RECLAMATION

Managing Water in the West

Desalination and Water Purification Research and Development Program Report No 183

Modification and Operation of a Full Solar Distillation Desalination Unit at the BGNDRF Site at Alamogordo, New Mexico, Phase II

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

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14. ABSTRACT
Phase I tested Suns River Solar Desalination process and identified several areas for further exploration and testing. Phase II tested a design change from a single large structure to modular structures designed and sized to facilitate larger production and multi-modal container shipping and several process improvement. The updated Suns River Solar Still operated with nighttime recovery of distillate from heated cooling water resulting in regeneration of the next day's cooling water is a process which can serve water needs for a family or a group of families.

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Prepared for the Bureau of Reclamation Under Agreement No. R13AC80024

by

Hill Kemp, Suns River

U.S. Department of the Interior
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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

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.

Disclaimer

Acronyms and Abbreviations

Reclamation	Bureau of Reclamation
TDS	total dissolved solids
UTEP	University of Texas, El Paso
ZLD	Zero Liquid Discharge

Measurements

°F	degree Fahrenheit
PPM	parts per million
liters/m^2	liters per square meter

Contents

Executive Summary

Activities under this Reclamation Desalination and Water Purification Research Program began with a thorough review of engineering design and construction of solar stills featuring solar powered Multi-Stage Flash. It became clear that changing from one large structure to modular systems sized for mass manufacturing and transport would provide a more economical, long-term design.

In an earlier phase of this research (conducted under a separate agreement), operating the first 5.5 square meter module indicated some areas for improvement. In this second phase, we tested a second module, which was designed for better performance and lower cost. Initial operation with both modules showed performance close to target: with interior temperatures more than 60 degrees Fahrenheit (°F) above ambient temperatures produced over 10 liters/square meter of product water.

The process was outfitted with simple timers to handle 24-hour operation and ran for 13 days uninterrupted in 2014, ending only for the July 4 long holiday weekend. Operations in August, September and October were heavily blocked by monsoon clouds, rain and flooding. Operations were suspended in mid-October because of requirements of the *Securing Water for Food Desal* Prize.

The second effect, used to recover additional distillate from daytime solar heated cooling water overnight was tested in several configurations. The most effective configuration used an internal circulating fan and pump, which resulted in high production and brought pool temperatures in line down enough to use the water for cooling the next day. Solar still evaporation floor circulation was concentrated up to 110,000 parts per million (PPM) of total dissolved solids (TDS) and this concentrate readily evaporated to dry salt in only two days, meeting the goal of Zero Liquid Discharge (ZLD). A University of Texas, El Paso (UTEP) graduate engineer based his master’s thesis on heat and material balances of the Suns River Solar Still. His work (Appendix) shows that the process recovers more than 80 percent of the incoming solar energy in the cooling water and explains in detail why that high recovery occurs concurrent with distillate production.

1. Introduction

Research under this activity follows on the work done under DWPR Grant # R11SF80835. Figure 1 shows the solar still used in Phase I. That activity conducted preliminary testing of the Suns River Solar Desalination process and identified several areas for further exploration and testing. The major shift in design equipment was changing from a single large structure to modular structures designed and sized to facilitate mass production and multi-modal container shipping. The new design incorporated several process improvements along with the change in size and shape.

Figure 1. The single 37 square meter Solar Still (Phase I design).

Phase II operations of the modular Solar Stills at BGNDRF had several key goals:

1. Test and optimize the modular design of the solar still
2. Stabilize operations to minimize operator attention required
3. Optimize recovery and thermal performance of the Second Effect night operations.
4. Reduce the concentrate from the evaporation floor circulation and evaporation to dry salt.

2. Conceptual Design

The revised design features a series of 5.5-square-meter modules built as two independent 2.75-square-meter halves. The physical dimensions permit loading in standard shipping containers (storing 16 to 18 modules in each container). The modules are built with a double layer of glass for solar power transmission and the cooling tubing is installed directly beneath the evaporation floor. Openings at the top and bottom of the evaporation floor facilitate solar generated hot, humid air rising up the sloped evaporation floor. The water cooled tubes establish a denser, colder air mass below. The combined effect is an internal, natural circulation within the module which enhances both evaporation from the salt solution on top and condensation of distillate below. The result is a compact, sturdy structure housing the entire process in a shape around 15 inches deep by

96 inches wide by 105 inches tall (Figure 2).

Figure 2. Two 5.5 square meter modules at left and the 12 square meter by 1 meter deep Second Effect at right.

