

# THE DESIGN AND OPERATION OF SOLAR SALT PLANTS

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## SOLAR SALT

### Introduction

Salt is a general term used for Sodium Chloride (NaCl). Its most common form is table salt used in food preparation, canning, preservation and adjusting taste of foods. However that is only a small fraction of the many uses of Salt such as Chemical Manufacture, highway deicing, water softening, hide tanning. There are thousands of end use products from the chemical industry use of salt such as plastics, glass, paints and on and on.

A major portion of the salt used today is Solar Salt. Most of the mined salt in the world is from ancient sea beds where salt was deposited and later covered with deposits of clay, sand or rock. Since these deposits were formed naturally, they all contain various levels of impurities. Mined salt, normally called rock salt requires extensive washing processes to refine to a level suitable for human use. In most cases the salt is dissolved in place and recrystallized in vacuum evaporating plants for human use. Solar Salt produced from sea water can be controlled to produce salt that is virtually as pure and clean as vacuum evaporated salt. Vacuum salt is about 99.9 % pure NaCl, Solar Salt is routinely produced by the worlds major salt plants at purity of 99.7 % pure

NaCl. The operating procedures to achieve that level of purity will be explained later in this discussion.

### Solar Salt Plant Design

The modern solar salt plant usually consists of a large series of ponds, reducing in size progressively from the sea water intake point to the crystallizing ponds. In plants where the rainfall is seasonal but not too severe the partially concentrated sea water brines are simply left in the "concentrating" ponds over the rainy season. The "crystallizing" ponds are drained, the salt remaining after the harvest dissolved by the rain and the ponds, dried, graded and compacted for the next years crop. In climates where there is minimal rain in the rainy season the plants operate year round only interrupting harvesting salt for a few days when it rains. In climates that are very hot with heavy evaporation and fairly significant rain but not all concentrated in a short period they also operate year round, just avoiding harvesting during the heaviest rainy periods. In climates where there is heavy evaporation and very heavy rains during the rainy season, the entire pond system is drained and restarted each year. The pond system design will have to provide

for handling dissolved salt brines from the crystallizers and rain diluted brines in the ponds that should be saved if the brines are stronger than sea water.

To start the design process, a check list is prepared and checked out. The first of the list are considered "knock out"--if any of these are unsatisfactory, study them very carefully before proceeding. They are weather, soil condition, topography and intake salinity. The rest of the list are things like road and/or port access, fuel and parts, contractors, labor and housing and all the amenities for personnel and supplies for the plant.

Evaporation and rainfall data are used in the design calculations to size the concentrating and crystallizing systems.

Measured evaporation from a class A evaporation pan as specified in the US Department of Commerce instructions for these weather stations. Most International Airports Meteorological Departments operate these weather stations and historical data is available at most of them going back for many years. At least a 10 Year average is desirable for solar salt plant design.

#### PRELIMINARY POND LAYOUT:

From the general survey determine the most desirable land area that is reasonably protected from sea storm activity and with adequate intake opportunities and proximity to highway and rail or sea transportation facilities.

For normal sea water the land should be divided into 1/11 for crystallizers and 10/11 for concentrators. If the sea water is diluted by runoff or concentrated by local shallows, this ratio should be modified (See

Figure 3).

The 10/11 of the available land that is suitable for concentrators would be divided into a minimum of ten ponds on the following basis: This division is generally based on the same amount of salt in solution in each pond at the same depth and a 10% increase in salinity in each pond in the series.

TABLE

1.	22.79%
2.	18.48%
3.	14.37%
4.	11.38%
5.	9.01%
6.	7.14%
7.	5.69%
8.	4.15%
9.	3.63%
10.	2.96%

If there is more land available than necessary for the plant capacity required; determine the amount of land necessary, then divide the 10/11 of that area as described above. This division is based on constant tonnage of salt in solution in each pond with all ponds in equilibrium, at the same depth.

In some cases land configuration will not permit this ideal pond division - use the ideal division as a general guide for combinations of ponds - the method shown under-water volume calculations will adjust pump capacities, gates, pipes and ditch sizes to compensate.

#### CONCENTRATOR SYSTEM:

Evaporation from the pond surface may be obtained either by meteorological-type calculations or by direct measurement with a U.S. Class A weather pan. The following calculations are all based on fresh water weather pan measurements. (See Appendix C for Description of Pan installation and operation.)

Since the weather pan value for gross evaporation is based on fresh water, some adjustments are necessary. Brine evaporates slower as it progresses from sea water to saturated brine and on to "bittern".

