Basic Concepts of Solar Pond Modeling and Their Use in Pond Operations.

D. S. Butts

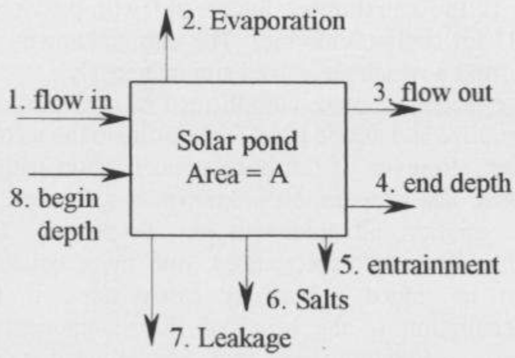
Consulting Chemical Engineer, DSB International Inc.
4232 Porter Ave. Ogden, Utah 84403, USA

1. INTRODUCTION

Most solar pond complexes consist of multiple ponds arranged such that brine flows in series from pond to pond. Some systems have strings of ponds operating in parallel. A computer model will help the operating engineer manage these complex ponds systems where weather and precipitation are in constant change. Modeling also aids in the design of a new complex or where expansion of an existing system is contemplated. A model lets the operator run scenarios by changing weather inputs, pond operating depth, seepage rates, and feed concentrations to test for sensitivity and operating variables. Models can be used for technical training and to determine actual evaporation rates, pond seepage constants and other solar pond data.

2. STREAMS BASIC TO MODELING

Modeling is no better than the accuracy of data inputted to it. Each pond may have 8 streams needed in the model. These streams are shown.



2.1 Flow into the pond, stream 1

In most cases this stream is relatively constant, such as sea brine. It may change from season to Season or in cases where plant effluent or other streams are added. This brine concentration must be known.

2.2 Evaporation, stream 2

Evaporation is one of the most difficult streams to define because it is constantly changing with weather and pond brine concentration. Since it is dependent on so many parameters, it may take several years to collect sufficient data to describe the curve. In the model, the curve must be defined mathematically as a function of time of year and brine concentration.

2.3 Flow out, stream 3

Both concentration and flow rate out of a given pond are a function of evaporation, but evaporation depends on the pond size and brine concentration. Since concentration and evaporation depend on each other, the model must use simultaneous solutions. There is a special case when the end brine is defined, such as a specified bitterns concentration. In this case the model is much simplified.

2.4 Ending depth, stream 4

At the end of a given period, how deep will the pond be? This may be a parameter set in the model, or it may be calculated by the model in order to satisfy a specified requirement given by the user.

2.5 Entrainment, stream 5

As salt crystallizes it forms void space within the crystal called encapsulation. Encapsulation is usually very small and is neglected in the material balance. Space is also formed between crystals. This space is very significant and captures, or entrains brine that is no longer available for further concentration or use unless it is released. In sodium chloride deposits, the amount captured is near 33 percent of the salt volume (about 25 percent by weight). For example, if a 10 millimeter salt floor is deposit, 3.3 millimeters will be entrained brine. Different salts have different entraiment factors. Some salts such as schoenite may be only 25 percent and others as carnallite may be 50 percent or more. The model must account for entrainment.

2.6 Salts, Stream 6

In the case of simple solar salt ponds, only one salt is significant (halite). In more complicated systems, other sodium, potassium, and magnesium bearing salts may need to be considered. The model will need to have a solubility curve, often called a concentration profile of the brine. This is well known for sea brine, but some laboratory tests may be needed for well brine, or brine unique to a specific area.

2.7 Leakage, stream 7

Leakage, also called seepage, is another parameter not usually known for the model. It is difficult to measure and assumptions are made to begin based on field tests. Good soils will leak about 0.25 millimeters of brine depth per day.

2.8 Beginning brine depth, stream 8

This is always known and is simply inputted to the model. In a new pond just being filled, the starting depth is zero. In an established pond, it is what ever is measured.

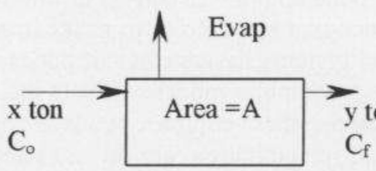
3. POND MODEL CASES

One pond model will not satisfy all cases. The case most often encountered is where ponds are already in operation, but the pre-concentration area to crystallizer area has not been optimized nor does the operator know how to adjust for changing weather efficiently. Another case is when a new area is being considered for solar salt and a pond complex needs to be designed to yield the most product possible from a specified area.

Pond models can be used as valuable training tools to show new and experienced engineers pond sensitivities to changing conditions, and cause-effect relations. Since each solar pond operation is unique to its layout and size, each solar pond model will be tailored for that system. Some assumptions are stated here for a steady state system that will simplify the model.

1. The concentration of brine in the pond is nearly homogeneous throughout.
2. The concentration of brine flowing out of the pond is the concentration in the pond.
3. The concentration of brine seeping, or leaking out is the concentration of brine in the pond.
4. The concentration of entrained brine is the concentration of brine in the pond.

The simplest case is one of a pre-concentration pond where no salts precipitate and the pond is at steady state. Let the feed concentration of a component C be C_o weight fraction and it is desired to concentrate it to C_f. Let leakage be zero, and the starting and ending inventories of brine (pond depth) be the same. How much brine, y, can be made from area A? The setup is simple.



Mass balance: $x = (evap)(A) + y$

C balance: $(x)(C_o) = (y)(C_f)$

Since only x and y are unknown, the equations can be solved. If salt is crystallizing, one more equation must be added which is done by knowing the chemical analysis of the brine. Let the water concentration in the brine be W_o and W_f. Suppose it is component C that is saturating and the tons of C crystallizing is S.

Mass balance: $x = (evap)(A) + y + (S)(E) + S$

C balance: $(x) = (y)(C_f) + (S)(E)(C_f) + S$

W balance: $(x)(W_o)=(evap)(A)+(y)(W_f)+ (S)(E)(W_f)$

E is the entrainmnet factor and will be known (0.33 for sodium chloride). The only unknowns are x, y, and S which are solved simultaneously.

The model becomes complicated as multiple salts crystallize and as one pond flows brine to the next in series. However, If the brine concentration path is known, and evaporation is known as a function of concentration, all unknowns may be solved. For each salt that co-precipitates, one more equation must be added. This is easily done if the concentration in the brine of that component is known. Equations are not compounded when streams 4, 7, and 8 are added because these streams will be known or estimated. These basics can be applied to even the most complicated system.