Seventh Symposium on Salt, Vol. I 519–524 (1993)
Elsevier Science Publishers B.V., Amsterdam

Elements of a Well Organized Weather Station and its Use in Solar Pond Design, Operation and Control

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ABSTRACT

In this paper, GSL explains the importance of a weather station at solar pond operations. A station layout is suggested that is simple in design, easy to operate, and easy to maintain. Each piece of equipment is discussed. Equipment problems and pitfalls are pointed out. Methods used to establish links between the weather station and solar ponds are explained. Linking of new weather stations with old, established stations is also discussed.

Use of stations to design, operate and control solar ponds is mentioned. Examples are given showing how evaporation rates are established for each season as a function of brine concentration and how these data are used in mathematical models to optimize solar pond systems.

INTRODUCTION

GSL Consultants have helped solar pond operators in many countries on every continent. It has been observed that most of these operators have either poorly organized weather stations or no stations at all. Imprecise data taken from these stations may lead to poor design, inaccurate basis for optimization, and pond mismanagement. In some cases, pond operators had good weather stations but the data obtained were improperly applied.

Generally it is found that the whole system of weather, pond design, and salt and brine management have not been given sufficient attention to assure optimization and uniform operation. Some operations have even failed because of this inattention. GSL consultants have seen pond systems produce only 60% of their potential.

Collection of weather data is slow and tedious. Nature cannot be hurried and is always fickle. In today's fast paced, competitive environment, one cannot wait for ten years to obtain weather information before competing in a venture. On the contrary, once the decision is made, capital is invested, plants are constructed and estimates are made that are needed to design, construct and operate the ponds. Unfortunately, evaporation rates are usually overstated, leakage rates understated, pond ground conditioning ignored, and pond control becomes much more difficult than expected. The results are underproducing ponds and low grade ore.

GSL engineers have observed some refineries that were built without the guidance of an evaporative weather station or any real knowledge of the solar ponds. In one venture the evaporation rate was overstated by 400%. Many problems and errors can be eliminated by proper use and application of an evaporative weather station.

DISCUSSION

Elements of a weather station

Figure 1 shows the elements of a functional weather station. Instruments should be simple and designed for rough use. Each physical element is listed below.

1. Location
2. Fenced enclosure.
3. Instrument shelter.
4. Max-Min thermometer.
5. Sling psychrometer.
6. Rain gauge
7. Anemometer
8. Class A water pan.
9. Sunken brine pans.

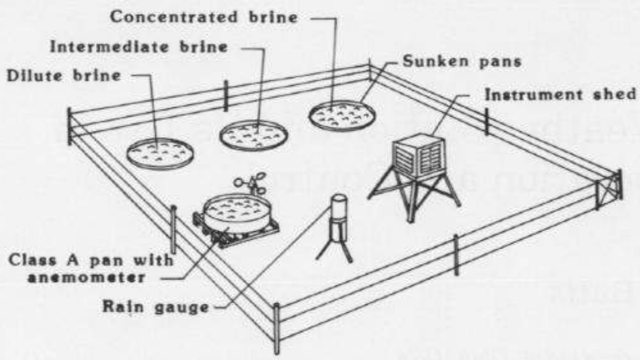

Fig. 1. Weather station.

1. Location. Stations should be located close to the solar pond site or proposed site. Keep the station away from buildings, walls, trees, and other obstructions. The objective is to subject the station to the same weather as the solar ponds.

2. Fenced enclosure. Fencing is needed to keep animals from drinking water from evaporation pans and to discourage intruders from disturbing the station. The fence must allow air to move freely through the station. Solid walls are not satisfactory; use open wire fencing. Sheep wire or chain-link is good. In areas remotely located where there is no danger of animals drinking from the pan, no enclosure is needed. Birds also like to use the water pans for drinking and bathing. If large flocks of birds come to the water pan, it will need to be covered with wire screen having openings large enough to permit free circulation of air but small enough to keep out birds.

3. Instrument shelter. It is standard practice to take ambient air temperatures in the shade. Instrument shelters provide shade and protection to the max-min thermometers and other weather instruments and supplies. Shelters are designed to allow unrestricted movement of air through it but at the same time provide shade and protection to instruments.

4. Max-Min thermometers. Maximum–minimum thermometers are used to measure the highest temperature and lowest temperature of the day–night cycle. They should be of simple design and easy to operate. Continuously recording thermometers are not recommended. They require much more attention and maintenance. Very accurate max-min thermometers are on the market that are maintenance free and easy to operate.