In these calculations a Discount Curve has been made up of an average 0.70 from U.S. Department of Commerce, "Evaporation Coefficients" (Appendix

C) and salinity effect evaporation experimental data- Bonython (Salt Symposium-1966).

Since rain falls into the ponds as fresh water but evaporates out as brine at the pond salinities, it is necessary to discount  $\text{Gross E} \times \text{DF} - \text{Rain} = \text{Net Evaporation}$  from the pond surface at the salinity of the pond. DF = Discount Factor from curve- Figure

The fundamental material balance equations for volume and salt weight in solution are as follows, these will be used to determine the area required to produce a given amount of salt per year:

A Ac	=	Area acres
I gal/yr	=	Intake gallons per year
O gal/yr	=	Output gallons per year
E gal/ac-yr	=	Evaporation gallons per acre per year
S gal/ac-yr	=	Seepage
I #/yr	=	Intake weight salt in solution pounds per year
O #/yr	=	Output weight salt in solution pounds per year
di #/gal	=	Intake weight salt in solution lb. per gal
do #/gal	=	Output weight salt in sol. lb. per gal

The material balance for this system:

$$\text{Volume } 1 - I \text{ gal/yr} = A \text{ ac } E \text{ gal/ac-yr} + A \text{ ac } S \text{ gal/ac-yr} + O \text{ gal/yr}$$

$$\text{Weight } 2 - I \text{ #/yr} = A \text{ ac } S \text{ #/ac yr} + O \text{ #/yr}$$

$$\text{\#/yr } 3 - I \text{ #/yr} = I \text{ gal/yr} \times \text{di \#/gal}$$

$$4 - O \text{ #/yr} = O \text{ gal/yr} \times \text{do \#/gal}$$

$$5 - S \text{ # ac/yr} = S \text{ gal/ac yr} \times \text{Average density in \#/gal}$$



results in a simplified equation for the area requirement for concentrating ponds

The simultaneous solution of all these equations

$$10. \quad A = \frac{O d_o - 0}{E + S - S(d_o - d_i)} = \frac{3.00 d_i}{3.00 d_i}$$

For normal sea water  $d_o = 2.177 \text{ \#/gal}$ ,  $d_i = .229$

$$A = \frac{O(2.177 - 0)}{E + S - S(2.177 - .229)} = \frac{9.51 O - 0}{E + S - S(1.948)} = \frac{3.00 \times .229}{.687}$$

$$11 - A = 8.51 O = \frac{8.51 O \text{ gal/yr}}{E + S - 2.84 S} = \frac{E - 1.84 S \text{ gal/ac yr}}{E + S - 2.84 S}$$

E and S are in gal/ac yr

If the plant is to occupy all the land available, it isn't absolutely necessary to make these types of calculations. Just allocate enough land for a wash plant, stockpile and what other facilities will be necessary. Divide the remaining land into 1/11th for crystallizers and 10/11th for concentrators as shown above. The concentrator to crystallizer ratio is 10 to 1 for normal sea water and a normal harvesting schedule. Most of the small plants around the world will have ratios of 5 or 6 to 1---they have crystallizers out of service often because of harvesting thin crops.

This will produce all the salt possible for the land available but will not predict the production--which will normally be required to finance the project.

### Computer Program

A computer program has been developed to determine the amount of land to produce a specified amount of salt or to calculate the amount of salt that can be produced from a given amount of land.

### Example

To calculate the amount of land to produce 1,000,000 short tons of salt per year with 100 inches of measured evaporation, rain of 15 inches per year, normal sea water intake of 3.5 deg Be and an estimated seepage of 146000 gallons per acre per year.

## Computer Run

### Site conditions

Seepage	0.146x 10 <sup>6</sup> gal/ac yr
Evaporation	100 in/yr
Rainfall	15.000 in/yr
Intake Salinity	3.500 Be
Intake Density	0.229 lb/gal
Output Salinity	25.900 Be
Output Density	2.177 lb/gal
Constant C for System	3.000
DF for System	0.670
Area	9422.835 ac
Input Volume	15955.222x10 <sup>6</sup> gal/yr
Total Evaporation	13311.488x10 <sup>6</sup> gal/yr
Total Seepage	1375.734x10 <sup>6</sup> gal/yr
Output Volume	1268.000x10 <sup>6</sup> gal/yr
Output Weight	1.000x10 <sup>6</sup> ton/yr

The program has several variations to run the system forward or backwards for design purposes to size pumps, gates and ditches or to run models of operations simply by changing the variables.

