

# Solar Evaporator for Integrated on-Farm Drainage Management System at Red Rock Ranch, San Joaquin Valley, California

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## ABSTRACT

The following summarizes the results of a three-year study of a 10,000 square ft solar evaporator pilot project for storing and concentrating subsurface drainage water effluent from a San Joaquin Valley farming operation. The goal of this project was to collect information for the development of a farm-scale solar evaporator for the 640-acre Integrated On-Farm Drainage Management (IFDM) system at Red Rock Ranch and for future IFDM systems in the San Joaquin Valley. IFDM is a zero liquid discharge farming system that manages its drainage water by sequentially reusing it to grow increasingly salt-tolerant crops and evaporating the final effluent in a solar evaporator. A solar evaporator is a type of enhanced evaporation system that is necessary at the end of the IFDM system for achieving the zero-liquid discharge regulatory requirement. IFDM systems are defined and regulated under Article 9.7 Health and Safety Code, Section 25209.11, (c), (1-4) of the State of California. Highly concentrated agricultural subsurface drainage water collected from the last drainage water reuse cycle of the IFDM system is discharged and evaporated in the solar evaporator using timed spray sprinklers. The remaining salts are stored on the surface of the evaporator for later recycling or disposal.

## OBJECTIVE

The purpose of this study was to evaluate data on evaporation rates of subsurface drainage water using a variety of evaporative substrates, nozzles, materials, and equipment so that a farm-scale solar evaporator could ultimately be designed and constructed. The pilot-scale solar evaporator was used to evaporate drainage water and recover salts, determine the optimum weather parameters for operating a solar evaporator, and examine methods to control the potential for salt drift. Data obtained from this pilot study will be used to design and construct a solar evaporator for Red Rock Ranch.

## APPROACH

Construction of the pilot-scale solar evaporator included 1) testing various nozzles (spray patterns, angles, and pressures) and substrates 2) evaluation of test data, 3) design and, 4) actual construction (Figure 1).



Figure 1, Pilot Solar Evaporator

#### DATA COLLECTION

Prior to operation of the solar evaporator, several types of nozzles or fan sprinklers were tested at a testing facility located at the California State University, Fresno (CSUF) Center for Irrigation Technology. Test Parameters included pressure, discharge and dispersion dimensions (height, radius, density). The pilot solar evaporator evaporative surface area was constructed using a 2% gradient. The evaporative surface and reservoir were lined with 30-mil plastic to prevent seepage. Three substrate types were tested on a 100 ft x 100 ft evaporative surface; 2-inch aggregate uniform fill, 2-inch randomly distributed aggregate, and a bare liner surface without aggregate. Accessory equipment included two five-horse power pumps. The test parameters, water discharge, pressure, rates of evaporation, total dissolved solids concentration, and chemical composition of brines, were assessed using appropriate measuring and monitoring equipment. Weather parameters were collected from a telemetered CIMIS Station near the project site. Tests to monitor salt drift outside of the solar evaporator area were conducted independently by teams from DWR and CSUF.

#### METHODOLOGY

Once coarse aggregate was determined to be the optimum surface material, it was distributed uniformly over the evaporator surface. The evaporation process was conducted as a batch operation in which a 10,000-gallon reservoir was filled daily with effluent from the RRR subsurface drainage water sump. The reservoir consisted of a perforated culvert covered with gravel. Water that fails to evaporate on the surface of the evaporator drains back into the reservoir and is circulated to the fan sprinklers and reapplied to the aggregate substrate. Nozzles with various spray patterns were tested on different sprinkler heights and with distribution configurations ranging from 0.25 to 2.5

ft. The nozzles with the horizontal spray pattern were ultimately selected and a screened chain link fence was installed to control most of the salt drift (Figure 1).

## RESULTS

The solar evaporator was constructed with a two percent gradient and the surface was uniformly covered with coarse, two inch aggregate. Two industrial nozzles the BETE TF 12-170 and BETE TF 12-180 proved to be the most effective for enhancing evaporation and reducing drift. These spray nozzles are made of brass, are energy efficient, and clog-resistant. The nozzles have a hollow cone spray pattern and 170 and 180 degree spray angles. Flow rates ranged from 2.12-7.35 gpm for water pressures of 5-60 psi.

During the spring and fall, daily evaporation rates ranged from 0.7-1.1 inches; during the summer months the range increased to 1.3-4.2 inches. Figure 3 compares evaporation rates from the solar evaporator to the actual daily evaporation rate measured at the RRR CIMIS station for nozzle heights of 0.25-2.0 ft. To take advantage of the increased daily evaporation rate, the optimum time to operate the solar evaporator is May through September.