5. Sling psychrometer. This is used to measure water vapor in air. There are many instruments on the market but GSL recommends a good quality sling psychrometer. The sling requires some caution in its use but any conscientious technician can learn to use it with 15 minutes of training.

6. Rain gauge. A wide mouth rain gauge is recommended. The mouth should be about 20 cm diameter.

7. Anemometer. The anemometer is needed to measure wind movement over the land. Recording anemometers are not recommended. Height of the anemometer above the ground is important. It should be the same height as the station to which correlations are to be made. If there are no other stations near by (within 50 km), place the anemometer about 20–30 cm above the top of the class A pan.

8. Class A water pan. Unfortunately, evaporation pans used by weather bureaus around the world are not standard. GSL recommends the U.S.A. Class A Pan because it is most commonly used. It is important that this pan be installed exactly as outlined by the U.S. Department of Agriculture (1972). Improper installation will make correlation with other pans in the area difficult or impossible. The class A pan is 4 feet in diameter and 10 inches deep.

9. Sunken brine pans

These pans are very important to establish evaporation rates of brine as a function of brine concentration. The pans are identical to the class A pan except they are placed below ground level such that 5 cm of the pan lip extend above the ground. A minimum of two pans should be used but three are recommended. Pans are filled with brine representative of the brine in the solar ponds. In the case where actual concentrated brine is not available, synthetic brine is made up representing three forms of brine; dilute, intermediate and concentrated.

Operating the weather station

The weather station is attended 5 or 6 days a week. It need not be attended on weekends or holidays. It should be attended the same time each day. This will divide the interval of time into 24 hour blocks or multiples of 24 hour blocks. Equal intervals make data handling much easier and weather correlations will be more accurate. GSL suggests the time be set between 7 and 9 a.m.

All data should be entered on one data sheet and summarized later on a monthly summary sheet. Do not keep separate data sheets for evaporation, rain, and temperatures.

The sunken evaporation pans are by far the most important instruments to establish solar pond evaporation rates. They are also the most difficult to maintain and operate. When operators add make-up water to replace evaporation, the water floats over the more dense brine. If this water is not mixed with the brine to make a homogeneous solution, evaporation of less dense brine at the surface will occur and data errors will result.

Pans incorporate all weather parameters into one and show the net result as evaporation. This makes it simpler to determine evaporation on large ponds. Wind measurements are needed to determine wave action for subsequent dike design. Temperature history is also needed to determine brine chemistry and must be considered in both pond and plant design and operation.

Data handling

One main purpose of the Class A water pan is to establish a normal evaporation year and deviations from normal. It is also used to link evaporation from the pan to evaporation from pans at other stations. For example, If a newly established station has been in operation for only a year, no one can be sure if the year was normal or how far it has deviated from normal. It is rare indeed to find a year where all the months are "normal" or average. Often one can go to a town nearby where a long history of weather has been recorded. This history is then used to determine if the weather year was normal. By correlating evaporation from the class A pan at the new station with the old station and other weather parameters, valuable information can be obtained and used at the new site.

Sunken brine pans give a good indication of evaporation that can be expected in large solar ponds. Studies made by engineers at Great Salt Lake Mineral Corporation showed solar ponds evaporated at about 0.72 times as fast as sunken pans. The actual correlation varied depending on solar pond size and small sunken pan size. Figure 2 shows the correlation. Note that the correlation depends on the evaporation rate. If brine from the pan evaporates at 8 mm per day, the large pond evaporated at 6 mm or 0.75 times as fast. At a pan rate of 3 mm, the correlation drops to 0.67. As a "rule of thumb," a correlation factor of 0.72 is used but actual correlation factors depend on location of the sunken pan. Surrounding vegetation, buildings, and wind obstructions can also affect pan correlation.

Establishing a normal weather year

Production of concentrated brine and salts varies directly with evaporation. Both design and operation of a solar pond and refinery should be correlated to production of salts and brine in the ponds; but this production is a function of evaporation which varies from month to month and year to year.

Overall weather patterns change slowly. Some areas are seen to have 10 and 20 year cycles. Other areas appear to be stable and little changes are seen year after year. In any case, a normal or average weather year must be defined to make the necessary solar pond production estimates. It is also important to know risks involved with weather. A plant and pond system may be designed for 100,000 tons production but if there is a 20% chance that a monsoon may cut production by 50%, some extra design and planning is needed to help hedge against the risk.