The total area of the concentration pond system is divided into individual ponds of gradually reduced sizes from intakes to crystallizers. The crystallizer area can be calculated but usually it is determined as just 10 % compared to the concentrating pond area and modified by the variation from standard sea water intake salinity.

### Solar Salt Production Process

The oceans of the world contain many chemicals, some in very minute quantities. The predominate chemicals are Sodium, Chloride, Magnesium and

Sulphur. These combine during crystallization to form various compounds as water evaporates in a situation where the compounds will crystallize out of solution.

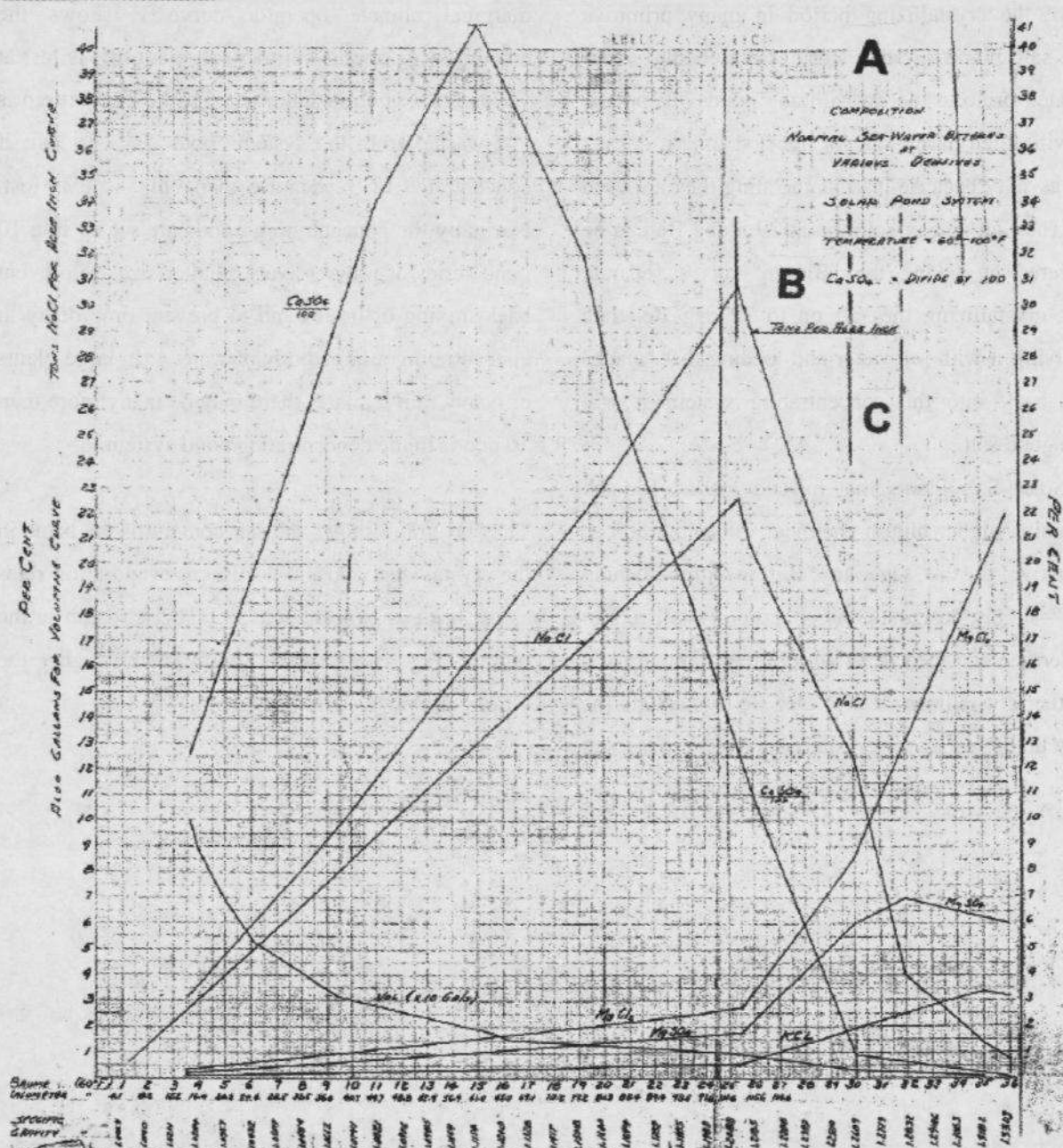
Fortunately these compounds form in what the chemists call fractional crystallization, that is they come out of solution sequentially. The various compounds crystallize at different times as the solution increases in density although they all overlap to some extent.

