering the density of the surface zone through pumping some surface brine out to evaporation ponds and adding fresh water onto the surface. Acid was added into the pond to control algae growth and maintain the pond clarity. The temperature in the lower convective zone was maintained between 75 and 91 °C during the period from early June through mid-December 1999, as shown in Figure . The highest temperature, 91 °C, occurred on August 11, 1999 and the lowest temperature, 75 °C, occurred on December 13, 1999. The maximum temperature difference between the lower convective zone and upper convective zone was 74 °C. This occurred on October 18, 1999 when the temperatures in the upper and lower convective zones were 10 °C and 84 °C, respectively. In June 1999 the thickness of the lower convective zone was increased from 115 cm (3.8 ft) to 135 cm (4.4 ft) by adding saturated brine from the evaporation ponds into the lower convective zone.

6.0 RESULTS AND ANALYSIS

MEMS testing was conducted from August through December 1999. Based on the data collected, the distillate production rate, energy consumption rate, and distillate recovery ratios were calculated. These results are summarized below. Detailed data for each of the tests are shown in the Appendices.

6.1 Operating Characteristics

The major operating parameters for the tests are summarized in Table 3. The top brine temperature is the temperature of the brine entering the first stage, which is the highest brine temperature among the four stages. The flash range is defined as the temperature difference between the brine entering the first stage and the rejected brine from the fourth stage.

As an example, Figure 14 shows plots of several critical temperatures of the MEMS during the test on September 16, 1999. “Pond Brine Temp” is the temperature of the heat source, i.e. hot brine from the solar pond, and “TBT” is the top brine temperature of the MEMS unit. The cooling temperature is the inlet temperature of the cooling water into the fourth stage condenser of the MEMS unit. During this test, the TDS level of feed water was 1650 mg/l, and the TDS level of the concentrate was 86,000 mg/l. For this test, the average distillate production rate was 1.24 gallons per minute (gpm), the performance ratio was about 2.61 pounds of distillate per 1000 Btu heat input, and the distillate recovery ratio was about 98 percent, meaning 98 percent of the feed water was recovered as distillate. It can be seen that the MEMS unit does not function to produce distillate immediately upon start up. Rather, the unit requires a “warm up” period of about one hour before reaching a steady-state operating condition. Ideal steady-state conditions in the case of this unit are a misnomer, due to the fact that slight temperature variations occur during normal operation. When the unit is said to be in “steady state” or warmed up, it really means that all four flash chambers are at adequate vacuum and are being supplied with concentrate at a high enough temperature to cause flashing, thus sending vapor into all four condensing bundles.

Table 3. Major Operating Parameters

Parameter	Test Range
Heat Source (Solar Pond Hot Brine)	
Temperature	77- 87 °C
Flow Rate	4 – 73 gpm
Cooling	
Inlet Temperature	11 – 36 °C
Flow Rate	7 – 34 gpm
Feed Water	
TDS	1400 - 58,000 mg/l
Temperature	12 – 28 °C
Reject Concentrate	
TDS	3000 - 311,000 mg/l
Temperature	35 – 51 °C
Distillate Product	
TDS	2 – 14 mg/l
Temperature	24 – 43 °C
Top Brine Temperature (TBT)	63 – 80 °C
Flash Range	16 – 37 °C
Vacuum	22 – 24 in. of Hg

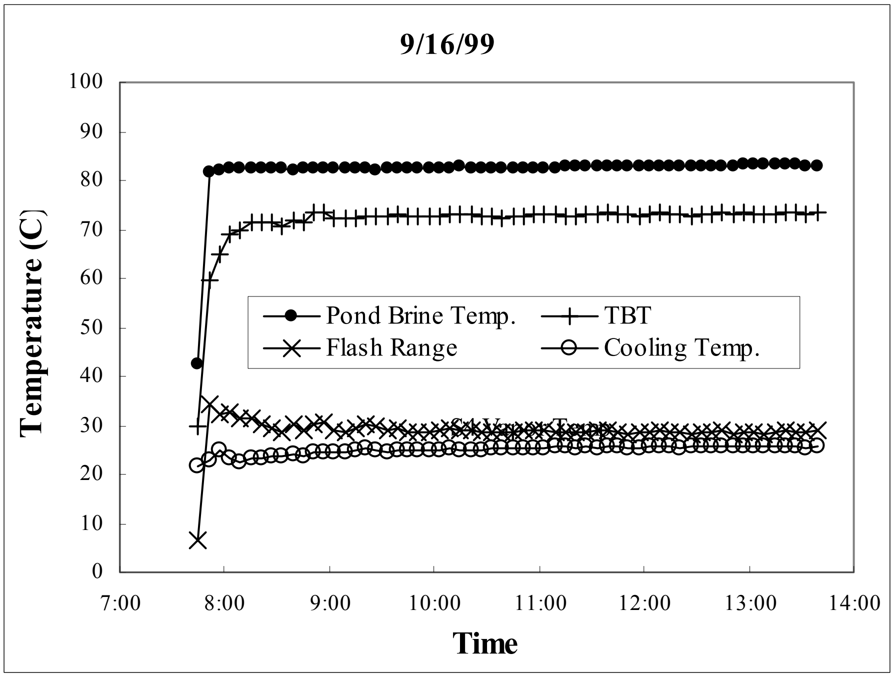

Figure 14. Operating Temperatures

Figure 15 shows the relationship of the vapor temperatures and corresponding vapor pressures of each stage. It can be seen that among the four stages, the largest temperature difference was between the third and fourth stages, while the largest vapor pressure drop occurred between the first and second stages. Both the temperature and pressure drops between the second and third stages have the lowest values.

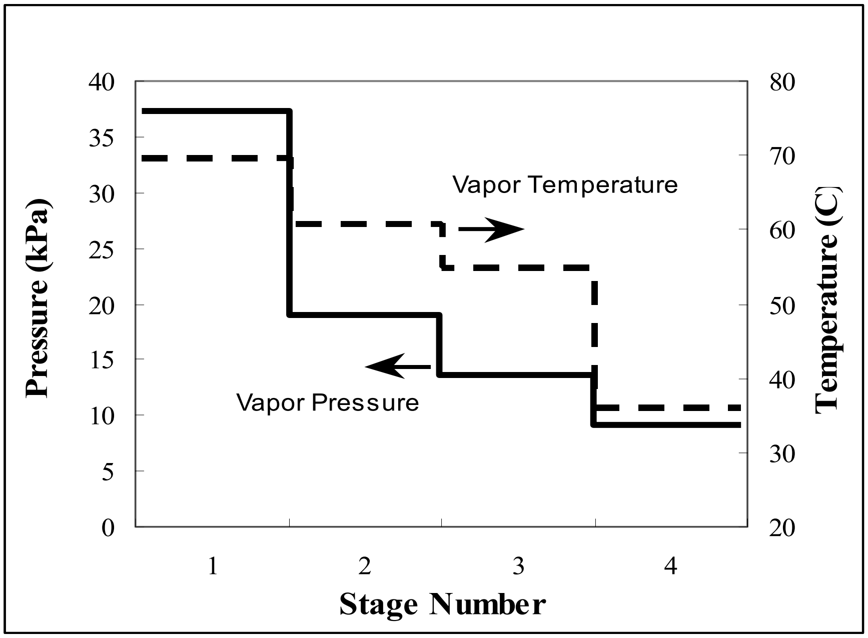

Figure 15. Thermal Operating Characteristics (9/16/99)
(TDS of feed water = 1650 mg/l; TDS of concentrate = 86,000 mg/l)

6.2 Distillate Production Rate

During the test period, the distillate production rate ranged from 0.43 to 1.32 gpm (1.63 to 5.0 liters per minute). The MEMS unit contains a conductivity probe that automatically controls the quality of disillate. 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 which is developed by SAS Institute Inc. A model was built to predict the production rate from the measured independent variables. Of the 13 independent variables, three were found to be statistically significant at the 95 percent confidence level. The significant variables as shown in Table 4 below are: flash range, concentration level of reject brine, and circulation rate of the first effect.

Table 4. Major Factors

Parameter	Production Rate	Performance Ratio
Solar pond brine temperature		
Solar pond brine flow rate		
Top brine temperature (TBT)		
Flash range	✔	✔
Feed water TDS		
Feed water temperature		
Reject brine TDS	✔	
Reject brine temperature		
Cooling water temperature		✔
Distillate TDS		
Distillate temperature		✔
Water circulation rate of 1st effect	✔	
Vacuum level		

Note: ✔ = significant effect; otherwise no significant effect noted.

The results of the analysis are presented in Figure 16 which shows the overall fit with all three independent variables and Figures 17, 18, and 19 which show the fit with each individual variable, respectively. It can be seen that the production rate increases with increased flash range and the circulation rate of the first effect, but decreases with concentration of reject brine.

Response: Production Rate (l/min)

Summary of Fit

Rsquare	0.910752
RSquare Adj	0.892903
Root Mean Square Error	0.2443
Mean of Response	3.334784
Observations (or Sum Wgts)	19

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Flash Range	1	1	1.2701944	21.2825	0.0003
TDS of concentrate	1	1	0.4277186	7.1666	0.0172
1st Stage Circ.	1	1	2.2215268	37.2224	<.0001

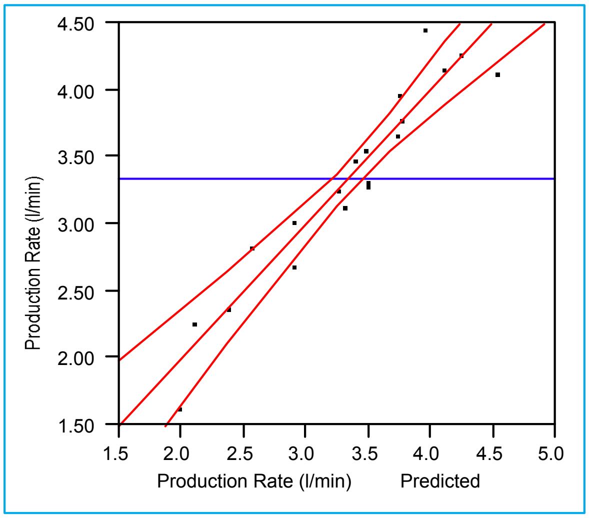

Figure 16. Whole-Model Test (Production Rate)
(Linear fit with ± 95 percent confidence interval)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	9.135684	3.04523	51.0238
Error	15	0.895237	0.05968	Prob>F
C Total	18	10.030921		<.0001

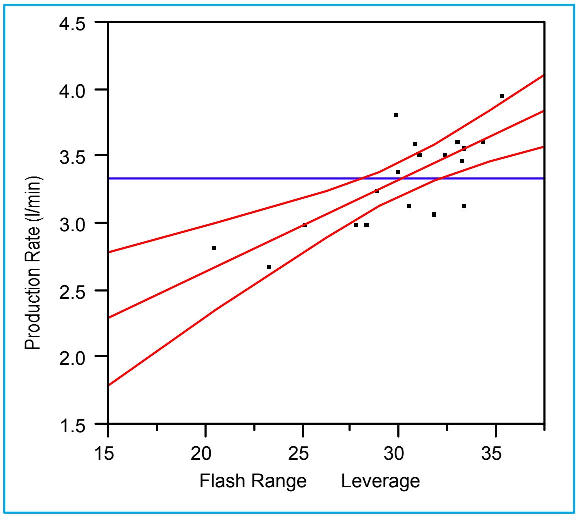

Figure 17. Production Rate vs. Flash Range
(Linear fit with ± 95 percent confidence interval, other variables set to the mean)