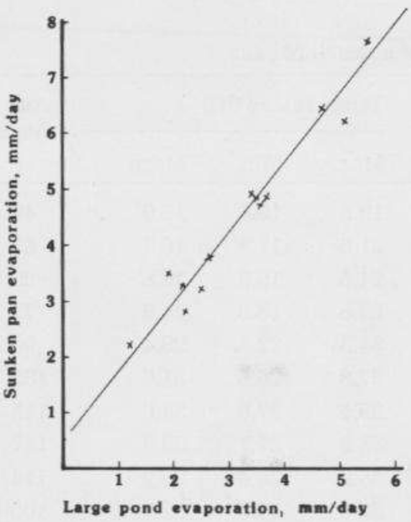

Fig. 2. Evaporation of large ponds versus small pans.

An average year calculation is one that would be obtained by operating a weather station for 30 years and running a mean and standard deviation on all data for each month. This is obviously not practical. However, there may be stations nearby that have been in operation for long periods. If so, all that is needed is to run the site station for a year to determine correlation factors between the two. If both stations have an A pan, correlation is much easier. If not, some research and educated guessing must be done. Then, as more and more data is obtained, it is used to update and refine calculations.

A standard year consists of averages for maximum temperatures, minimum temperatures, precipitation, absolute humidity, wind, and evaporation. This is calculated for each of the 12 months. Actually, the standard year represents a target around which weather parameters are constantly moving but usually never hit. That is why it is so important to know the standard deviation to see how far the weather can deviate from its average. The wider the deviations, the more design contingencies are needed to compensate. Table 1 shows an example of a typical Standard year. In Table 2, July is used as a example. A sheet like this should be filled out for each month.

Evaporation as a function of brine concentration in solar ponds

Once the standard year is established, standard evaporation curves can be generated. These curves

TABLE 1

Example of a standard year

Month	Temperature (°C)			Abs. humid	Wind (km/h)	Precip. (mm/month)	Pan evaporation (mm/d)			
	Max.	Min.	Mean				A pan	1.21*	1.26*	1.31*
Jan	19.6	10.4	15.0	49	6.5	9.5	3.7	1.9	1.2	0.5
Feb	21.6	11.8	16.7	53	7.3	11.9	5.2	2.6	1.8	1.0
Mar	24.6	15.0	19.8	59	8.4	10.4	7.4	3.4	2.9	1.6
Apr	29.8	18.8	24.3	71	9.3	3.7	10.6	5.9	4.8	3.1
May	34.3	22.5	28.4	90	9.5	0	13.8	7.7	6.6	4.6
Jun	37.8	25.6	31.6	102	9.4	0	15.7	8.9	7.5	5.4
Jul	39.6	27.6	33.6	115	9.4	0	16.0	9.3	7.6	5.4
Aug	38.9	27.7	33.3	117	9.2	0	14.8	8.4	7.0	4.8
Sep	35.9	26.0	30.9	114	8.8	0	12.2	7.1	5.4	3.5
Oct	32.6	22.8	27.7	100	6.9	0.6	8.8	5.1	3.8	2.4
Nov	25.6	16.2	20.9	66	6.5	3.5	6.1	3.1	2.5	1.6
Dec	20.6	11.6	16.1	52	5.4	14.0	3.7	1.7	1.4	0.6
Average	30.1	19.7	24.9	82	8.1		9.8	5.4	4.4	2.9
Totals for year						53.5	3577	1971	1606	1058

* Specific gravity.

TABLE 2

Example of a standard July

Year	Temperature (C)			Abs. humid	Wind (km/h)	Precip (mm/month)	Pan evaporation (mm/d)			
	Max.	Min.	Mean				A pan	1.21	1.26	1.31
1978	41.2	27.8	34.5	108	8.6	0	17.1		7.8	6.1
1979	40.1	27.3	33.7	136	9.1	0	16.6		8.4	5.1
1980	40.2	27.5	33.8	102	8.9	0	15.8		6.5	4.5
1981	39.8	28.6	34.2	116	9.4	0	13.9		6.8	5.2
1982	38.6	27.4	33.0	120	10.0	0	15.7	9.5	7.6	5.6
1983	38.3	27.6	33.0	121	9.9	0	16.4	9.2	7.3	4.9
1984	38.7	27.1	32.9	104	8.9	0	15.8	9.3	7.8	5.6
Avg.	39.6	27.6	33.6	115	9.4	0	16.0	9.3	7.6	5.4
S.dev	1.1	0.5	0.6	12	0.8	0	0.9	0.2	0.7	0.5
Totals for month (average)						0	496	288	235	167

should be made for each month but may be combined to reflect each season. In many cases, spring and fall are so similar that they are combined to form one set of equations. This results in three sets of equations. One for winter, one for spring and fall and one for summer. Figures 3 and 4 illustrate how these curves are generated. Figure 3 shows a plot of evaporation pans for each month of a standard year. There are three plots, one for each brine pan at the weather station. From these plots, evaporation as a function of brine concentration is generated. The month of July is shown as an example. Points A, B, and C shown on Fig. 3 are plotted as shown on Fig. 4. The line on the figure can now be described by an equation and programmed on a computer with appropriate correction factors such as Fig. 2. A plot such as this, if accurate, will be one of the keys to successful pond design, operation and control. This is a first approximation of evaporation rates. As more data are obtained, evaporation curves are updated.