The graph "A" demonstrates which compound crystallizes over what range of density.

The various density measurements are shown on the bottom of the graph, we will use Degrees Baume--deg BE.

The curves on the "A" graph are labeled CaSO<sub>4</sub>, (Gypsum) NaCl, (Salt) MgCl, (Magnesium

Chloride)  $\text{MgSO}_4$  (Magnesium Sulphate) and  
KCL.(Potassium Chloride).



The Gypsum crystallizes first and it can be seen that a very large part of the Gypsum has crystallized before Salt starts to crystallize at 25.9 deg Be. This feature is used in the production of high quality Solar Salt by not allowing brine of less than 25.9 deg Be to be fed to the crystallizing ponds.

On the graph the vertical lines show a crystallizing

section B and C. The section labeled B ends at 29.5 deg Be and is the point that the strong brines must be drained from the crystallizers to produce the 99.7% pure NaCl required by the Chemical Industries. The C section of the crystallizing area on the graph ends at 32 deg Be and produces salt suitable for human use but contains more of the Magnesium



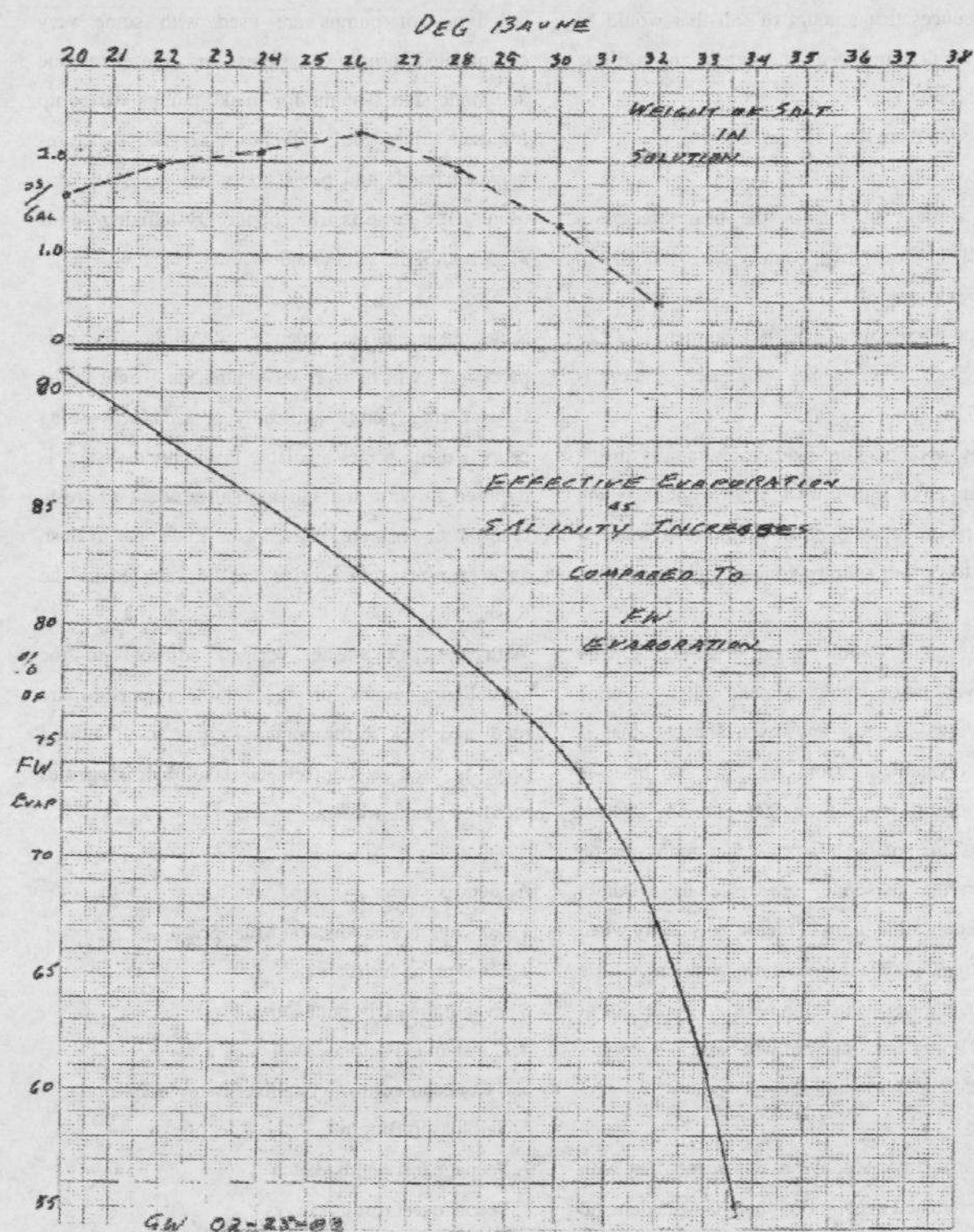
chemicals and gives the salt a slight sting to the taste. The gypsum is crystallized with the salt on the front end of the crystallizing period in many primitive solar salt plants in the world (by feeding under saturated brine to the crystallizing ponds. To people receiving high purity salt for the first time it doesn't taste as salty because it lacks the sting they are used to. The Salt still in solution at 29.5 deg Be can be recovered by taking the "Bittern" to a separate pond, crystallizing the salt on to 32 deg Be, then dissolving it with sea water and feeding that "made" brine back into the concentrating system--it will make good salt.