Effect Test

Sum of Squares	F Ratio	DF	Prob>F
1.2701944	21.2825	1	0.0003

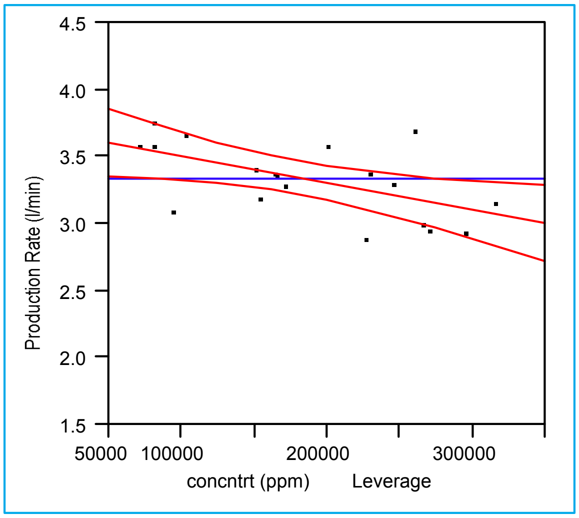

Figure 18. Production Rate vs. Reject Concentration
(Linear fit with ± 95 percent confidence interval, other variables set to the mean)

Effect Test

Sum of Squares	F Ratio	DF	Prob>F
0.42771857	7.1666	1	0.0172

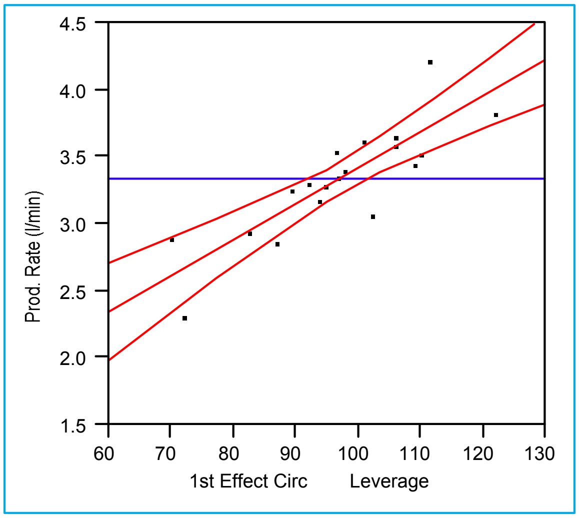

Figure 19. Production Rate vs. 1st Effect Circulation Rate
(Linear fit with ± 95 percent confidence interval, other variables set to the mean)

Effect Test

Sum of Squares	F Ratio	DF	Prob>F
2.2215268	37.2224	1	<.0001

Based on this model, the production rate (PD) can be expressed as:

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

Where:
PD is the production rate (l/min)
FR is the flash range (°C)
COR is the concentration of reject brine (mg/l)
CSI is the circulation rate of brine in the first stage (l/min).

Predicted production rates calculated by this equation fit the actual values very well as shown in Figure 20.

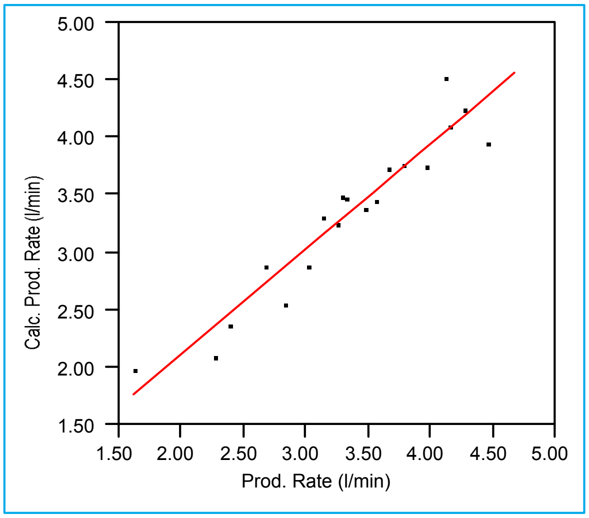

Figure 20. Comparison of Calculated Production Rate with Actual Production Rate

Linear Fit

Calc. Prod. Rate (l/min) = 0.29217 + 0.91136 Production Rate (l/min)

Summary of Fit

Rsquare	0.910749
RSquare Adj	0.905499
Root Mean Square Error	0.219151
Mean of Response	3.331354
Observations (or Sum Wgts)	19

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	8.3314225	8.33142	173.4735
Error	17	0.8164599	0.04803	Prob>F
C Total	18	9.1478824		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.2921704	0.236163	1.24	0.2328
Production Rate (l/min)	0.9113583	0.069195	13.17	<.0001

6.3 Energy Consumption Rate and Performance Ratio

The energy consumption rate is summarized in Table 5. One of the most important characteristics of a thermal desalination plant is how much heat it uses to produce a specific quantity of distillate. In practice, the most widely used index is the performance ratio (PR), which is defined as the pounds of distillate produced per 1000 Btu of thermal energy input (Howe, 1974). Performance ratio is also called economy ratio (ER). Theoretically, the maximum PR value equals the number of total stages for MSF desalination. However, actual PR will be much less than the theoretical values, due to both heat losses and the higher evaporation enthalpy values at lower temperatures. The PR values of this test ranged from 1.70 to 3.72. In this calculation, the heat input from the solar pond was used as the thermal energy input. Since this total heat input included both the heat used for distillation and the heat losses through piping and the heat exchanger, the calculated performance ratios are underestimated.

About 10 percent of the total energy consumed by the MEMS is electricity consumed by the three circulation pumps, each sized at 1 horsepower (hp), and one 3-hp distillate pump. In addition, the cooling tower has a 0.75-hp water pump and a 0.75-hp fan. This results in a total electricity consumption of 7.5 hp for tests with the cooling tower and 6.75 hp when pond surface water was used for cooling.

The relationship between PR and operating conditions was also analyzed statistically with the JMP software. A model is 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 percent confidence level. They are as listed in Table 4: flash range, temperature of reject brine, and temperature of distillate.

The results of this analysis are presented in Figure 21 which shows the overall fit with all three independent variables and Figures 22, 23, and 24 which show the fit with each individual variable, respectively. It can be seen that the production rate decreases with increased flash range and the temperature of reject brine, but increases with the temperature of distillate.

Response: Performance Ratio

Summary of Fit

Rsquare	0.807382
RSquare Adj	0.788121
Root Mean Square Error	0.209751
Mean of Response	2.319118
Observations (or Sum Wgts)	34

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Flash Range	1	1	2.6628146	60.5245	<.0001
T of Dist. (C)	1	1	2.6476482	60.1798	<.0001
T of Reject	1	1	2.4398759	55.4572	<.0001

Table 5. Energy Consumption Rate

Date	Metric Units			English Units			Percentage of Thermal (percent)
	Thermal (kJ/kg)	Electricity (kJ/kg)	Total (kJ/kg)	Thermal (Btu/lbm)	Electricity (Btu/lbm)	Total (Btu/lbm)	
Test 1: Feed water: solar pond surface brine							
08/16/99	755.5	117.3	872.8	324.8	50.4	375.2	86.6
08/17/99	920.9	111.8	1032.6	395.9	48.0	444.0	89.2
08/19/99	868.2	97.4	965.6	373.3	41.9	415.1	89.9
08/24/99	937.1	191.9	1129.0	402.9	82.5	485.4	83.0
08/25/99	1044.2	128.5	1172.7	449.0	55.2	504.2	89.0
08/26/99	927.3	75.1	1002.5	398.7	32.3	431.0	92.5
08/27/99	980.0	112.2	1092.2	421.3	48.3	469.6	89.7
08/30/99	667.4	67.3	734.7	286.9	29.0	315.9	90.8
08/31/99	887.9	115.7	1003.6	381.7	49.8	431.5	88.5
09/01/99	859.0	164.3	1023.3	369.3	70.7	439.9	83.9
Test 2: Feed water: local well water							
09/07/99	632.6	118.6	751.2	272.0	51.0	323.0	84.2
09/13/99	623.9	146.7	770.7	268.3	63.1	331.3	81.0
09/14/99	880.0	87.0	966.9	378.3	37.4	415.7	91.0
09/16/99	886.2	71.5	957.7	381.0	30.7	411.8	92.5
09/23/99	1062.1	86.5	1148.6	456.6	37.2	493.8	92.5
10/04/99	1093.9	88.9	1182.8	470.3	38.2	508.5	92.5
Test 3: Feed water: "seawater"							
10/05/99	1199.2	106.3	1305.6	515.6	45.7	561.3	91.9
10/11/99	990.7	141.4	1132.0	425.9	60.8	486.7	87.5
10/13/99	1093.2	103.0	1196.2	470.0	44.3	514.3	91.4
10/14/99	1138.2	94.5	1232.7	489.4	40.6	530.0	92.3
10/20/99	1097.3	124.6	1221.9	471.8	53.6	525.3	89.8
10/25/99	1086.0	91.1	1177.1	466.9	39.2	506.1	92.3
10/26/99	981.7	117.4	1099.1	422.0	50.5	472.5	89.3
10/27/99	1180.2	111.2	1291.4	507.4	47.8	555.2	91.4
10/29/99	1186.3	100.7	1287.1	510.0	43.3	553.4	92.2
Test 4: Feed water: "seawater" (cooling with pond surface water)							
11/02/99	1251.9	91.7	1343.6	538.2	39.4	577.6	93.2
11/03/99	1169.9	86.7	1256.6	503.0	37.3	540.3	93.1
11/05/99	1365.7	185.6	1551.2	587.1	79.8	666.9	88.0
Test 5: Feed water: Rio Grande water (cooling with pond surface water)							
11/16/99	1071.6	70.6	1142.2	460.7	30.4	491.1	93.8
11/18/99	1079.1	72.5	1151.6	463.9	31.2	495.1	93.7
11/22/99	976.9	76.0	1052.9	420.0	32.7	452.7	92.8
11/23/99	1170.3	73.2	1243.5	503.1	31.5	534.6	94.1
Test 6: Feed water: East El Paso ground water (cooling with pond surface water)							
12/02/99	1079.0	72.5	1151.5	463.9	31.2	495.1	93.7
12/03/99	1322.7	133.0	1455.7	568.7	57.2	625.9	90.9

