Importance of Microorganisms in Solar Salt Production

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ABSTRACT

Sodium chloride production from solar-salt works depends upon location, favorable climate, and the living microorganisms growing in the concentrating ponds and crystallizers. These essential microorganisms (algae, protozoa, bacteria, etc.) constitute a biological system which serves two important functions in salt production. The microorganisms produce a thick, many-layered mat on the bottom of the ponds which prevents leakage of the brine. The microorganisms also color the brine by producing floating, colored cells in high concentrations. The colored cells increase the absorption of solar energy which raises brine temperature and thus improves evaporation.

In an efficiently operating solar-salt works, the biological system is self-maintaining. In a new solar-salt works, the biological system may develop completely, partially, or not at all. The biological system may develop only partially or not at all when essential nutrients are limiting. In such cases, the biological system can be started and maintained by artificially applying fertilizers to the ponds. Data gathered from a five year study at a solar-salt works indicates that salt production is dependent upon, and increases with, the development of the biological system in the evaporating ponds.

INTRODUCTION

The purpose of a solar salt works is to produce sodium chloride from sea water. In theory nothing could be easier, for one needs only to acquire low-lying seaside land with a favorable climate, and then construct a series of shallow, interconnecting concentrating ponds and crystallizers—these of course must have the proper surface area ratio to each other. If pumps have been installed at strategic places, then sea water can be made to flow through the system, evaporate, and eventually precipitate sodium chloride. This would seem to be ideal industry, since the reserves (sea water) are virtually inexhaustable, the energy for evaporation is free (sun), the product is in demand, and such systems require relatively little maintenance.

If everything proceeds as expected, there will be little or no leakage of brine from the ponds, or infiltration of sea water into the ponds. Furthermore, the water in the concentrating ponds will become yellow to brown. This color will result in sufficient heat and light absorption to raise water temperatures, which will materially increase evaporation. The brine in the storage ponds and crystallizers will become deeply red-colored. This also promotes solar absorption, elevated temperatures, and thus increased evaporation. The first salt harvest might be realized some three years after the system has been completed.

Thus far, this outlines the ideal situation—everything proceeding as expected, according to calculations, and adjusted to climate. Even the amount of product can be closely estimated.

PROBLEMS IN SOLAR SALT WORKS

Why is it, then, that solar salt works sometimes produce less than the expected amount of salt? Or perhaps no salt at all?

There are inefficient or non-productive salt works in many areas of the world, including the Carribean, south Atlantic, Australia, and Continental North America. From 1967 to the present, the author had the good fortune to spend extended periods of time studying a solar salt works in the Bahamas, where observations were made on a series of biological events in the concentrating ponds which changed a non-productive salt works into a productive one. Experience and knowledge gained from numerous observations of solar salt works, from laboratory work, and from the literature, provides some of the answers as to why solar salt works sometimes are poor producers. These answers lie in the absence of the so-called "expected" aspects of solar salt works.

Again, one expects from a solar salt works:

1. Little or no leaking of brine, or leaking at such a level that it can be tolerated.
2. Turbid, dark-colored brine in all the condensing or concentrating ponds.
3. Deep-red colored brine in crystallizers.

These three expectations are functions of the biology of the salt works; they occur as expected only when the biological conditions are ideal or nearly so. When excessive leaking and clear brine occur, a salt works can become non-productive, or production may drop below profitable levels. These problems can occur even in salt works constructed by experienced solar salt-system builders. The builders are not usually interested in the biological aspects of salt ponds, but eventually even they "expect" certain aspects already mentioned to develop in their completed projects. However, the living organisms just may not cooperate with them. Since water color and sealing are clearly important, we need to know the factors involved in obtaining them.

BIOLOGICAL FACTORS

Most solar salt works consist of three distinct biological areas, which can be conveniently considered as a function of salinity. The first area includes ponds whose salinities vary from that of sea water to approximately three times sea water salinity. The second ranges from three to seven times sea water salinity, and the last area from six times sea water salinity to saturation in respect to sodium chloride.

There is a biological basis for color and sealing. In the first series of ponds, the causal agents of water coloring are the planktonic or the free-floating algae. These are microscopic one-celled plants which are nutritionally independent, since they make their own food by the process of photosynthesis. This processes is briefly summarized by the equation:

$$\text{Minerals} + \text{Carbon dioxide} + \text{water} \xrightarrow{\text{Light}} \text{Algae} + \text{Oxygen} + \text{Water}$$

Carbon dioxide, water, and light almost never limit the photosynthetic process in shallow ponds. However, the algae also require the rather large array of minerals normally found in sea water (e.g., Ca, Mg, P, K, N, S, Fe, etc.). It is well known that photosynthesis can be limited by inadequate minerals. When sufficient dissolved minerals are available, the planktonic algae multiple to such an extent as to color the water green to yellow-green to brown.