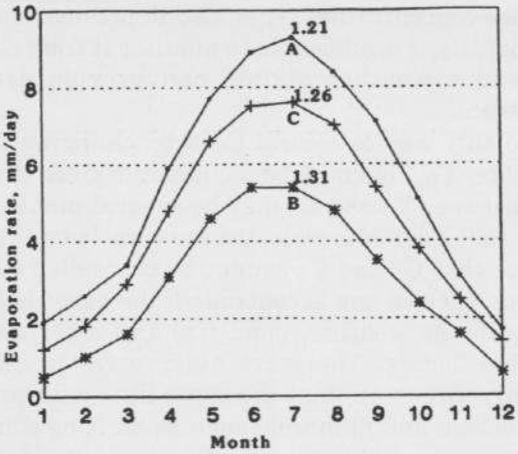

Fig. 3. Evaporation from sunken pans.

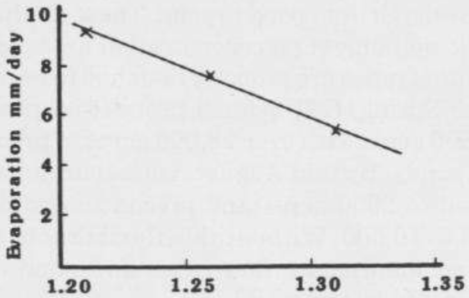

Fig. 4. July evaporation versus concentration.

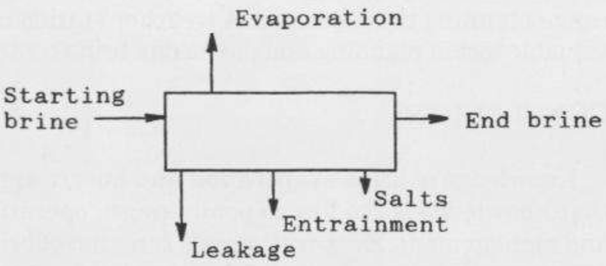

Fig. 5. Basic stream of a steady-state solar pond.

Pond design

Initial pond sizing is usually estimated from yearly evaporation data. Final design refinements should be made from monthly calculations. These monthly calculations are needed because dilute brine is not affected by weather as much as concentrated brine. For example, dilute brine may have a yearly evaporation rate of 75 cm but concentrated brine may only have 25. The yearly ratio of 75:25 (3:1) is a false ratio because it never exists for any given period during the year. In the early summer, the concentrated brine may have near zero evaporation while dilute brine will continue to evaporate with ratios of 10:1 or higher. Then, in the hot period, evaporation of concentrated brine accelerates and ratios may fall back to 2:1. The average of all ratios from month to month will yield 3:1, but for any given month this 3:1 ratio never really exists.

It is obvious that pond design must take account of these changing ratios. Use of a weather station to determine these ratios is better than pilot ponds alone. Weather station pans eliminate many errors inherent in pilot ponds. Pans do not leak. Pans do not soak up brine in their floors. Pan brine can be controlled at a given concentration, depth, and area. Pans do not seep brine through their side walls as ponds can.

Pilot ponds run in conjunction with weather station pans is an excellent idea however. The data correlated all together will provide good information needed to determine solar pond leakage, floor conditioning, evaporation for all seasons, pond brine management data, and pond control parameters.

Figure 5 shows the typical streams of a steady state pond. Data for each stream must be known. Brine chemistry can easily be estimated in a few weeks from bench studies. Feed brine concentration and exit brine concentration can likewise be determined in a relatively short time. Two streams cannot be determined in a short period. One is leakage and the other is evaporation. If evaporation is known, then an estimate of leakage can be made.

The bottle neck in evaluating a pond system is therefore the weather. For this reason, the first thing that should be established in a new solar pond venture is a weather station. Unfortunately, it is usually established last or not at all.