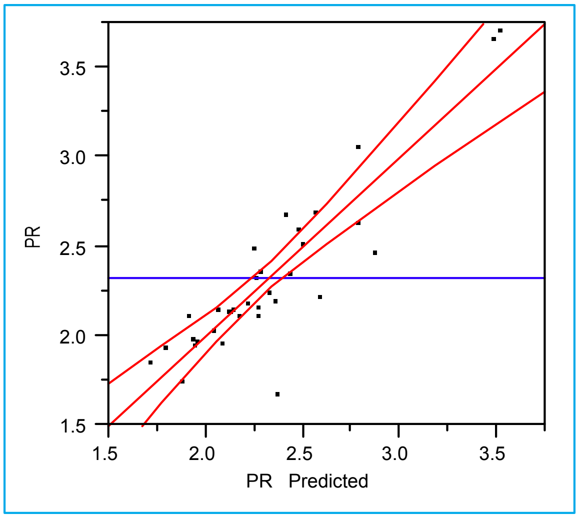

Figure 21. Whole-Model Test (Performance Ratio)
(Linear fit with ± 95 percent confidence interval)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	5.5324044	1.84413	41.9163
Error	30	1.3198691	0.04400	Prob > F
C Total	33	6.8522735		< .0001

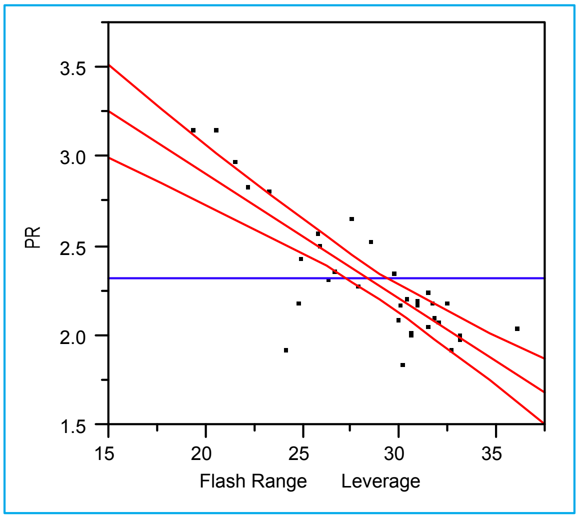

Figure 22. Performance Ratio vs. Flash Range
(Linear fit with ± 95 percent confidence interval, other variables set to the mean)

Effect Test

Sum of Squares	F Ratio	DF	Prob > F
2.6628146	60.5245	1	< .0001

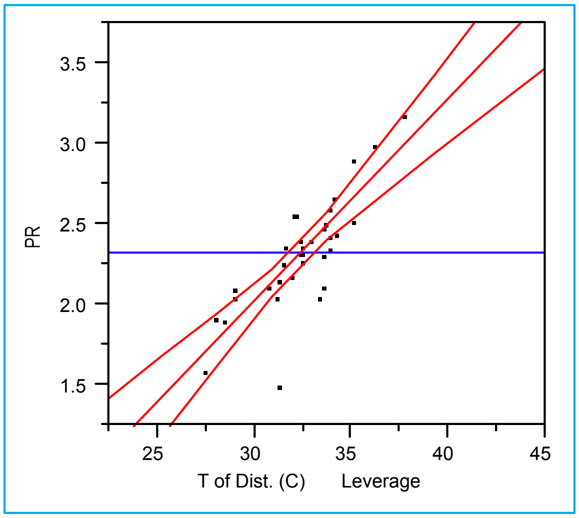

Figure 23. Performance Ratio vs. Temperature of Distillate
(Linear fit with ± 95 percent confidence interval, other variables set to the mean)

Effect Test

Sum of Squares	F Ratio	DF	Prob>F
2.6476482	60.1798	1	<.0001

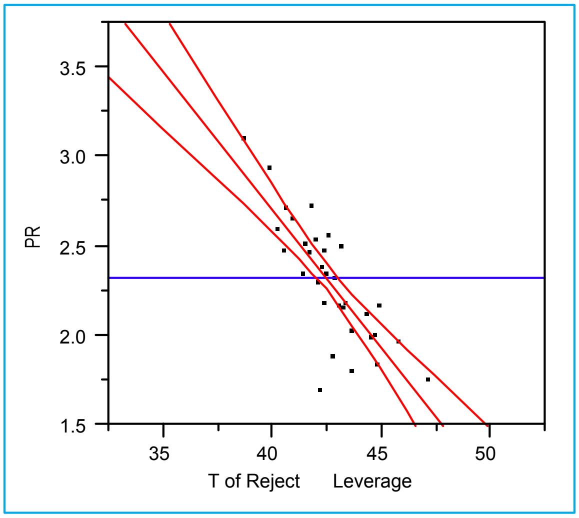

Figure 24. Performance Ratio vs. Temperature of Reject Brine
(Linear fit with ± 95 percent confidence interval, other variables set to the mean)

Effect Test

Sum of Squares	F Ratio	DF	Prob>F
2.4398759	55.4572	1	<.0001

Based on this model, the performance ratio (PR) can be expressed as:

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

Where: *PR* is the performance ratio (pounds of distillate product per 1000 Btu heat input)
FR is the flash range (°C)
TOD is the temperature of the distillate (°C)
TOR is the temperature of the reject brine (°C).

Predicted performance ratios calculated by this equation fit the actual values very well as shown in Figure 25.

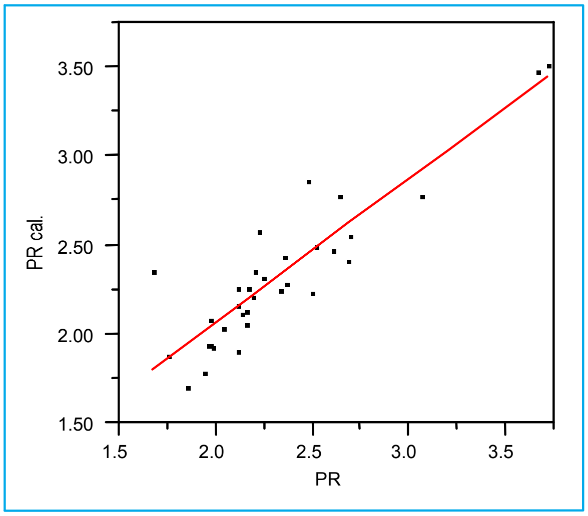

Figure 25. Comparison of Calculated PR with Actual PR

Linear Fit

PR cal. = 0.4467 + 0.80738 PR

Summary of Fit

Rsquare	0.807382
RSquare Adj	0.801363
Root Mean Square Error	0.182486
Mean of Response	2.319119
Observations (or Sum Wgts)	34

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	4.4667621	4.46676	134.1322
Error	32	1.0656381	0.03330	Prob>F
C Total	33	5.5324003		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.4467049	0.164673	2.71	0.0107
PR	0.807382	0.069713	11.58	<.0001

6.4 Quality of Distillate Product

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 results obtained from the testing in 1992 (Barron, 1992). Table 6 shows the TDS levels of the feed water, reject brine, and distillate for eight tests. Tables 7 through 9 show the chemical analyses for the distillate and concentrate at three different salinities of concentrate -- 10, 15, and 20 percent by weight, respectively.

Table 6. Quality of Distillate Product

Test #	TDS of Feed Water (mg/l)	TDS of Reject Brine (mg/l)	TDS of Distillate (mg/l)
1	1,650	83,000	< 2
2	1,650	135,000	< 4
3	17,000	102,000	< 2
4	17,000	160,000	< 2
5	17,000	242,000	< 2
6	43,000	161,000	< 4
7	52,000	245,000	< 4
8	58,000	259,000	< 5

Table 7. Chemical Analysis of Distillate and Concentrate (10 percent)

Parameter	10 percent Concentrate (mg/l)	Distillate (mg/l)
Total Hardness as $CaCO_3$	3500	< 1
Calcium as $CaCO_3$	3500	< 1
Total Solids	102,700	380
Total Dissolved Solids	101,610	< 2
Suspended Solids	1150	< 2
Chloride	66,500	8
Sulfate	700	< 1
Sodium	38,460	< 4

Table 8. Chemical Analysis of Distillate and Concentrate (15 percent)

Parameter	15 percent Concentrate (mg/l)	Distillate (mg/l)
Total Hardness as $CaCO_3$	6250	< 1
Calcium as $CaCO_3$	5230	< 1
Total Solids	162,220	18
Total Dissolved Solids	160,170	< 2
Suspended Solids	1310	< 2
Chloride	105,250	36
Sulfate	1330	< 1
Sodium	61,400	< 2

Table 9. Chemical Analysis of Distillate and Concentrate (20 percent)

Parameter	20 percent Concentrate (mg/l)	Distillate (mg/l)
Total Hardness as $CaCO_3$	9380	< 1
Calcium as $CaCO_3$	8130	< 1
Total Solids	245,240	< 2
Total Dissolved Solids	242,130	< 2
Suspended Solids	4680	< 2
Chloride	167,000	3
Sulfate	2330	< 1
Sodium	91,840	< 2

6.5 Scaling and Corrosion

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, and stainless steel and titanium alloy heat exchanger bundles in order to minimize scaling and corrosion problems. Low temperature operation is known to minimize scaling (Howe, 1974, Al-Shammiri and Safar, 1999).

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 the production rate or the performance ratio. This indicates that the limited scaling that occurred during operations did not significantly affect the performance of the unit.

6.6 Cooling with Pond Surface Water

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 percent 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 the 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) as shown in Figure 5. 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.

6.7 Comparison with Spinflash Unit

6.7.1 Spinflash Unit and Process Description

The Spinflash unit tested at the El Paso Solar Pond site is a 24-stage, falling-film flash evaporator. A schematic of its process is shown in Figure 26.

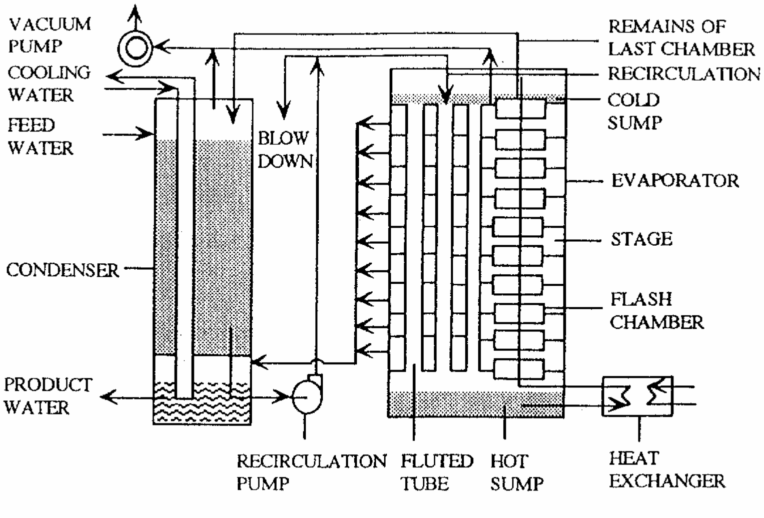

Figure 26. Schematic of Spinflash Process

To start the process, saltwater is pumped from the saltwater source to the storage portion of the heat reject vessel. The saltwater is then pumped by a recirculation pump from this storage area to the cold sump at the top of the evaporator. This recirculation rate is adjusted by throttling a valve on the discharge side of the recirculation pump.