First series of ponds

The variety of algae in the first series of ponds is relatively high, since the salinity does not yet exclude large numbers of species. Thus, these ponds are biologically characterized by great species diversity, with relatively few numbers of each species. For the salt producer, these algae are of value because the color they impart to the water results in increased solar absorption. This heats the water and thus materially increases evaporation. This is a naturally occurring process which often goes not unnoticed by managers of solar salt works, but little appreciated.

Again, the algae will do their "job" only when adequate minerals are available. Frequently, two minerals limit the photosynthetic process of algae in ponds which then results in fewer algae, and thus lighter-colored or clear water. The minerals often limiting algal growth in sea water and brine are nitrogen and phosphorous. All the other necessary minerals are almost always present in adequate amounts.

When sufficient minerals are present, especially nitrogen and phosphorous, a multi-layered mat of a few millimeters to several inches in thickness will grow on the bottom of the concentration ponds. There is evidence which clearly indicates that such mats are almost impervious to water. Thus, these mats naturally seal the ponds against leakage. Bottom mats, when viewed from a cut made perpendicular to the surface, are composed of an uppermost layer of green to orange-colored algae that are dead or nearly dead, and whose green chlorophyll has been bleached by sunlight. Just under this is a bright green layer with an actively growing community of algae, one celled animals (protozoa and ciliates), bacteria, nematodes, small shell fish, and a few rotifers. All the bacteria and animals in the mat are nutritionally dependent on the algae. The lowermost part of the mat consists of dead and decaying algae, animals and bacteria. Under ideal conditions, the bottom mat maintains its thickness, for about as much of it decays on the bottom as is added by the green layer. In addition to sealing ponds, the mat performs another valuable biological function. This has to do with the recycling of minerals.

Whenever a living organism in the salt ponds dies, it sinks to the bottom, becomes overgrown by the algae of the mat, and it eventually becomes located in the lower layer of the mat. Here bacteria slowly decompose the organism, and the minerals which were bound in its organic material are then released into solution. Electrical potentials in the mat, along with other forces, may be important in pumping the mineral nutrients to the upper parts of the mat and even into the water. At these locations, the minerals can be reused to synthesize more algae in the mat and in the water. It should be mentioned that the colored top layer of the bottom mat also helps to raise pond water temperature by increasing solar absorption.

Second series of ponds

In the second series of ponds, whose salinity varies from three to seven times that of sea water, the water is usually darker colored and the bottom mats are thicker than those of the previous series. Many of the organisms in these saltier ponds are similar to those of the first series. However, fewer kinds of organisms are involved, but these are present in relatively high concentrations. Fish rarely live in these ponds, but brine shrimp and brine fly larvae are common, and often serve to attract large numbers of birds. Microorganisms and the color they impart to the brine in these ponds are absolutely essential to salt production, since vapor pressures reach such low values (Rothbaum, 1958) as to seriously retard evaporation. The elevated temperatures from the increased solar absorption caused by algae helps of offset the effects of the low vapor pressures and thus permits adequate evaporation. Other factors, of course, are also important. These include wind speed, humidity, temperature, day length, and good brine management practices.

The sealing function by the bottom mat is of somewhat greater importance in these more concentrated ponds, since the brine here is of greater value than that in the weaker ponds. Again, the organisms composing the bottom mat are similar to those of the ponds of lower salinity, but fewer kinds of organisms are involved. Mats from one up to eight inches thick can be observed in ponds of three to seven times sea water salinity.

Third series of ponds

The biology of the crystallizers and final concentrators is perhaps the most obvious and striking part of a successful salt works. These ponds, under ideal conditions, become deep-red colored by organisms known as the red halophilic bacteria. These are the only forms which stay alive and reproduce in highly concentrated brines. These bacteria are not photosynthetic—they cannot make their own food. When sufficient material such as algae, brine shrimp, protozoa, brine flies, etc., are supplied to the crystallizers, the red halophilic bacteria multiply sufficiently to color the brine red. If these organic materials are present in greater quanities than that required by the red bacteria for food, the excess material which is not used by the bacteria filters downward and seals these ponds against leakage. Brightly red-colored crystallizers never leak.

All production managers at solar salt works know the value of color to raise the brine temperature in crystallizers. Without natural coloration from red halophilic bacteria, evaporation proceeds only with great difficulty, since vapor pressures reach their lowest values in crystallizer brine. Managers with clear brine must then use green dyes to raise crystallizer brine temperatures to promote evaporation. These green dyes can be expensive. In some locations, they may create more problems than they solve.

It should be mentioned that with increasing salinity and decreasing diversity, the microorganisms become sensitive to the environment. Thus in brine storage ponds and crystallizers, a heavy rain which lowers salinity might kill large numbers of red halophilic bacteria and cause the brine to become clear.