Pond operation and control

Controlling pond concentration is critical to an efficient operation. If preconcentrated brine is left to concentrate beyond the control point, valuable salts will crystallize in the wrong area or be contaminated with unwanted minerals. If brine is advanced too fast, it will also bring unwanted minerals into the production pond resulting in low ore grade and loss of pond efficiency. It could result in a poor product as well. This is often seen in Third World Countries where sodium chloride is produced from sea water. Many times the product is high in calcium sulfate, calcium carbonate and magnesium salts that could have been avoided with proper pond area ratios and brine management.

In most pond systems there are at least two critical concentration points: One where brine is flowed to production ponds and one at the discharge point where brine is finished. In ponds where there are

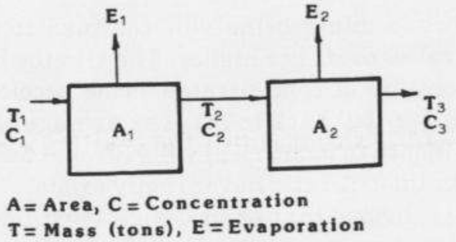

Fig. 6. Degrees of freedom.

multiple products there may be many more control points. Pond concentrations are affected by weather and controlled by flow rates. Therefore, daily knowledge of evaporation rates from the weather station can be used directly in pond management.

Degrees of freedom

There is one important fact that plays a key role in solar pond management yet it is little known or understood. Brine management allows for a change in one and only one parameter to control brine concentration. Figure 6 shows an example of a simple two pond system that will be used to illustrate.

A brine having concentration C_1, such as sea water, enters a pond with area A_1. It is concentrated to C_2 when it is ready to crystallize salt and transferred to a production pond with area A_2. End brine with concentration C_3 is discharged. The amount of brine moved in each case is T_1, T_2, and T_3 respectively.

Since C_1 is fixed, pond operators have no control over it. Pond area A_1, and Evaporation E_1 are also fixed. Therefore, to obtain the desired concentration, C_2, operators have no other choice but to control flow rates of T_1 into the pond. Once T_1 is fixed, all other parameters are fixed including the amount of production feed brine T_2. The operators have one and only one degree of freedom to control the concentration C_2 and that is by controlling T_1.

Once T_1 is fixed, it is easy to see why control of the production pond is impossible. In this pond, C_2, T_2, E_2, and A_2 are fixed. C_3 and T_3 are a functions of C_2 and T_2 which are also fixed (because C_1 and T_1 are fixed). None of these parameters can be varied at the discretion of the operator. He has no degree of freedom and the pond system cannot be controlled!

Often it is seen that operators attempt to force ponds to comply to desired concentrations when they have no degree of freedom. Nature will not allow forced compliance. Ponds simply react to forced compliance by going farther out of control or by automatically changing another parameter, such as a partial drying of the pond.

Since concentration C_3 is also dependent on the weather, E_2, it is advisable to monitor it from day to day and a weather station can provide needed assistance.

The only way to control C_3 is by changing input feed rate, T_1. This may be a challenge since the lag time between T_1 and C_3 may be several months. At Great Salt Lake Minerals, the lag time is two years.

Note that C_3 and C_2 cannot be controlled simultaneously. Once one is controlled, the other is fixed depending on weather, pond size and other uncontrollable factors. There are other ways to control several concentration at the same time with proper pond design and planning; such as shifting some of area A_2 to A_1 and *vice versa*. Strategically locating dikes and subdivisions of the concentration ponds and production ponds can make shifting areas easy. Some control also results by shifting pond inventory and brine depth from pond to pond. These methods will not work well unless preconcentration areas and production area ratios are properly matched to begin with.

In the Spring, GSL potash production pond area is only 500 acres with over 18,000 acres of preconcentration ponds. By mid August, potash area has been increased to 2000 acres and preconcentration area reduced to 16,500. Without this flexibility to change areas and manipulate flow rates and pond depths, control would be impossible.

Because there is a lag time between adjusting flow rate at the first pond and its affect on concentration in intermediate ponds and the last pond, some long range planning must be used. A weather station is a valuable tool in planning and day to day brine control.

CONCLUSIONS

Knowledge of brine evaporation and how to apply that knowledge is the key to pond design, operation and management. Evaporation as a function of brine concentration, time of year, and probably of weather deviations can be obtained from a weather station properly equipped and operated.

REFERENCES

1972, National Weather Service Observation Handbook No. 2, National Oceanic and Atmospheric Administration (NOAA), U.S.A.

Readers may be interested in a list of over 500 references concerning salt extraction from brine in a publication by the Society of Mining Engineers, Salts and Brine '85, W. Joseph Schlitt (Editor).