The solar stills' modular design also opens the possibility of desert food gardening with stills configured in a pergola roof design to create a partially shaded space below. The combination of distillate production and shaded ground space can yield a food garden from a space of desert and some salt water. This design provides both the needed shade and water (Figure 3).

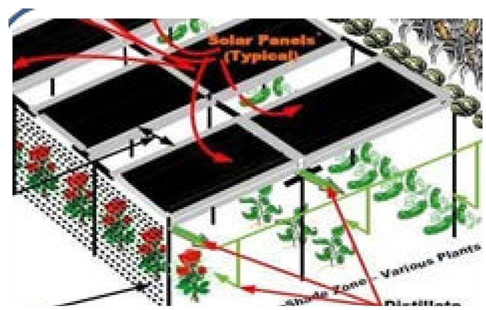

Figure 3. Artist sketch demonstrates the desert food garden concept.

2.1. Equipment and Methods

2.1.1. Overview:

The basic design change from a single large structure to modules based on mass manufacturing and shipping yields a much more marketable product at less expense. The basic module, shown below, incorporates double pane glass to reduce condensation on the inner glass, evaporation floor treatment to maximize area for the thin film and cooling tubing looped in the space below the evaporation floor. The module uses "sandwich structural composite" construction using sheet metal and the thermal insulation eliminating heavy structural members. With this lightweight construction the principal weight of the module is glass (around 175 pounds for a single module). Figure 4 shows the schematic for the solar still.

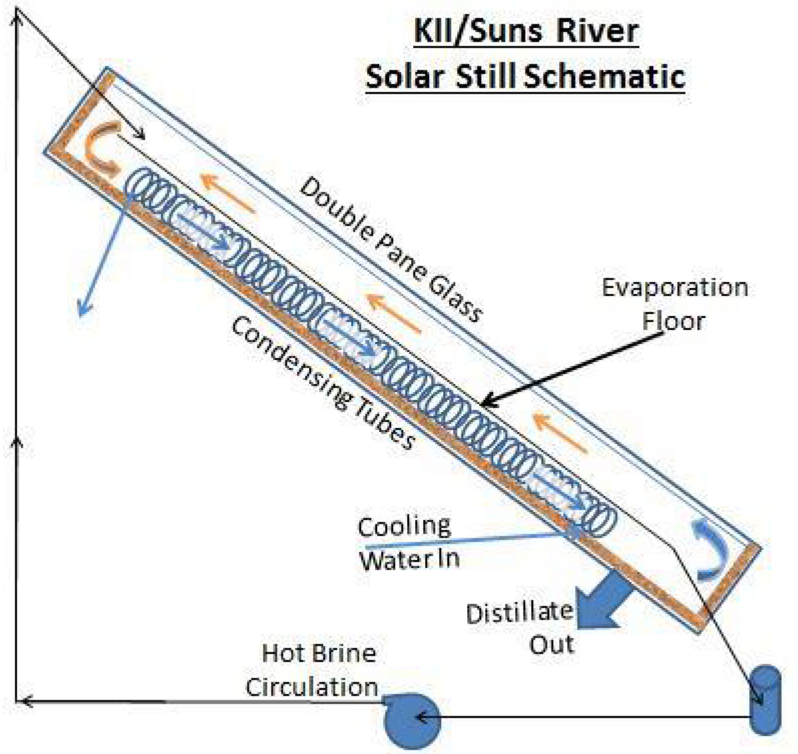

Figure 4. KII/Suns River solar still schematic.

2.1.2. Equipment Design

The module is constructed with insulation on the bottom and all sides (shown in brown in Figure 4. The double pane glass admits solar energy, which is absorbed on the black evaporation floor. The floor is covered with a black wick material and has a thin film of brine recirculating by flowing down the slope. The hot water vapor generated flows up the slope between the evaporation floor and the inner glass. The space under the evaporation floor contains coils of tubing supplied from the bottom with cooling water. As shown by the blue arrows, the colder air flows down condensing distillate for collection. This establishes a natural circulation removing the hot water as it is generated and condensing it in the underside downflow. The process is similar to a natural weather system. Module configuration can be as a single 2.75 square meter module or built as a pair with 5.5 square meter surface for convenience of manufacturing and transport.

The Suns River Second Effect is essentially a classic Solar Still with a large greenhouse placed over a pool of salt water. A key difference, however, is the water in the large pool enters the space already hot: 20 to 40 °F above ambient temperature. At night when the desert ambient temperature drops another 30 to 40 °F, the Second Effect thermal drive goes up to above 60 °F and production rises significantly. Adding a pump circulating the pool inventory and fan(s) circulating the internal environment assures recovery. This arrangement both increases distillate production and, by dawn, brings the pool temperature to within 5 to 10 °F of the nighttime low temperature. At dawn, this water is pumped to the Cooling Water Tank for use as cooling water for the next day. Well water is added to the Cooling Water Tank to make up for distillate production and for brine sent to the Evaporation Pan (Figure 5).