The saltwater is then heated as it falls down the inside walls of 54, two-inch diameter, aluminum fluted tubes. This preheated saltwater is collected in the hot sump at the bottom of the evaporator. The partially-heated saltwater is then drawn, under vacuum, through the heat exchanger where heat is added from the solar pond, through a hot sump level control valve, and into the first of 24 flash chambers. Here a partial vacuum, created by a vacuum pump, causes a small amount of the hot saltwater to evaporate or "flash," producing fresh water vapor.

The remaining saltwater is then pumped by rotating impellers up through the 24 flash chambers, which operate at sequentially lower pressures and temperatures. The impellers aid in separating the water vapor from the liquid saltwater. About one-tenth of the saltwater is evaporated by the 24th flash chamber. The remaining saltwater returns to the storage portion of the reject vessel where saltwater makeup is added to replace the volume of water produced. The fresh water vapor, which is produced in the 24 flash chambers, is condensed on the outside of the 54 fluted vertical tubes. This condensing vapor releases its latent heat of vaporization to the aluminum fluted tubes which in turn heat the saltwater falling from the top (cold sump) to the bottom (hot sump) of the evaporator.

The condensed fresh water is collected, tested for purity, and in a commercial system would be ready for delivery. Salt is removed from the system by allowing a small amount of the re-circulation saltwater to bleed off from the re-circulation line, carrying the excess salt out of the system. The "bleed off," more commonly referred to as "blow down" is adjusted by a throttling a small valve, which varies the mass balance of the system. In our configuration, the bleed-off rate was set for 0.5 gallons per minute.

6.7.2 Comparison with the MEMS Unit

Table 10 lists the operating conditions and performance results for both the Spinflash unit and MEMS unit. The information about the Spinflash unit was obtained from the tests that were conducted at the El Paso Solar Pond site in 1988 (McElroy, 1993).

Table 10. Comparison between Spinflash and MEMS Units

Parameters	Spinflash Unit	MEMS Unit
TDS of Feed Water	1000 - 10,000 mg/l	1400 - 58,000 mg/l
TDS of Concentrate	41,100 - 49,800 mg/l	3000 - 311,000 mg/l
Top Brine Temp. (TBT)	57 – 77 °C	63 – 80 °C
Flash Range	28 – 54 °C	16 – 37 °C
Production Rate	1.6 - 9.4 m^3/day	2.3 - 7.2 m^3/day
Performance Ratio	3.2 - 6.2	1.7 - 3.7
TDS of Distillate	25 – 600 mg/l	2 – 14 mg/l

- The MEMS unit was tested under a wider range of operating conditions than the Spinflash.

- The distillate production rates of the Spinflash unit and the MEMS unit are in the same range. The flash range and circulation rate significantly affect the production rates for both units.

- The performance ratio (PR) of the Spinflash unit is about two times higher than that of the MEMS unit. However, the total number of stages of the MEMS unit is only one sixth that of the Spinflash unit. Comparing their theoretical limit of performance ratios, which equals the number of stages (Barron 1992, McElroy 1993), the PR of the MEMS unit reached about 90 percent of its theoretical value, while the PR of the Spinflash unit was only about 26 percent of its theoretical value.

- The quality of distillate produced by the MEMS unit is higher than the distillate produced by the Spinflash unit.

- Scaling and corrosion were major problems for the Spinflash unit, but had no significant effect on the performance of the MEMS unit.

- The MEMS was found to be more reliable and easier to operate than the Spinflash.

6.8 Economic Analysis

The MEMS unit is a small pilot system that is no longer commercially available. The important economic question is the cost of desalinated water using a full scale system of this type of unit in conjunction with a salinity gradient solar pond. The economics of solar pond based desalination were studied by Esquivel (1992).

Two factors which influence the cost of desalting water at inland locations are energy and brine disposal. Currently the lowest cost option for desalination of brackish water is reverse osmosis (RO) or nanofiltration. However, pressure membranes tend to degrade when used with more concentrated and complex waters leading to systems designed to recover only 75-80 percent of the treated water. The remaining 15-25 percent of the water represents a disposal problem at an inland site. The potential use for thermal desalination systems such as MEMS would be to treat RO (or nanofiltration) reject waters with the final concentrate going into construction of salinity gradient solar ponds. For a 12.5 MGD (0.55 m^3/s) combined RO and MSF plant powered completely by a solar pond, Esquivel (1992) estimated costs of 1.95 to 2.33 \$/kgal (0.52 to 0.62 $\$/m^3$), depending on the cost of the solar pond liner.

Table 11 shows the results of an economic analysis for a 1-MGD and 10-MGD solar-pond-coupled plant based on a $4/m^2 pond liner cost. The overall costs for these plants are estimated to be less than an RO plant combined with evaporation ponds and about the same as RO combined with deep well injection of concentrate.

Table 11. Economic Analysis

RO Plant Capacity	**1 MGD**	**10 MGD**
Feed Stream Volume	1.3 MGD	12.9 MGD
Actual Production	0.9 MGD	9 MGD
Thermal Plant Capacity	**0.4 MGD**	**3.9 MGD**
Feed Stream Volume	0.4 MGD	0.4 MGD
Recovery Rate	90 percent	90 percent
Plant Load Factor	90 percent	90 percent
Actual Production	0.36 MGD	3.51 MGD
Total Production	**1.26 MGD**	**12.51 MGD**
Solar Pond Size	210,000 m^2	1,900,000 m^2
Capital Costs:		
RO Equipment	$1,200,000	$8,000,000
Pretreatment Equipment	$430,000	$2,800,000
Solar Pond	$2,374,159	$15,876,715
ORC Engine	$485,168	$2,859,058
Thermal Desalination Equipment	$242,360	$2,363,010
Total Capital:	**$4,721,687**	**$31,898,783**
O & M Costs:		
RO Equipment	$398,800	$3,112,000
Pretreatment Equipment	$147,000	$980,000
Thermal Desalination Equipment	$36,354	$354,452
Purchased Electric Power	$105,192	$1,057,436
Purchased Thermal Power	$60,875	$582,505
Solar Pond	$166,191	$317,534
ORC Engine	$19,081	$190,374
Total O & M:	**$933,493**	**$6,594,301**
Water Cost:		
Amortized Capital	$343,021	$2,317,383
O&M Yearly (Plus)	$933,493	$6,594,301
Kgal Produced Yrly (Div)	4.60E+08	4.57E+09
COST ($ / kgal)	**$2.78**	**$1.95**

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APPENDICES

APPENDIX A

SUMMARY OF TEST DATA

Appendix A. Summary of Test Data

Date	Feedwater		Reject Brine	Heat Exchanger						Vacuum
	TDS (mg/l)	Temp. (C)	TDS (mg/l)	Hot In T (C)	Hot out T (C)	Hot Flow (gpm)	Cold in T (C)	Cold out T (C)	Cold Flow (gpm)	(in. Hg)
08/16/99	17,000	27.7	110,000	87.1	59.0	5.1	57.6	62.9	NA	-23.91
08/17/99	17,000	28.0	103,000	87.1	64.4	8.0	62.2	68.7	NA	NA
08/19/99	17,000	25.9	110,000	85.0	66.6	10.7	63.9	70.8	NA	-23.52
08/24/99	17,000	27.5	180,000	84.6	64.5	5.3	61.9	69.5	NA	-23.08
08/25/99	17,000	27.4	155,000	84.1	72.1	14.9	67.0	75.4	NA	-22.78
08/26/99	17,000	27.4	244,500	85.1	79.1	45.1	70.9	80.1	30.55	-22.48
08/27/99	17,000	26.6	246,200	85.3	72.0	14.4	64.1	73.7	NA	-22.97
08/30/99	17,000	26.2	244,500	87.1	71.1	13.7	66.4	75.5	NA	-23.25
08/31/99	17,000	27.9	244,500	85.0	65.5	8.7	62.0	70.7	NA	-22.78
09/01/99	18,000	27.1	226,700	83.2	59.9	5.0	57.8	65.6	NA	-21.71
09/07/99	1,650	25.7	63,000	86.2	60.5	4.6	58.4	65.2	NA	-22.40
09/13/99	1,650	24.1	83,000	85.1	58.7	3.6	56.8	63.6	20.71	-22.65
09/14/99	1,650	23.1	83,000	86.3	65.0	10.5	60.3	69.1	NA	-23.16
09/16/99	1,650	23.7	86,000	82.7	71.2	23.7	64.2	72.9	NA	-22.99
09/23/99	1,650	21.5	134,000	83.9	71.9	22.7	65.7	74.0	NA	-22.54
10/04/99	1,650	21.1	135,000	84.3	72.9	23.7	64.9	74.5	28.72	-23.16
10/05/99	43,000	22.2	261,000	83.8	75.1	28.6	67.3	75.9	29.40	-22.64
10/11/99	43,000	20.0	161,000	84.2	59.4	6.0	55.5	64.3	21.09	-23.47
10/13/99	43,000	20.9	189,000	84.2	69.3	15.6	61.8	72.3	23.11	-23.75
10/14/99	43,000	21.4	311,000	84.4	75.3	29.6	66.2	76.0	27.83	-23.52
10/20/99	54,000	11.6	165,500	83.1	67.6	12.5	60.9	70.8	22.22	-23.66
10/25/99	54,000	14.8	178,000	82.9	75.4	35.0	65.2	75.5	26.82	-23.54
10/26/99	52,000	15.2	244,500	82.2	62.7	9.5	56.3	67.3	18.40	-24.14
10/27/99	52,000	16.8	244,500	81.9	70.7	20.9	62.0	72.5	22.75	-23.43
10/29/99	50,500	17.4	251,000	81.6	75.5	42.2	65.4	75.2	28.41	-23.14
11/02/99	50,500	13.7	257,750	82.0	75.7	43.4	65.5	75.4	28.28	-23.70
11/03/99	58,000	13.8	259,400	81.1	71.4	27.6	61.5	72.3	25.30	-24.10
11/05/99	50,500	13.7	266,000	79.6	60.6	7.7	55.3	65.5	16.32	-23.88
11/16/99	1,000	16.2	66,800	79.5	74.5	60.2	62.6	73.2	29.22	-23.73
11/18/99	1,000	18.4	75,600	78.9	72.1	43.3	61.2	71.5	28.83	-23.63
11/22/99	1,000	14.1	75,600	78.8	64.1	17.4	56.2	66.1	27.09	-23.99
11/23/99	1,000	13.0	83,300	79.0	71.7	43.9	60.5	71.1	31.33	-24.44
12/02/99	2,200	12.9	3,000	77.4	73.3	72.5	61.4	72.0	NA	-23.96
12/03/99	2,200	13.7	7,000	76.7	64.1	15.7	57.4	66.2	NA	-22.89

