Biological Management of Solar Saltworks

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ABSTRACT

Whether a solar saltworks is fed with seawater, intermediate salinity brine or saturated brine, a biological system exists in the ponding system able to aid or decrease the production and quality of the product. Three types of biological systems are described. A "balanced" biological system produces optimum quantities of organic materials properly distributed between the living planktonic and bottom communities in a salina; these materials color brine to increase evaporation, seal ponds against brine leakage, and perform other functions promoting the production of high quality product at design capacity. An "inadequate" biological system lacks sufficient organic productivity; saltworks with these systems experience insufficient brine coloration and evaporation, and leaking ponds. "Unbalanced" biological systems, caused by a sub-optimal distribution of organic materials between the two living communities, can result in mucilaginous brine, decreased evaporation, and low quality product (particularly the color, insolubles and sulfate content, and crystal size of the salt). Some methods are mentioned to obtain and maintain the balanced biological system, to restore the other two kinds of systems to balance, and to prevent problems from reoccurring. It is suggested that salinas constructed with proper provision for biological concepts would be largely immune to biological problems.

INTRODUCTION

In the brine ponds of any solar saltworks (salina), living organisms constitute a biological system or ecosystem essential to salt production. Every salina possesses some kind of ecosystem; depending on type and development, the ecosystem's performance is often responsible for the degree of success (as measured by product quality and output) of a solar saltworks. The biological system's value to salt manufacture lies in its ability to organize living organisms into useful compartments having the ability to: 1) color brine of all ponds resulting in sufficient heat and light absorption to raise water temperatures and thus aid evaporation, and to supply biological fuel to downstream ponds, 2) form living mats and deposits on the bottom of ponds to prevent brine leakage and 3) recycle and entrap minerals and organic matter, and 4) oxidize to safe levels organic materials produced. In a saltworks producing high quality product at design capacity, a balanced biological system performing these functions operates in the brine ponds. Salinas producing salt of decreased quality and at less than design capacity and failing in one or more of the functions, may possess an inadequate biological system or one that is out of balance.

This paper will describe some characteristics of balanced biological systems, inadequate ecosystems, and unbalanced biological systems. Concepts and practices apply broadly to salinas whose intake is seawater, concentrated brine, or saturated brine. Certain management procedures to develop and maintain balanced biological systems, and to prevent biological problems in solar saltworks will also be mentioned.

THE BALANCED BIOLOGICAL SYSTEM

The brine biological system (ecosystem) is a number of interconnected living compartments, consisting of the planktonic, bottom-dwelling, and fringe communities inhabiting the ponds of a saltworks. The planktonic community, serving to color water, is the group of algae, protozoa, bacteria, and brine animals suspended in the brine. The bottom community, which aids in sealing ponds, consists of microorganisms, small molluscs and nematodes growing on the floor of the ponds as mats and deposits. The fringe community (of minor importance) includes the mangroves, grasses and salt bushes growing in the ponds or near the pond borders.

The ponds of a solar saltworks can be grouped conveniently into low (3.5–9 Be), intermediate (8.5–18 Be) and high (18–29 Be) salinity ranges. Each group of ponds has a distinct biota with a well-defined role in the brine ecosystem. Low salinity ponds display the greatest organism diversity (Davis, 1978), biological productivity of organic matter (Carpelan, 1957), and ecological stability of the entire system. As salinity increases in a salina (from intake to crystallizers), there is a decrease in organism diversity, biological productivity (Copeland and Jones, 1965), but dissolved (Wilson, 1963) and particulate organic matter increase. The latter increase is due to concentration by brine evaporation, and to the inability of the bacteria in downstream ponds to breakdown organic matter as fast as it arrives. Salinity increments in a salina also induce a succession of microorganisms permitting the reuse of essential minerals and organic matter. Thus, when organisms flow from a lower to a higher salinity pond, they die and make available to a new set of organisms their minerals and organic matter.

Of the diverse organisms in the ponds of low salinity, photosynthetic algae and bacteria manufacture organic materials from carbon dioxide, water, light energy and essential minerals. This organic fuel is an important power source for the organisms of the downstream ponds, since with increasing salinity, the brine ecosystem changes from a nutritionally-independent biota dominated by algae to a nutritionally-dependent system (Nixon, 1974) mainly of bacteria.

The organization of the biota into planktonic and bottom communities in the low salinity ponds is facilitated by small molluscs and other organisms that produce fecal pellets; these organisms thus concentrate essential minerals and organic materials on the bottom of the pond to aid mat construction. Suspended fecal pellet fragments contribute important quantities of colored debris that improve solar absorption.