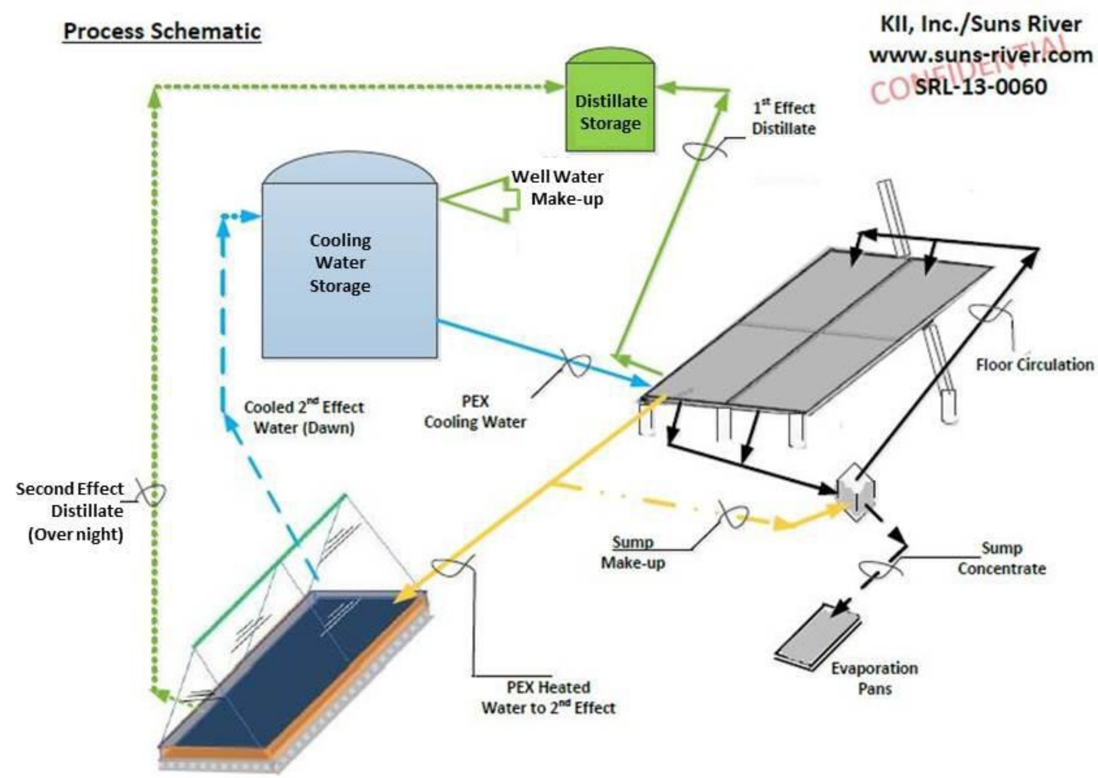

Figure 5. Solar still process schematic.

The Evaporation Pans are shallow large pans for receiving concentrated brine from the Module Floor Circulation. The concentrated brine depth is established at a low level ($^1/_2$ to $^3/_4$ inches) so that the liquid component of the concentrate is evaporated leaving dry salt within 2 to 3 days. In a user installation, multiple pans would be available so that there would always be a pan with a dry salt layer to receive new brine. The amount of dissolved solids removed with the concentrate equals the amount coming in with the feed water. The dried salt can either be sequestered in place in solid form or sold for mineral

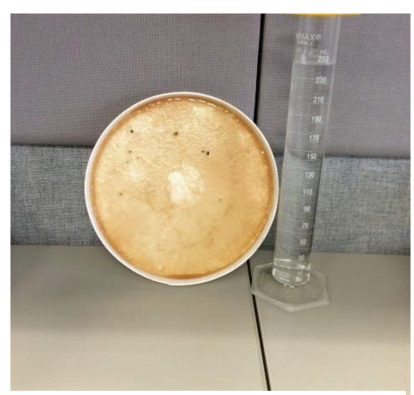

Figure 6. A small pan with salt deposit from concentrated brine after two days drying time.

content. The only net products are distilled water and sun-dried salt.

2.2. Project Testing

Alamogordo experienced monsoon storms nearly every day in August and the average humidity in September was higher than August. Several of the operations testing plans, delayed by the weather, had to be dropped when operations were suspended due to the approaching *Securing Water for Food Desal Prize*. However, most all of the key tests got at least limited runs and the design advanced.