THE MINERAL CYCLE IN SALT PONDS

Having established the importance of microorganisms in the production of solar salt, it is pertinent to discuss how the nitrogen and phosphorous are obtained by the organisms in salt ponds.

The incoming ocean water flowing into the first ponds always contains small amounts of nitrogen and phosphorous. This nitrogen and phosphorous is quickly removed by the algae in the plankton and bottom mats in the first ponds of the salt works. Some algae and other oganisms (including fish) entering the salt ponds from the ocean die and decay as the salinity increases; their phosphorous and nitrogen are then released into solution and become available to the algae. Some of the nitrogen and phosphorous is washed into the next ponds of the series where algae multiply, die, and the minerals are recycled. This reoccurs until the brine reaches the crystallizers. In crystallizers nitrogen and phosphorous are of little or no value; only the organic materials flowing in are useful to the red halophilic bacteria. These bacteria can break down many varieties of organic material and convert it into their own substance.

In addition to the nitrogen and phosphorous coming in with the ocean water, there is another source of these important minerals. This is the animals, such as fish and the birds of the area. Many fish which enter a salt pond die, and their bodies decay, furnishing both food for the one celled animals, bacteria, and minerals for the algae of the ponds. Certain varieties of tiny fish actually live and reproduce in the less saline ponds of a system. Perhaps more important than the fish are the birds in supplying and cycling essential minerals. Sea birds often feed in salt ponds. They eat fish, brine shrimp, brine flies, and tiny shell fish. The bird droppings provide valuable amounts of nitrogen and phosphorous. Birds, then, should be encouraged to feed in the salt ponds.

Nitrogen fixation by blue-green algae and bacteria may very well be the most important source of nitrogen for the algae in concentrating ponds. Certain blue-green algae and bacteria normally present in concentrating ponds can take gas nitrogen from the atmosphere and make their own proteins with it. This nitrogen represents a large nitrogen supply available to the algae of both the plankton and bottom mat.

Mineral availability

How does one insure that adequate amounts of nitrogen and phosphorous will be available? The location of the salt works is of prime importance in this respect. Ordinarily, climate, price of the land, and political stability are the factors in deciding where to locate a solar salt works. The mineral situation also must be considered. Salt works should be located as close as possible to mineral-rich areas. Certain areas which would qualify as mineral rich include:

1. Proximity to population centers
2. Proximity to river mouths
3. Proximity to deep water
4. Proximity to ocean upwellings.

Water taken in from such areas would be definitely advantageous for any salt works. Such mineral considerations are more important than salinity when deciding the potential location of a salt works. For example, consider the situation of the solar salt works of Leslie Salt Co. which is located in the south end of San Francisco Bay, California. The water taken in from the bay during certain times of the year has a salinity considerably below that of sea water (Carpelan, 1953), but it is so rich in nitrogen and phosphorous that it serves this company very well. Thus one sees a value for polluted water. Morton International Co. Works at Great Inagua, Bahamas pumps in mineral-rich water from the Old Bahama Channel which is an extension of the Puerto Rico Trench. In addition, climate, flamingos, and a host of other birds work for them.

Some measures can be taken to encourage birds to inhabit the salt ponds. Mangroves or other trees should not be disturbed, for in addition to providing nesting sites, their leaves, which drop in the salt water, constitute an important mineral source. Furthermore, human disturbances to birds can be eliminated by forbidding entry to persons on company property. International Salt Co. on Bonaire, Netherlands Antilles has implemented a plan to encourage birds. At considerable cost, they have established a flamingo sanctuary among their concentrating ponds, where the birds now nest and breed. Although International's motives were primarily public relations and conservation, the flamingo sanctuary will be paid for again and again by the birds themselves.

CORRECTIVE MEASURES

Is it possible to "cure" a solar salt works which is a poor salt producer? A salt works with leaking ponds and clear brine can be cured. The cure involves the judicious use of fertilizers to encourage the native pond organisms (algae, protozoa, bacteria, etc.) to multiply and produce the desired color and bottom mats. The fertilizer supplies the missing essential elements which may be limiting photosynthesis. Such fertilizing not only results in the desired brine coloration and pond sealing, but serves to start a series of events which may obviate or materially decrease the need for continued fertilizer additions. Fertilizer stimulates the growth of algae which are eaten by protozoa which eventually become the food for small fish, tiny shell fish, brine flies, brine shrimp and other small animals. These animals multiply and attract birds whose droppings are rich in nitrogen and phosphorous. The droppings in the ponds further stimulate algal growth (and nitrogen-fixing organisms) and the entire cycle is repeated. In one salt works whose ponds have been extensively fertilized, a many-fold increase in the bird and fish populations occurred.

Thus, it seems clear that the biological events which result from the activities of microorganisms living in concentrating and crystallizing ponds are essential for the efficient operation of a solar salt works. Solar salt works with a properly performing biological system produce quantities of sodium chloride which are close to the theoretical maximum for a given area.

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