Appendix A. Summary of Test Data

Date	Stage 1			Stage 2				Stage 3			
	Cond. In T (C)	Vapor T (C)	Vacuum (in. Hg)	Cond. In T (C)	Cond. Out T (C)	Vapor T (C)	Vacuum (in. Hg)	Cond. In T (C)	Cond. Out T (C)	Vapor T (C)	Vacuum (in. Hg)
08/16/99	56.3	60.7	-17.4	49.0	53.1	55.0	-19.3	42.0	45.3	48.9	-21.9
08/17/99	60.3	65.4	-19.1	52.3	56.9	58.7	-21.2	43.3	47.7	52.1	-23.7
08/19/99	61.6	67.1	-17.1	54.7	58.7	59.7	-19.5	45.0	49.8	54.4	-21.4
08/24/99	59.3	65.2	-15.6	56.1	57.9	57.7	-19.4	49.4	50.6	55.0	-20.7
08/25/99	64.1	70.8	-15.2	59.5	62.0	62.3	-18.4	50.9	53.3	59.1	-20.2
08/26/99	68.2	75.3	-12.7	60.3	64.7	66.0	-17.2	46.6	51.3	59.7	-18.7
08/27/99	61.2	68.1	-16.1	54.7	58.1	59.2	-19.8	44.0	47.4	54.3	-20.9
08/30/99	63.6	70.6	-15.3	55.3	60.0	61.5	-19.2	43.0	47.1	54.8	-20.8
08/31/99	59.1	66.0	-15.5	52.6	56.4	57.5	-20.4	43.5	46.1	52.2	-21.8
09/01/99	55.1	61.5	-16.3	47.9	51.8	53.6	-19.4	42.2	43.1	47.5	-20.8
09/07/99	56.4	61.9	-19.3	52.5	54.9	55.2	-20.4	44.8	47.5	52.2	-22.1
09/13/99	54.5	60.7	-16.9	51.5	53.1	53.5	-21.7	47.2	47.6	51.5	-21.9
09/14/99	57.8	65.6	-15.6	51.7	54.8	56.4	-21.0	42.5	45.0	51.8	-22.2
09/16/99	61.9	69.6	-14.7	55.0	58.5	60.5	-20.1	44.1	47.3	55.2	-21.8
09/23/99	63.5	70.3	-14.8	57.5	60.7	61.9	-19.7	47.5	50.2	57.6	-20.1
10/04/99	62.5	69.9	-14.1	55.4	58.8	60.2	-19.9	44.1	46.9	55.0	-21.5
10/05/99	65.2	71.4	-13.7	59.0	62.0	63.0	-19.3	49.6	51.6	58.2	-20.7
10/11/99	53.3	59.9	-17.9	48.5	50.4	51.1	-22.3	42.3	43.0	47.8	-22.7
10/13/99	59.2	66.3	-16.2	51.4	54.6	56.3	-21.6	39.6	42.3	49.9	-22.5
10/14/99	64.1	70.5	-14.7	56.4	59.6	61.1	-20.1	43.6	46.2	54.9	-21.8
10/20/99	58.7	64.7	-16.4	52.4	54.9	55.5	-21.6	42.7	44.0	50.6	-22.8
10/25/99	62.9	69.7	-15.5	54.9	58.3	59.9	-21.0	41.6	44.5	53.3	-22.5
10/26/99	53.3	61.0	-18.1	46.7	49.3	50.7	-22.4	36.2	38.3	45.5	-22.5
10/27/99	59.4	66.4	-16.1	52.8	55.5	56.3	-20.3	42.9	44.6	52.0	-21.2
10/29/99	63.4	69.4	-14.7	56.3	59.3	60.0	-20.0	45.1	47.0	55.4	-21.2
11/02/99	63.3	69.2	-15.3	56.2	59.2	59.9	-20.7	44.8	46.1	54.8	-21.9
11/03/99	58.9	66.5	-16.5	51.2	54.5	55.9	-21.7	38.9	41.2	50.0	-22.8
11/05/99	52.4	60.1	-17.7	47.1	49.1	50.0	-22.6	39.0	39.9	45.6	-23.1
11/16/99	59.9	68.5	-15.0	51.5	55.4	58.0	-20.4	38.6	41.9	51.6	-21.8
11/18/99	58.5	66.5	-16.2	50.7	54.2	56.2	-21.2	38.0	41.6	50.8	-21.9
11/22/99	53.6	61.0	-16.9	46.4	49.6	51.0	-22.0	35.3	37.3	46.6	-22.7
11/23/99	57.8	66.0	-16.5	49.1	53.1	55.4	-21.7	35.0	38.0	49.3	-22.6
12/02/99	58.6	66.5	-16.0	50.8	54.6	55.9	-21.0	34.9	40.0	51.0	-22.1
12/03/99	54.9	61.1	-16.4	49.9	52.3	52.4	-21.6	39.7	40.2	49.9	-22.2

Appendix A. Summary of Test Data

Date	Stage 4				Cooling	Production	Performance	Distillate	
	Cond. In T (C)	Cond. Out T (C)	Vapor T (C)	Vacuum (in. Hg)	Flow Rate (gpm)	Rate (gpm)	Ratio (lbm/kBtu)	Quality (µS/sec)	Temp. (C)
08/16/99	24.5	27.8	34.4	-23.8	NA	0.76	3.07	27.6	31.2
08/17/99	25.2	29.6	35.1	-23.8	NA	0.79	2.52	23.3	33.1
08/19/99	27.3	31.9	35.9	-23.5	33.1	0.91	2.69	3.9	34.7
08/24/99	34.6	38.2	40.3	-23.1	32.8	0.46	2.48	26.9	40.6
08/25/99	35.3	38.7	41.6	-22.8	33.6	0.69	2.23	4.4	42.6
08/26/99	27.8	33.8	37.2	-22.5	33.2	1.18	2.50	3.8	39.6
08/27/99	26.2	30.7	34.1	-23.0	33.2	0.79	2.20	5.3	35.2
08/30/99	24.2	29.0	33.2	-23.5	32.5	0.82	2.17	11.3	34.8
08/31/99	23.5	27.2	33.7	-22.8	32.5	0.66	2.25	5.0	32.9
09/01/99	22.8	25.1	32.7	-21.9	32.2	0.54	2.70	6.7	31.1
09/07/99	28.1	35.4	37.8	-22.8	10.9	0.75	3.67	5.6	40.0
09/13/99	36.3	38.5	39.5	-22.8	31.8	0.60	3.72	2.9	41.0
09/14/99	27.3	31.7	34.9	-23.3	7.4	1.02	2.64	3.7	35.0
09/16/99	25.3	31.1	36.3	-23.1	NA	1.24	2.61	3.5	35.8
09/23/99	25.6	30.5	37.2	-22.6	31.7	1.02	2.19	7.5	36.6
10/04/99	23.5	29.1	34.3	-23.4	31.4	1.00	2.12	7.1	34.2
10/05/99	23.3	28.5	38.7	-22.8	30.3	0.83	1.94	6.2	35.7
10/11/99	19.2	22.1	33.8	-23.7	30.6	0.63	2.34	5.8	28.0
10/13/99	21.0	25.7	30.6	-24.0	29.8	0.86	2.12	6.5	30.7
10/14/99	21.4	26.8	32.3	-23.7	17.7	0.94	2.04	7.8	33.7
10/20/99	17.6	21.3	33.8	-23.8	NA	0.71	2.12	8.4	29.1
10/25/99	19.7	24.9	33.1	-23.8	NA	0.97	2.14	7.9	32.7
10/26/99	17.8	21.6	26.8	-24.3	NA	0.75	2.36	6.0	27.0
10/27/99	20.4	24.7	32.9	-23.6	NA	0.80	1.97	10.1	31.6
10/29/99	20.0	25.0	34.5	-23.3	NA	0.88	1.96	9.6	33.5
11/02/99	16.2	22.4	32.9	-24.0	NA	0.87	1.86	9.9	31.5
11/03/99	15.2	21.6	28.2	-24.2	28.6	0.92	1.99	9.4	27.6
11/05/99	17.2	21.4	27.1	-24.0	26.5	0.43	1.68	8.2	27.3
11/16/99	17.2	26.8	30.8	-23.9	28.0	1.13	2.16	5.0	29.5
11/18/99	15.8	24.4	29.8	-23.8	28.2	1.10	2.14	3.7	28.0
11/22/99	14.0	22.6	27.4	-24.1	28.1	1.05	2.37	3.2	24.5
11/23/99	11.9	20.8	26.3	-24.6	28.1	1.09	1.98	2.9	24.4
12/02/99	12.6	22.0	28.3	-24.1	28.2	1.10	2.16	4.5	25.7
12/03/99	11.2	17.8	28.6	-23.2	24.4	0.60	1.76	3.5	24.3

APPENDIX B

DAILY TEST RESULTS

DATE:	8/16/99					
Operation Time (min.):		295		**Heat Input (kJ/min):**		2161.66
Total Production (gal.):		223		**Performance Ratio:**		3.07
Production Rate (gpm):		0.76		**Recovery Ratio:**		85.47%
Total Feed In (gal):		265				
Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
Solar Pond Surface Brine	1.011	1.54	16000	27.7		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.075	10.32	110000			
Distillate:	Temp. (C)	Conductivity (µS/cm)				
	31.2	27.6				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	87.1	59.0	5.1	57.6	62.9	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	
1st Stage	62.9	60.7	-17.36	56.3	57.6	
2nd Stage		55.0	-19.26	49.0	53.1	
3rd Stage		48.9	-21.86	42.0	45.3	
4th Stage		34.4	-23.84	24.5	27.8	
4th Condenser			-23.91			
Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)				
	24.5	27.8				

DATE:	8/17/99					
Operation Time (min.):		329		**Heat Input (kJ/min):**		2765.11
Total Production (gal.):		261		**Performance Ratio:**		2.52
Production Rate (gpm):		0.79		**Recovery Ratio:**		84.48%
Total Feed In (gal):		320				
Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
Solar Pond						
Surface Brine	1.011	1.54	16000	28.0		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.07	9.65	103000			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	33.1	23.3				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	87.1	64.4	8.0	62.2	68.7	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	
1st Stage	68.7	65.4	-16.57	60.3	57.6	
2nd Stage		58.7	-19.06	52.3	56.9	
3rd Stage		52.1	-21.24	43.3	47.7	
4th Stage		35.1	-23.67	25.2	29.6	
4th Condenser			-23.76			
Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)				
	25.2	29.6				

DATE:	8/19/99					
Operation Time (min.):		435		**Heat Input (kJ/min):**		2990.29
Total Production (gal.):		398		**Performance Ratio:**		2.69
Production Rate (gpm):		0.91		**Recovery Ratio:**		85.46%
Total Feed In (gal):		460				
Feed Stock:	S. G.	Salinity	TDS	Temp.		
Solar Pond		(%)	(mg/l)	(C)		
Surface Brine	1.011	1.54	16000	25.9		
Concentrate:	S. G.	Salinity	TDS			
		(%)	(mg/l)			
	1.074	10.19	110000			
Distillate:	Temp.	Conductivity				
	(C)	(mS/cm)				
	34.7	3.9				
Heat Exchanger:	Brine in T	Brine out T	Brine Flow	2nd in T	2nd out T	
	(C)	(C)	(gpm)	(C)	(C)	
	85.0	66.6	10.7	63.9	70.8	
MEMS:	Water in T	Vap. T	Vacuum	Con. In T	Con. Out T	
	(C)	(C)	(in. Hg)	(C)	(C)	
1st Stage	70.8	67.1	-17.13	61.6	63.9	
2nd Stage	N/A	59.7	-19.48	54.7	58.7	
3rd Stage	N/A	54.4	-21.37	45.0	49.8	
4th Stage	N/A	35.9	-23.47	27.3	31.9	
4th Condenser			-23.52			
Cooling Mode:	Cooling tower					
	Inlet T	Outlet T				
	(C)	(C)				
	27.3	31.9				