3. Discussion of Results

We tested operations using Module #1 (5.5 square meters [m^2]) from December through April 2014, adding Module #2 (5.5 m^2) in early May and Module #3 in early July. Module #3 performance was a 7% improvement over Module #1 in kwh/liter (1.29 vs 1.39).

Modules #1 and #2 were outfitted with timers and controls and operated around the clock from June 20 through July 3. This is the longest continuous run to date. There was some cloud cover during the period, especially in early July. Production ranged from 51 liters per day (4.6 liters per square meter [liters/m^2]) to 105 liters per day (9.5 liters/m^2). Total production for the run was approximately 910 liters (240 gallons), with average daily production of 70 liters.

Table 1 is a sample of operation data from one 24-hour period during the 13-day run. The total production of 105 liters in 24 hours is among the higher production days and there was only minor cloud interference.

Solar Stills: Suns River

Time		Cloud?	Wind?	Temperatures, Degrees F Ambient	M1 Btm	M1 Top	M2 Btm	M2 Sump	M1 Sump	M2 PEX In	M2 PEX out	PEX>2nd	Distillate Make, liters M1 Prod E	M1 Prod W	M2 Prod E	M2 Prod W	2nd Eff. Prod	Temperatures, Degrees F 2nd Pool Top	2nd Pool Btm	2nd Dry bulb	2nd Dew PT	2nd Rel H	W/m² Solar Meter Cum
700		Clear	Wdy			79.6												102	103	74		99.2	
930		Clear	Brz										0.35	0.13	550	0.25							0.70
1000		Clear	Brz	83	115.3	133.4	103		124			109.2						105	101	111	102		1.10
1100		Clear	Brz	87			106	128		99	127	123	1.63	1	1.52	1.43		116	112	118	113		1.69
1200		Clear	Sl br	94			109					131					11.3	123	118	125	118		2.48
1300		Clear	calm	97		168.3	115.2		137	101	149.5	139	4.34	2.8	4.1	4	15.1	130	125	134	122	73.9	3.40
1400		Clear	Sl br	96		169.5	117.5				151.6	140					20.8	131	129	137	122	68	4.40
1500		Clear	VSBr	99.5		170	116.8				145	139					26.5	132	130	136	121	69	5.08
1600		PC	VSBr	99				134	139		146.7	136	8.25	5.21	8.13	7.67	30.2	132	131	131	124	87	5.84
700	25-Jun	Clear	calm	80.4		78.6	75						9.62	5.93	8.94	8.94	71.8	86.2	86	87	86	97.8	7.10

Notes: Total Production 105 liters, 11 square meters, 9.5 liters/m2, 78.1 kwh, 1.34 liters/kwh
Wdy - windy, Brz = breezy, Sl br = slight breeze, VSBr = very slight breeze, Top = Still interior at top, Btm = Still interior at bottom, 2nd = Second Effect,

Sample Logsheet, During 13-Day Run, June 24 -> 25, 2015, 24 hour operation

Table 1. Sample Logsheet

UTEP graduate student, Houman Azari, used data from the August 28 2015 run of Module #3 to analyze the Suns River Still in detail. Data from that run is in his Master's Thesis in the Appendix. Mr. Azari found that the solar still's First Effect captured 83% of the incoming solar energy as heat in the cross-linked polyethylene (PEX) cooling water system while the theoretical energy requirement for the production of distillate required 56% of that energy (Figure 7). The plot below is of that run showing the liters of distillate production for each half hour.