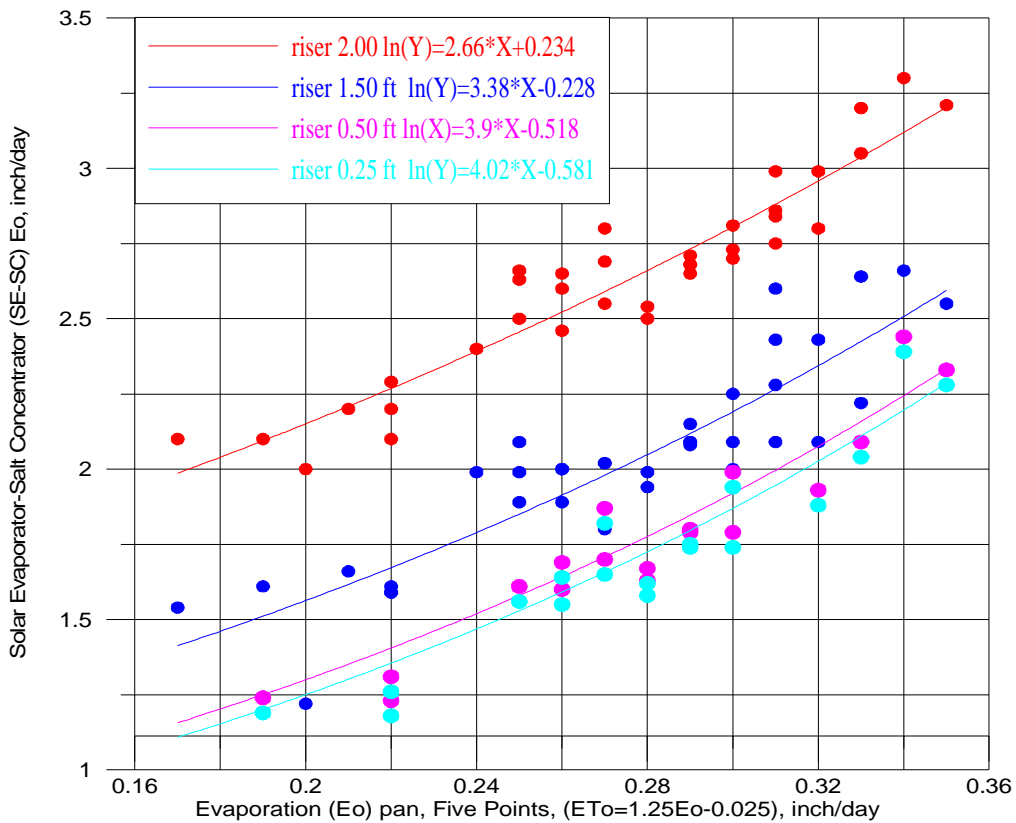


Figure 2, Solar Evaporator Evaporation Rates by Nozzle Height

The brine resulting from the last IFDM drainage water reuse cycle was concentrated in four steps using containers located outside the solar evaporator. The first step increased salt concentrations to 10-48 g/l, the second increased concentrations to 48-107 g/l; the

third produced a concentration increase of 107-220 g/l; and the final step increased the brine salt concentration to 120-250 g/l or greater. Any brine reaching a concentration greater than 250 g/l was subsequently evaporated onto the solar evaporator using only BETE TF 12-170 spray nozzles. Before evaporation, four 3000-gallon tanks were used to store the concentrated brine. Site experiments using a solar still demonstrated the possibility of precipitating calcium carbonate, calcium sulfate and sodium sulfate from the brine solution. These salts could be separated by using the solar evaporator to manipulate concentration ratios. Calcium carbonate and calcium sulfate constitute 18% of the total TDS, and sodium sulfate makes up another 38%. The remaining 44% of the total TDS is composed of various other salts.

Evidence of salt drift outside of the pilot solar evaporator was evaluated separately by a DWR team and by CSU-Fresno team led by Charles Krauter, Ph.D. DWR collected data for a one month period. Using glass plates as collectors and placing them at key locations outside the solar evaporator, DWR monitored salt drift within a 175 ft swath in an area downstream of the prevailing wind. At the end of one month, the glass collectors were weighed. The results concluded that for nozzles raised at 1.5 ft, the average emission is 1.2 lbs of salt per hour, 90% of which is deposited within 75 ft outside of the solar evaporator.