DATE:	8/24/99					
Operation Time (min.):		158		**Heat Input (kJ/min):**		1638.83
Total Production (gal.):		73		**Performance Ratio:**		2.48
Production Rate (gpm):		0.46		**Recovery Ratio:**		91.12%
Total Feed In (gal):		88				
Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
Solar Pond Surface Brine	1.011	1.54	16000	27.5		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.119	16.10	180000			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	40.6	26.9				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	84.6	64.5	5.3	61.9	69.5	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	
1st Stage	69.5	65.2	-15.65	59.3	61.9	
2nd Stage	N/A	57.7	-19.41	56.1	57.9	
3rd Stage	N/A	55.0	-20.70	49.4	50.6	
4th Stage	N/A	40.3	-23.05	34.6	38.2	
4th Condenser			-23.08			
Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)				
	34.6	38.2				

DATE:	8/25/99					
Operation Time (min.):		424		**Heat Input (kJ/min):**		2727.17
Total Production (gal.):		293		**Performance Ratio:**		2.23
Production Rate (gpm):		0.69		**Recovery Ratio:**		89.68%
Total Feed In (gal):		341				
Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
Solar Pond Surface Brine	1.011	1.54	16000	27.4		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.108	14.68	155000			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	42.6	4.4				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	84.1	72.1	14.9	67.0	75.4	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	
1st Stage	75.4	70.8	-15.24	64.1	67.0	
2nd Stage		62.3	-18.36	59.5	62.0	
3rd Stage		49.4	-20.17	50.9	53.3	
4th Stage		41.6	-22.85	35.3	38.7	
4th Condenser			-22.78			
Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)				
	35.3	38.7				

DATE:	8/26/99					
Operation Time (min.):		294		**Heat Input (kJ/min):**		4141.68
Total Production (gal.):		347		**Performance Ratio:**		2.50
Production Rate (gpm):		1.18		**Recovery Ratio:**		93.46%
Total Feed In (gal):		350				
Feed Stock:	S. G.	Salinity	TDS	Temp.		
Solar Pond		(%)	(mg/l)	(C)		
Surface Brine	1.011	1.54	16000	27.4		
Concentrate:	S. G.	Salinity	TDS			
		(%)	(mg/l)			
	1.159	21.14	244500			
Distillate:	Temp.	Conductivity				
	(C)	(mS/cm)				
	39.6	3.8				
Heat Exchanger:	Brine in T	Brine out T	Brine Flow	2nd in T	2nd out T	
	(C)	(C)	(gpm)	(C)	(C)	
	85.1	79.1	45.1	70.9	80.1	
MEMS:	Water in T	Vap. T	Vacuum	Con. In T	Con. Out T	
	(C)	(C)	(in. Hg)	(C)	(C)	
1st Stage	80.1	75.3	-12.70	68.2	70.9	
2nd Stage		66.0	-17.25	60.3	64.7	
3rd Stage		59.7	-18.66	46.6	51.3	
4th Stage		37.2	-22.49	27.8	33.8	
4th Condenser			-22.48			
Cooling Mode:	Cooling tower					
	Inlet T	Outlet T				
	(C)	(C)				
	27.8	33.8				

DATE:	8/27/99					
Operation Time (min.):		420		**Heat Input (kJ/min):**		2930.33
Total Production (gal.):		331		**Performance Ratio:**		2.36
Production Rate (gpm):		0.79		**Recovery Ratio:**		93.50%
Total Feed In (gal):		341				
Feed Stock:	S. G.	Salinity	TDS	Temp.		
Solar Pond		(%)	(mg/l)	(C)		
Surface Brine	1.011	1.54	16000	26.6		
Concentrate:	S. G.	Salinity	TDS			
		(%)	(mg/l)			
	1.16	21.26	246200			
Distillate:	Temp.	Conductivity				
	(C)	(mS/cm)				
	35.2	5.3				
Heat Exchanger:	Brine in T	Brine out T	Brine Flow	2nd in T	2nd out T	
	(C)	(C)	(gpm)	(C)	(C)	
	85.3	72.0	14.4	64.1	73.7	
MEMS:	Water in T	Vap. T	Vacuum	Con. In T	Con. Out T	
	(C)	(C)	(in. Hg)	(C)	(C)	
1st Stage	73.7	68.1	-16.13	61.2	64.1	
2nd Stage	N/A	59.2	-19.76	54.7	58.1	
3rd Stage	N/A	54.3	-20.95	44.0	47.4	
4th Stage	N/A	34.1	-22.98	26.2	30.7	
4th Condenser			-22.97			
Cooling Mode:	Cooling tower					
	Inlet T	Outlet T				
	(C)	(C)				
	26.2	30.7				

DATE:	8/30/99					
Operation Time (min.):		60		**Heat Input (kJ/min):**		3326.06
Total Production (gal.):		79		**Performance Ratio:**		3.48
Production Rate (gpm):		1.32		**Recovery Ratio:**		93.46%
Total Feed In (gal):		83				
Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
Solar Pond Surface Brine	1.011	1.54	16000	26.2		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.159	21.14	244500			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	34.8	11.3				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	87.1	71.1	13.7	66.4	75.5	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	
1st Stage	75.5	70.6	-15.28	63.6	66.4	
2nd Stage		61.5	-19.18	55.3	60.0	
3rd Stage		54.8	-20.77	43.0	47.1	
4th Stage		33.2	-23.52	24.2	29.0	
4th Condenser			-23.25			
Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)				
	24.2	29.0				

DATE:	8/31/99					
Operation Time (min.):		372		**Heat Input (kJ/min):**		2574.58
Total Production (gal.):		285		**Performance Ratio:**		2.61
Production Rate (gpm):		0.77		**Recovery Ratio:**		93.46%
Total Feed In (gal):		311				
Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
Solar Pond Surface Brine	1.011	1.54	16000	27.9		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.159	21.14	244500			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	32.9	5.0				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	85.0	65.5	8.7	62.0	70.7	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	
1st Stage	70.7	66.0	-15.52	59.1	62.0	
2nd Stage	N/A	57.5	-20.38	52.6	56.4	
3rd Stage	N/A	52.2	-21.83	43.5	46.1	
4th Stage	N/A	33.7	-22.84	23.5	27.2	
4th Condenser			-22.78			
Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)				
	23.5	27.2				

DATE:	9/1/99					
Operation Time (min.):		380		**Heat Input(kJ/min):**		1753.85
Total Production (gal.):		205		**Performance Ratio:**		2.70
Production Rate (gpm):		0.54		**Recovery Ratio:**		92.06%
Total Feed In (gal):		222				
Feed Stock:	S. G.	Salinity	TDS	Temp.		
Solar Pond		(%)	(mg/l)	(C)		
Surface Brine	1.013	1.83	18000	27.1		
Concentrate:	S. G.	Salinity	TDS			
		(%)	(mg/l)			
	1.148	19.78	226700			
Distillate:	Temp.	Conductivity				
	(C)	(mS/cm)				
	31.1	6.7				
Heat Exchanger:	Brine in T	Brine out T	Brine Flow	2nd in T	2nd out T	
	(C)	(C)	(gpm)	(C)	(C)	
	83.2	59.9	5.0	57.8	65.6	
MEMS:	Water in T	Vap. T	Vacuum	Con. In T	Con. Out T	
	(C)	(C)	(in. Hg)	(C)	(C)	
1st Stage	65.6	61.5	-16.26	55.1	57.8	
2nd Stage		53.6	-19.41	47.9	51.8	
3rd Stage		47.5	-20.80	42.2	43.1	
4th Stage		32.7	-21.87	22.8	25.1	
4th Condenser			-21.71			
Cooling Mode:	Cooling tower					
	Inlet T	Outlet T				
	(C)	(C)				
	22.8	25.1				

DATE:	9/7/99		
Operation Time (min.):	206	**Heat Input(kJ/min):**	1789.92
Total Production (gal.):	154	**Performance Ratio:**	3.67
Production Rate (gpm):	0.75	**Recovery Ratio:**	97.39%
Total Feed In (gal):	169		

Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)
Local Well Water	1		1650	25.7

Concentrate:	S. G.	Salinity (%)	TDS (mg/l)
	1.044	6.12	63000

Distillate:	Temp. (C)	Conductivity (mS/cm)
	40.0	5.6

Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)
	86.2	60.5	4.6	58.4	65.2

MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)
1st Stage	65.2	61.9	-19.31	56.4	58.4
2nd Stage	N/A	55.2	-20.38	52.5	54.9
3rd Stage	N/A	52.2	-22.06	44.8	47.5
4th Stage	N/A	37.8	-22.78	28.1	35.4
4th Condenser			-22.40		

Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)
	28.1	35.4

DATE:	9/13/99					
Operation Time (min.):		240		**Heat Input (kJ/min):**		1426.75
Total Production (gal.):		145		**Performance Ratio:**		3.72
Production Rate (gpm):		0.60		**Recovery Ratio:**		98.01%
Total Feed In (gal):		143				
Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
Local Well Water	1		1650	24.1		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.057	7.90	83000			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	41.0	2.9				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	85.1	58.7	3.6	56.8	63.6	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	
1st Stage	63.6	60.7	-16.85	54.5	56.8	
2nd Stage		53.5	-21.70	51.5	53.1	
3rd Stage		51.5	-21.93	47.2	47.6	
4th Stage		39.5	-22.77	36.3	38.5	
4th Condenser			-22.65			
Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)				
	36.3	38.5				

DATE:	9/14/99		
Operation Time (min.):	257	**Heat Input (kJ/min):**	3395.51
Total Production (gal.):	262	**Performance Ratio:**	2.64
Production Rate (gpm):	1.02	**Recovery Ratio:**	98.01%
Total Feed In (gal):	268		

Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)
Local Well Water	1		1650	23.1

Concentrate:	S. G.	Salinity (%)	TDS (mg/l)
	1.057	7.90	83000

Distillate:	Temp. (C)	Conductivity (mS/cm)
	35.0	3.7

Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)
	86.3	65.0	10.5	60.3	69.1

MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)
1st Stage	69.1	65.6	-15.62	57.8	60.3
2nd Stage		56.4	-20.99	51.7	54.8
3rd Stage		51.8	-22.25	42.5	45.0
4th Stage		34.9	-23.30	27.3	31.7
4th Condenser			-23.16		

Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)
	27.3	31.7

DATE:	9/16/99		
Operation Time (min.):	300	**Heat Input (kJ/min):**	4159.40
Total Production (gal.):	371	**Performance Ratio:**	2.61
Production Rate (gpm):	1.24	**Recovery Ratio:**	98.08%
Total Feed In (gal):	368		

Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)
Local Well Water	1		1650	23.7

Concentrate:	S. G.	Salinity (%)	TDS (mg/l)
	1.059	8.17	86000

Distillate:	Temp. (C)	Conductivity (mS/cm)
	35.8	3.5

Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)
	82.7	71.2	23.7	64.2	72.9

MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)
1st Stage	72.9	69.6	-14.72	61.9	64.2
2nd Stage	N/A	60.5	-20.11	55.0	58.5
3rd Stage	N/A	55.2	-21.77	44.1	47.3
4th Stage	N/A	36.3	-23.12	25.3	31.1
4th Condenser			-22.99		

Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)
	25.3	31.1

DATE:	9/23/99					
Operation Time (min.):		364		**Heat Input (kJ/min):**		4119.36
Total Production (gal.):		373		**Performance Ratio:**		2.19
Production Rate (gpm):		1.02		**Recovery Ratio:**		98.77%
Total Feed In (gal):		379				
Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
Local Well Water	1		1650	21.5		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.089	12.19	134000			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	36.6	7.5				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	83.9	71.9	22.7	65.7	74.0	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	
1st Stage	74.0	70.3	-14.81	63.5	65.7	
2nd Stage	N/A	61.9	-19.69	57.5	60.7	
3rd Stage	N/A	57.6	-20.12	47.5	50.2	
4th Stage	N/A	37.2	-22.60	25.6	30.5	
4th Condenser			-22.54			
Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)				
	25.6	30.5				

DATE:	10/4/99		
Operation Time (min.):	414	**Heat Input (kJ/min):**	4130.42
Total Production (gal.):	413	**Performance Ratio:**	2.12
Production Rate (gpm):	1.00	**Recovery Ratio:**	98.79%
Total Feed In (gal):	403		

Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)
Local Well Water	1		1650	21.1

Concentrate:	S. G.	Salinity (%)	TDS (mg/l)
	1.091	12.45	135600

Distillate:	Temp. (C)	Conductivity (mS/cm)
	34.2	7.1

Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)
	84.3	72.9	23.7	64.9	74.5

MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)
1st Stage	74.5	69.9	-14.08	62.5	64.9
2nd Stage	N/A	60.2	-19.85	55.4	58.8
3rd Stage	N/A	55.0	-21.51	44.1	46.9
4th Stage	N/A	34.3	-23.36	23.5	29.1
4th Condenser			-23.16		

Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)
	23.5	29.1

DATE:	10/5/99					
Operation Time (min.):		373		**Heat Input (kJ/min):**		3784.55
Total Production (gal.):		311		**Performance Ratio:**		1.94
Production Rate (gpm):		0.83		**Recovery Ratio:**		83.53%
Total Feed In (gal):		311				
Feed Stock: "Sea Water"	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
	1.03	4.19	43000	22.2		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.169	22.37	261000			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	35.7	6.2				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	83.8	75.1	28.6	67.3	75.9	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	
1st Stage	75.9	71.4	-13.66	65.2	67.3	
2nd Stage	N/A	63.0	-19.28	59.0	62.0	
3rd Stage	N/A	58.2	-20.69	49.6	51.6	
4th Stage	N/A	38.7	-22.80	23.3	28.5	
4th Condenser			-22.64			
Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)				
	23.3	28.5				

DATE:	10/11/99					
Operation Time (min.):		354		**Heat Input (kJ/min):**		2351.49
Total Production (gal.):		222		**Performance Ratio:**		2.34
Production Rate (gpm):		0.63		**Recovery Ratio:**		73.29%
Total Feed In (gal):		437				
Feed Stock: "Sea Water"	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
	1.03	4.19	43000	20.0		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.108	14.68	161000			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	28.0	5.8				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	84.2	59.4	6.0	55.5	64.3	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	
1st Stage	64.3	59.9	-17.94	53.3	55.5	
2nd Stage	N/A	51.1	-22.33	48.5	50.4	
3rd Stage	N/A	47.8	-22.72	42.3	43.0	
4th Stage	N/A	33.8	-23.66	19.2	22.1	
4th Condenser			-23.47			
Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)				
	19.2	22.1				

DATE:	10/13/99					
Operation Time (min.):		294		**Heat Input (kJ/min):**		3560.70
Total Production (gal.):		253		**Performance Ratio:**		2.12
Production Rate (gpm):		0.86		**Recovery Ratio:**		77.25%
Total Feed In (gal):		272				
Feed Stock:	S. G.	Salinity	TDS	Temp.		
"Sea Water"		(%)	(mg/l)	(C)		
	1.03	4.19	43000	20.9		
Concentrate:	S. G.	Salinity	TDS			
		(%)	(mg/l)			
	1.125	16.87	189000			
Distillate:	Temp.	Conductivity				
	(C)	(mS/cm)				
	30.7	6.5				
Heat Exchanger:	Brine in T	Brine out T	Brine Flow	2nd in T	2nd out T	
	(C)	(C)	(gpm)	(C)	(C)	
	84.2	69.3	15.6	61.8	72.3	
MEMS:	Water in T	Vap. T	Vacuum	Con. In T	Con. Out T	
	(C)	(C)	(in. Hg)	(C)	(C)	
1st Stage	72.3	66.3	-16.21	59.2	61.8	
2nd Stage	N/A	56.3	-21.58	51.4	54.6	
3rd Stage	N/A	49.9	-22.53	39.6	42.3	
4th Stage	N/A	30.6	-23.96	21.0	25.7	
4th Condenser			-23.75			
Cooling Mode:	Cooling tower					
	Inlet T	Outlet T				
	(C)	(C)				
	21.0	25.7				

DATE:	10/14/99		
Operation Time (min.):	354	**Heat Input (kJ/min):**	4040.40
Total Production (gal.):	332	**Performance Ratio:**	2.04
Production Rate (gpm):	0.94	**Recovery Ratio:**	86.17%
Total Feed In (gal):	365		

Feed Stock: "Sea Water"	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)
	1.03	4.19	43000	21.4

Concentrate:	S. G.	Salinity (%)	TDS (mg/l)
	1.2	26.08	311000

Distillate:	Temp. (C)	Conductivity (mS/cm)
	33.7	7.8

Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)
	84.4	75.3	29.6	66.2	76.0

MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)
1st Stage	76.0	70.5	-14.69	64.1	66.2
2nd Stage	N/A	61.1	-20.11	56.4	59.6
3rd Stage	N/A	54.9	-21.82	43.6	46.2
4th Stage	N/A	32.3	-23.71	21.4	26.8
4th Condenser			-23.52		

Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)
	21.4	26.8

DATE:	10/20/99					
Operation Time (min.):		281		**Heat Input (kJ/min):**		2956.11
Total Production (gal.):		200		**Performance Ratio:**		2.12
Production Rate (gpm):		0.71		**Recovery Ratio:**		67.37%
Total Feed In (gal):		199				
Feed Stock:	S. G.	Salinity	TDS	Temp.		
"Sea Water"		(%)	(mg/l)	(C)		
	1.038	5.30	54000	11.6		
Concentrate:	S. G.	Salinity	TDS			
		(%)	(mg/l)			
	1.11	14.94	165500			
:	Temp.	Conductivity				
	(C)	(mS/cm)				
	29.1	8.4				
Heat Exchanger:	Brine in T	Brine out T	Brine Flow	2nd in T	2nd out T	
	(C)	(C)	(gpm)	(C)	(C)	
	83.1	67.6	12.5	60.9	70.8	
MEMS:	Water in T	Vap. T	Vacuum	Con. In T	Con. Out T	Flow Rate
	(C)	(C)	(in. Hg)	(C)	(C)	(gpm)
1st Stage	70.8	64.7	-16.37	58.7	60.9	22.2
2nd Stage	N/A	55.5	-21.59	52.4	54.9	N/A
3rd Stage	N/A	50.6	-22.75	42.7	44.0	N/A
4th Stage	N/A	33.8	-23.84	17.6	21.3	N/A
4th Condenser			-23.66			
Cooling Mode:	Cooling tower					
	Inlet T	Outlet T				
	(C)	(C)				
	17.6	21.3				

DATE:	10/25/99		
Operation Time (min.):	294	**Heat Input (kJ/min):**	3998.56
Total Production (gal.):	286	**Performance Ratio:**	2.14
Production Rate (gpm):	0.97	**Recovery Ratio:**	69.66%
Total Feed In (gal):	287		

Feed Stock: "Sea Water"	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)
	1.038	5.30	54000	14.8

Concentrate:	S. G.	Salinity (%)	TDS (mg/l)
	1.118	15.97	178000

Distillate:	Temp. (C)	Conductivity (mS/cm)
	32.7	7.9

Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)
	82.9	75.4	35.0	65.2	75.5

MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)
1st Stage	75.5	69.7	-15.49	62.9	65.2
2nd Stage	N/A	59.9	-20.99	54.9	58.3
3rd Stage	N/A	53.3	-22.49	41.6	44.5
4th Stage	N/A	33.1	-23.78	19.7	24.9
4th Condenser			-23.54		

Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)
	19.7	24.9

DATE:	10/26/99					
Operation Time (min.):		408		**Heat Input (kJ/min):**		2804.85
Total Production (gal.):		308		**Performance Ratio:**		2.36
Production Rate (gpm):		0.75		**Recovery Ratio:**		78.73%
Total Feed In (gal):		327				
Feed Stock: "Sea Water"	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
	1.036	5.02	52000	15.2		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.159	21.14	244500			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	27.0	6.0				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	82.2	62.7	9.5	56.3	67.3	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	
1st Stage	67.3	61.0	-18.07	53.3	56.3	
2nd Stage	N/A	50.7	-22.39	46.7	49.3	
3rd Stage	N/A	45.5	-22.47	36.2	38.3	
4th Stage	N/A	26.8	-24.32	17.8	21.6	
4th Condenser			-24.14			
Cooling Mode:	Cooling tower					
	Inlet T (C)	Outlet T (C)				
	17.8	21.6				

DATE:	10/27/99					
Operation Time (min.):		360		**Heat Input (kJ/min):**		3561.16
Total Production (gal.):		287		**Performance Ratio:**		1.97
Production Rate (gpm):		0.80		**Recovery Ratio:**		78.73%
Total Feed In (gal):		381				
Feed Stock: "Sea Water"	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
	1.036	5.02	52000	16.8		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.159	21.14	244500			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	31.6	10.1				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	81.9	70.7	20.9	62.0	72.5	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	
1st Stage	72.5	66.4	-16.11	59.4	62.0	
2nd Stage	N/A	56.3	-20.34	52.8	55.5	
3rd Stage	N/A	52.0	-21.24	42.9	44.6	
4th Stage	N/A	32.9	-23.61	20.4	24.7	
4th Condenser			-23.43			
Cooling Mode:	Cooling tower					
	Inlet T (C)	Outlet T (C)				
	20.4	24.7				