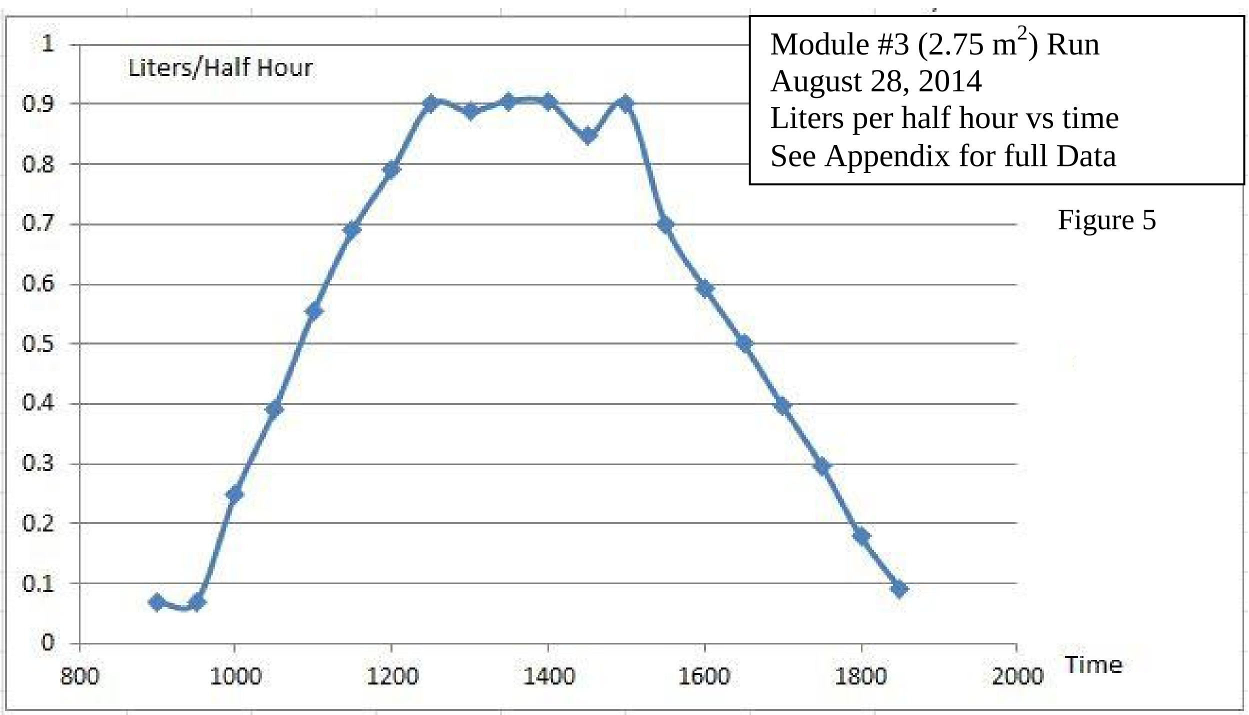

Figure 7. Liters of distillate production for each half hour on August 28, 2014,

Mr. Azari also found that 86% of the heat loss from the process is from the glass window and this is an area for future improvement in the design.

Early operations of the Second Effect indicated that there was some room for improvement in both distillate production and pool cooling. A small version of the Second Effect was built with triple the roof surface/pool surface ratio. Repeated tests indicated no improvement in performance with greater roof condensation area. We added an industrial vibrator to the existing Second Effect and used it to clear droplets off the clear roof interior periodically. While the results were visually dramatic, there was no discernable impact on productivity so use of the vibrator was suspended.

Addressing the internal air and water dynamic, a circulating fan was added inside the Second Effect. Additionally a small submersible pump was outfitted to circulate the pool inventory. These latter changes yielded the results we sought:the Second Effect produced 6.2 liters/m^2 based on First Effect area. With Module #3 production at 4 liters/m^2 and the Second Effect adding 6.2 liters/m^2, total production was 10.2 liters/m^2.

In the final run during October, the two halves of Module #2 were piped with the PEX cooling water in series. That hot water was routed as cooling water to Module #3. The result was a total rise in cooling water temperature of 32 °F. Distillate production remained the same for both sides of Module #2 and decreased by 17% in Module #3 reflecting the hotter condensing water. Mr. Azari's thesis calculations show that a hypothetical fifth stage in such a series would lose about 25% in distillate production (Appendix).

4. Conclusions and Recommendations

4.1. Conclusions

1) The updated Suns River Solar Still provides the ability to recover distillate from heated cooling water at night—thus regenerating the next day's cooling water.

2) The operation is simple, upkeep is nominal.

3) Adapting the Second Effect with a circulating pump and internal fan is a marked improvement in equipment performance and the design; however this would also add capital cost and would consume solar energy.

4) Concentration of the evaporation floor circulation to high levels to create brine for evaporation to dry salt is a key addition to the process and eliminates any brine waste. The dry salt can be sequestered onsite or sold for mineral value.

4.2. Recommendations

1) Heat loss through the glass needs to be reduced heat loss. Investigate using Low-E glass and vacuum insulation between the two glass layers to lessen heat loss through the glass.

2) Investigate using the moderate temperature energy contained in the heated PEX coolant

3) Address constructive use for the dried salt as building materials or for salt sales.

4) Explore reusing the incoming solar energy as heat in the solar still cooling water investigations multiple times before finally sending it to the existing Second Stage for recovery and cooling water regeneration. This is particularly germane to application of the process in seaside locations.

5) Develop relatively simple automation so equipment can be operated with very little attention for normal household applications.