The CSUF team used Petri dishes to evaluate salt drift. The dishes were placed at multiple locations within a 660 ft radius outside the evaporator and were aligned in the direction of the prevailing wind. Data was collected over a 3-day period and a range of sprinkler heights was used. The contents of the Petri dishes were dissolved and analyzed using a mass spectrometer. The CSUF results concluded that nearly all salt emissions occurring outside the evaporator fall within the 660 ft test area. The rate of salt drift varied from 0.2 to 1.8 lbs per hour depending on the height of the fan sprinkler which ranged from 0.25 to 2.5 ft translating into 0.2 to 5.3% of total salt input into the solar evaporator.

Based on the results of these two tests, the optimal fan sprinkler height was determined to be 1.5 ft with a corresponding emission rate of 1 lb/hr. Selection of this sprinkler height enabled us to achieve the goals of maximizing evaporation rates while reducing salt drift (Figure 3). In order to control the greatest amount of salt drift, a 6 ft fence was designed and placed around the evaporator. Future addition of strategically placed, tall, salt tolerant trees could also further prevent salt drift. By creating a more effective drift barrier, sprinkler height could be increased which would promote increased evaporation rates.

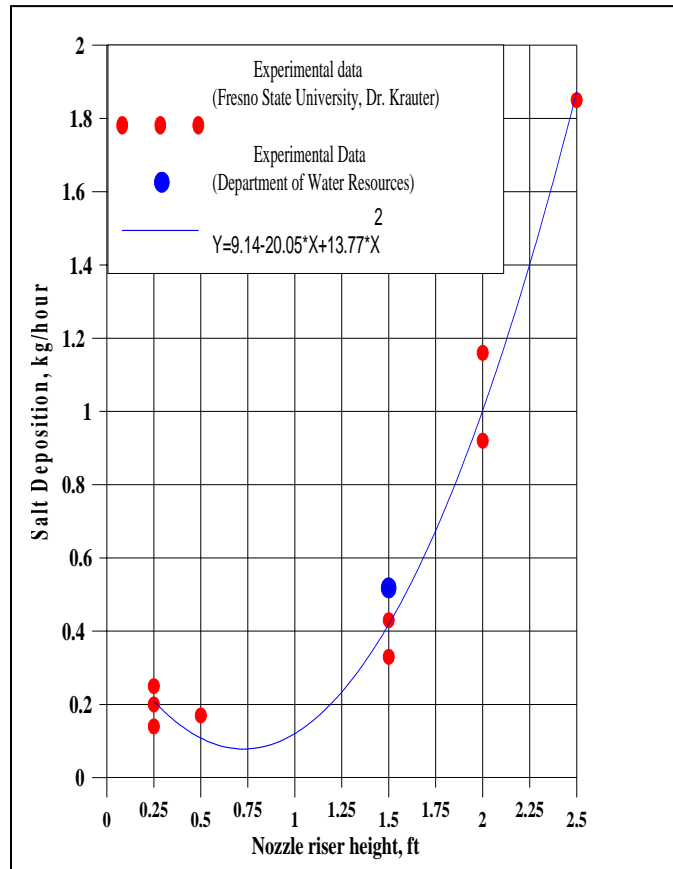


Figure 3, Pilot Solar Evaporator Salt Emissions Results

## CONCLUSIONS

Operation of the pilot-scale solar evaporator demonstrated that it could enhance evaporation up to 3.3 times the normal pan evaporation rates using 1.5 ft high fan sprinklers with minimum salt drift. Evaporation rates could be increased by raising the height of the fan sprinklers in conjunction with using a tree barrier to help control salt drift. Salts stored on the surface of the solar evaporator, such as calcium sulfate and sodium sulfate, can be recovered for future use. Selenium and boron can also be extracted from the brine mixture by applying biological and chemical processes. The information presented in this paper demonstrates that a simple and efficient solar evaporator can be developed as a viable tool for managing agricultural subsurface drainage water within the boundaries of the IFDM system at Red Rock Ranch. Data developed during this pilot study could be used as a reference for other designers wishing to develop similar enhanced evaporation systems for IFDM projects or for projects requiring management of brine effluents from desalting operations.

## REFERENCES

Westside Resource Conservation District and Center for Irrigation Technology California State University; Fresno. A technical Advisor's Manual, Managing Irrigation Drainage Water: A guide for developing Integrated On-Farm Drainage Management Systems