DATE:	10/29/99					
Operation Time (min.):		360		**Heat Input (kJ/min):**		3951.40
Total Production (gal.):		318		**Performance Ratio:**		1.96
Production Rate (gpm):		0.88		**Recovery Ratio:**		79.88%
Total Feed In (gal):		409				
Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
"Sea Water"	1.035	4.88	50500	17.4		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.163	21.63	251000			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	33.5	9.6				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	81.6	75.5	42.2	65.4	75.2	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	Flow Rate (gpm)
1st Stage	75.2	69.4	-14.72	63.4	65.4	28.4
2nd Stage	N/A	60.0	-20.02	56.3	59.3	N/A
3rd Stage	N/A	55.4	-21.19	45.1	47.0	N/A
4th Stage	N/A	34.5	-23.33	20.0	25.0	N/A
4th Condenser			-23.14			
Cooling Mode:	Cooling tower Inlet T (C)	Outlet T (C)				
	20.0	25.0				

DATE:	11/2/99					
Operation Time (min.):		240		**Heat Input (kJ/min):**		4122.32
Total Production (gal.):		209		**Performance Ratio:**		1.86
Production Rate (gpm):		0.87		**Recovery Ratio:**		80.43%
Total Feed In (gal):		273				
Feed Stock: "Sea Water"	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
	1.035	4.88	50500	13.7		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.167	22.12	258000			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	31.5	9.9				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	82.0	75.7	43.4	65.5	75.4	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	Flow Rate (gpm)
1st Stage	75.4	69.2	-15.35	63.3	65.5	28.3
2nd Stage	N/A	59.9	-20.74	56.2	59.2	N/A
3rd Stage	N/A	54.8	-21.87	44.8	46.1	N/A
4th Stage	N/A	32.9	-23.96	16.2	22.4	N/A
4th Condenser			-23.70			
Cooling Mode:	Solar pond surface brine					
	Inlet T (C)	Outlet T (C)				
	16.2	22.4				

DATE:	11/3/99					
Operation Time (min.):		198		**Heat Input (kJ/min):**		4073.67
Total Production (gal.):		183		**Performance Ratio:**		1.99
Production Rate (gpm):		0.92		**REcovery Ratio:**		77.61%
Total Feed In (gal):		245				
Feed Stock:	S. G.	Salinity	TDS	Temp.		
"Sea Water"		(%)	(mg/l)	(C)		
	1.04	5.60	58000	13.8		
Concentrate:	S. G.	Salinity	TDS			
		(%)	(mg/l)			
	1.168	22.25	259000			
Distillate:	Temp.	Conductivity				
	(C)	(mS/cm)				
	27.6	9.4				
Heat Exchanger:	Brine in T	Brine out T	Brine Flow	2nd in T	2nd out T	
	(C)	(C)	(gpm)	(C)	(C)	
	81.1	71.4	27.6	61.5	72.3	
MEMS:	Water in T	Vap. T	Vacuum	Con. In T	Con. Out T	Flow Rate
	(C)	(C)	(in. Hg)	(C)	(C)	(gpm)
1st Stage	72.3	66.5	-16.47	58.9	61.5	25.3
2nd Stage	N/A	55.9	-21.73	51.2	54.5	N/A
3rd Stage	N/A	50.0	-22.81	38.9	41.2	N/A
4th Stage	N/A	28.2	-24.24	15.2	21.6	N/A
4th Condenser			-24.10			
Cooling Mode:	Solar pond surface brine					
	Inlet T	Outlet T				
	(C)	(C)				
	15.2	21.6				

DATE:	11/5/99					
Operation Time (min.):		240		**Heat Input (kJ/min):**		2222.68
Total Production (gal.):		102		**Performance Ratio:**		1.68
Production Rate (gpm):		0.43		**Recovery Ratio:**		81.02%
Total Feed In (gal):		131				
Feed Stock: "Sea Water"	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
	1.036	4.88	50500	13.7		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.172	22.73	266000			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	27.3	8.2				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	79.6	60.6	7.7	55.3	65.5	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	Flow Rate (gpm)
1st Stage	65.5	60.1	-17.67	52.4	55.3	16.3
2nd Stage	N/A	50.0	-22.59	47.1	49.1	N/A
3rd Stage	N/A	45.6	-23.12	39.0	39.9	N/A
4th Stage	N/A	27.1	-24.03	17.2	21.4	N/A
4th Condenser			-23.88			
Cooling Mode:	Solar pond surface water					
	Inlet T (C)	Outlet T (C)				
	17.2	21.4				

DATE:	11/16/99		
Operation Time (min.):	365	**Heat Input (kJ/min):**	4583.23
Total Production (gal.):	411	**Performance Ratio:**	2.16
Production Rate (gpm):	1.13	**Recovery Ratio:**	98.51%
Total Feed In (gal):	406		

Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)
Rio Grande Water	1	0.00		16.2

Concentrate:	S. G.	Salinity (%)	TDS (mg/l)
	1.046	6.40	66800

Distillate:	Temp. (C)	Conductivity (mS/cm)
	29.5	5.0

Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)
	79.5	74.5	60.2	62.6	73.2

MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	Flow Rate (gpm)
1st Stage	73.2	68.5	-14.97	59.9	62.6	29.2
2nd Stage	N/A	58.0	-20.44	51.5	55.4	N/A
3rd Stage	N/A	51.6	-21.83	38.6	41.9	N/A
4th Stage	N/A	30.8	-23.88	17.2	26.8	N/A
4th Condenser			-23.73			

Cooling Mode:	Solar pond surface water	
	Inlet T (C)	Outlet T (C)
	17.2	26.8

DATE:	11/18/99		
Operation Time (min.):	300	**Heat Input (kJ/min):**	4492.81
Total Production (gal.):	329	**Performance Ratio:**	2.14
Production Rate (gpm):	1.10	**Recovery Ratio:**	98.68%
Total Feed In (gal):	332		

Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)
Rio Grande Water	1	0.00		18.4

Concentrate:	S. G.	Salinity (%)	TDS (mg/l)
	1.052	7.20	75600

Distillate:	Temp. (C)	Conductivity (mS/cm)
	28.0	3.7

Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)
	78.9	72.1	43.3	61.2	71.5

MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	Flow Rate (gpm)
1st Stage	71.5	66.5	-16.17	58.5	61.2	28.8
2nd Stage	N/A	56.2	-21.23	50.7	54.2	N/A
3rd Stage	N/A	50.8	-21.95	38.0	41.6	N/A
4th Stage	N/A	29.8	-23.79	15.8	24.4	N/A
4th Condenser			-23.63			

Cooling Mode:	Solar pond surface brine	
	Inlet T (C)	Outlet T (C)
	15.8	24.4

DATE:	11/22/99		
Operation Time (min.):	360	**Heat Input (kJ/min):**	3882.42
Total Production (gal.):	377	**Performance Ratio:**	2.37
Production Rate (gpm):	1.05	**Recovery Ratio:**	98.68%
Total Feed In (gal):	379		

Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)
Rio Grande Water	1	0.00		14.1

Concentrate:	S. G.	Salinity (%)	TDS (mg/l)
	1.052	7.22	75600

Distillate:	Temp. (C)	Conductivity (mS/cm)
	24.5	3.2

Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)
	78.8	64.1	17.4	56.2	66.1

MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	Flow Rate (gpm)
1st Stage	66.1	61.0	-16.85	53.6	56.2	27.1
2nd Stage	N/A	51.0	-22.00	46.4	49.6	N/A
3rd Stage	N/A	46.6	-22.69	35.3	37.3	N/A
4th Stage	N/A	27.4	-24.12	14.0	22.6	N/A
4th Condenser			-23.99			

Cooling Mode:	Solar pond surface brine	
	Inlet T (C)	Outlet T (C)
	14.0	22.6

DATE:	11/23/99		
Operation Time (min.):	340	**Heat Input (kJ/min):**	4828.18
Total Production (gal.):	370	**Performance Ratio:**	1.98
Production Rate (gpm):	1.09	**Recovery Ratio:**	98.80%
Total Feed In (gal):	369		

Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)
Rio Grande Water	1			13.0

Concentrate:	S. G.	Salinity (%)	TDS (mg/l)
	1.057	7.90	83300

Distillate:	Temp. (C)	Conductivity (mS/cm)
	24.4	2.9

Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)
	79.0	71.7	43.9	60.5	71.1

MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	Flow Rate (gpm)
1st Stage	71.1	66.0	-16.50	57.8	60.5	31.3
2nd Stage	N/A	55.4	-21.66	49.1	53.1	N/A
3rd Stage	N/A	49.3	-22.65	35.0	38.0	N/A
4th Stage	N/A	26.3	-24.56	11.9	20.8	N/A
4th Condenser			-24.44			

Cooling Mode:	Solar pond surface water	
	Inlet T (C)	Outlet T (C)
	11.9	20.8

DATE:	12/2/99		
Operation Time (min.):	184	**Heat Input (kJ/min):**	4492.29
Total Production (gal.):	203	**Performance Ratio:**	2.16
Production Rate (gpm):	1.10	**Recovery Ratio:**	26.69%
Total Feed In (gal):	199		

Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)
Paso View Water	1.002		2200	12.9

Concentrate:	S. G.	Salinity (%)	TDS (mg/l)
	1.002	0.30	3000

Distillate:	Temp. (C)	Conductivity (mS/cm)
	25.7	4.5

Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)
	77.4	73.3	72.5	61.4	72.0

MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	Flow Rate (gpm)
1st Stage	72.0	66.5	-16.04	58.6	61.4	N/A
2nd Stage	N/A	55.9	-21.01	50.8	54.6	N/A
3rd Stage	N/A	51.0	-22.14	34.9	40.0	N/A
4th Stage	N/A	28.3	-24.09	12.6	22.0	N/A
4th Condenser			-23.96			

Cooling Mode:	Solar pond surface water	
	Inlet T (C)	Outlet T (C)
	12.6	22.0

DATE:	12/3/99					
Operation Time (min.):		300		**Heat Input (kJ/min):**		3003.95
Total Production (gal.):		181		**Performance Ratio:**		1.76
Production Rate (gpm):		0.60		**Recovery Ratio:**		68.59%
Total Feed In (gal):		175				
Feed Stock:	S. G.	Salinity (%)	TDS (mg/l)	Temp. (C)		
Paso View Water	1.002		2200	13.7		
Concentrate:	S. G.	Salinity (%)	TDS (mg/l)			
	1.005	0.70	7000			
Distillate:	Temp. (C)	Conductivity (mS/cm)				
	24.3	3.5				
Heat Exchanger:	Brine in T (C)	Brine out T (C)	Brine Flow (gpm)	2nd in T (C)	2nd out T (C)	
	76.7	64.1	15.7	57.4	66.2	
MEMS:	Water in T (C)	Vap. T (C)	Vacuum (in. Hg)	Con. In T (C)	Con. Out T (C)	Flow Rate (gpm)
1st Stage	66.2	61.1	-16.41	54.9	57.4	N/A
2nd Stage	N/A	52.4	-21.59	49.9	52.3	N/A
3rd Stage	N/A	49.9	-22.20	39.7	40.2	N/A
4th Stage	N/A	28.6	-23.22	11.2	17.8	N/A
4th Condenser			-22.89			
Cooling Mode:	Solar pond surface water					
	Inlet T (C)	Outlet T (C)				
	11.2	17.8				