For Solar Salt Plants that have a market for salt containing higher bittern chemical values there is an alternative to the separate "Bittern Strengthening Pond"--simply designate one or more crystallizers to this service and feed them with bittern drained from the other crystallizers at 29.5 Deg Be to maintain the purity in the rest of the crystallizers and keep the salt

from the bittern strengthening crystallizers separate in the stockpile. This is critical for many of the marginal climate operators--curve E shows the amount of incoming salt to a salt plant that is lost at various bittern drain salinities. If the 29.5 bittern is just wasted from the system about 20 % is lost; if concentrated to 32 deg Be then only 4 % is lost. Normally the concentrating ponds are set up in a 10 pond series of progressively smaller sizes to prevent back mixing of brines and to prevent time delay in concentrating a large body of water. In large plants or heavy rain climates there may be many more than 10 ponds in the concentrating pond system.

The "D" graph shows the salt content of the brine in the crystallizers and the decline in evaporation rates as the brine is concentrated to higher strength in the bittern range. Less salt is produced the higher the bittern discharge salinity.

D



The common practice of retaining bittern (salt brines in the crystallizers above 32 deg baume) should be

changed and not carried over from crop to crop. Salt produced from this type operation is not as



firm as normal salt and will not support harvesting or transport equipment. Additionally this practice actually reduces that amount of salt that would be produced by draining away the bittern and refilling with new brine.

As can be seen from the "D" graph:

1. The amount of salt in the brine decreases significantly in the high salinity ranges as shown on the upper graph.

At saturated conditions -- 25.9 deg be there is 2.177 lbs/gal of NaCl in the brine, at 32 deg be there is only 0.865 lbs /gal.

2. The evaporation rate deteriorates rapidly in the high be ranges as shown on the lower graph where the evaporation of an open body of fresh water is compared to various salinity brines in open ponds.

This is a major double negative effect, greatly reduced evaporation trying to make salt from brine that has very little salt anyway. The salt that is visible as crystallizing from high strength brine is probably mostly magnesium salt and not sodium chloride. This visible effect is the major reason most operating personnel are reluctant to drain bittern. The visible jump in measured salinity when adding bittern back into a virgin brine is a false impression, the resultant brine will not make salt at the normal 25.9 deg baume but will have to be higher before it starts making salt.

One other effect not so obvious is the fact that with the greatly reduced evaporation there is little demand for fresh brine (containing salt) to be added to the crystallizing area.

All the machinery required for the concentrating pond part of the system is adequately sized pumps

The simplest to operate are vertical or sloped propeller pumps similar to those used for irrigation. All types of pumps are used with some very complicated priming systems and diesel engine automatic start systems for Intake pumps started up for each high tide. Ditches and gate structures between ponds and pipes under roads etc are also used. The same is true for the crystallizing ponds as well until the salt is made.

Salt made in accordance with the previous procedures will be over 99% pure NaCl right in the Crystallizing ponds and only a simple washing process using brines available in the pond system is required to wash the salt—a small amount of fresh, brackish or sea water is used as a final spray to flush away some residual brine as the salt leaves the washer.

With the salt washer located adjacent to the crystallizing ponds, all the soluble impurities are recovered back to the pond system—a small settling pond is used to deposit the insoluble impurities removed by the washer.

## Appendix

1. Concentrator Production Monograph
2. Monograph instructions
3. Evaporation Discount Curve Fig 1
4. Constant C Factor Table 1
5. Concentrator to Crystallizer Ratio Graph
6. Salt loss in Bittern
7. Seepage test ponds sketch
8. Seepage test results curves
9. Accuracy comparison --salinity discount curve