Whether the salina's intake is seawater or intermediate salinity brine, a specialized biota develops in the ponds of intermediate salinity. Most noteworthy is the plankton component consisting of brine shrimp, brine flies and blue-green algae. Depending on the intake water of the salina, brine shrimp and brine fly larvae feed on organisms and debris produced in the low and the intermediate ponds or only in the latter. In a balanced biological system, non mucilage producing planktonic blue-green algae thrive and impart important dark colors to the brine. In a salina whose ecosystem is out of balance or improperly managed, the planktonic blue-green algae, *Coccochloris elabens*, universally common in intermediate salinity brine, may predominate and harm the salina. Problems involved with the latter organism associated with mucilage production will be reviewed later.

Brine shrimp living in the ponds of intermediate salinities synthesize more hemoglobin (Fox, 1949), expend greater amounts of energy (Kuenen, 1939) and thus consume more food than they would require at lower salinities because of the extra osmoregulation work they must perform in order to maintain themselves. This "forced" feeding by brine shrimp is of particular value to a solar saltworks. Brine shrimp ingest all particles (microorganisms, debris, carbonate and sulfate crystals) able to enter their mouths, but they can live only when organisms other than the indigestible *Coccochloris* are the main constituents in their diet (Gibor, 1956). (The author assumes the "*Stichococcus*" of Gibor is *Coccochloris*.) Instead of mineralizing as soluble feces the food they consume and thus encouraging the ever present *Coccochloris* to reproduce excessively and form copious amounts of mucilage, brine shrimp excrete their wastes in membrane-bound fecal pellets (Reeve, 1963) that sink to the bottom. Brine shrimp grazing vocaciously and defecating fecal pellets effectively remove suspended plankton, particulate organic material and minerals from the brine where they could do harm. Thus, much organic matter is oxidized by the brine shrimp's metabolism, and the minerals and non-digested *Coccochloris* in the brine shrimp's excrement pass to the bottom community. Bottom mats thus favored not only seal ponds, but their color aids evaporation, their growth removes minerals from the water, and their photosynthesis helps to oxygenate the brine.

Brine shrimp, brine fly larvae, and algae produced in the ponds of intermediate salinities eventually flow into high salinity ponds. There, the algae break up into colored fragments, and the animals dissolve; it seems reasonable to assume that red halophilic bacteria living in the high salinity ponds aid both of these processes. The minerals, and part of the organic matter thus released become incorporated into the algae and bacteria of the bottom mats. Much of the dissolved organic matter becomes food for the planktonic red halophilic bacteria. The riding of excessive organic materials in the high salinity ponds is probably the most important function of the red halophilic bacteria, but the algal fragments, and the bacteria also color the brine of storage ponds and crystallizers red. Without this color, the rate of brine evaporation would be reduced. Brine shrimp and brine fly larvae are an important ecological link between the biota of the low salinity ponds, and the red halophilic bacteria of the highly saline ponds and crystallizers. These bacteria need high concentrations of protein in their diet in order to grow and reproduce (Dundas et al., 1963; Onishi et al., 1965); brine shrimp and brine fly larvae in many salinas supply these protein requirements.

Thus, a salina with a balanced biological system is characterized by a diverse biota of microorganisms with high biological productivity in the low salinity ponds, the proper balance of planktonic blue-green algae and brine animals in the intermediate salinity ponds, and high concentrations of red halophilic bacteria in the ponds of high salinity. The brine of all ponds will be brightly colored, and the pond bottoms will be covered with living mats and deposits composed primarily of blue-green algae and bacteria. Most importantly, an optimum balance exists between the planktonic and bottom communities.

INADEQUATE BIOLOGICAL SYSTEMS

Inadequate systems occur in solar saltworks that leak brine and lack adequate water color in the ponds; these poorly developed ecosystems fail to manufacture sufficient biological materials necessary to produce mats to seal ponds and plankton populations to properly color brine. Leakage and poor coloration, often due to a paucity of essential minerals in the intake water, occur frequently in new salinas and in solar saltworks that have been operating for a number of years.

UNBALANCED BIOLOGICAL SYSTEMS

Excessively deep ponds, severe wave action and high concentrations of combined nitrogen and phosphorus in the water favor the development of the planktonic community and suppress the formation of the bottom community. This imbalance between the two communities often causes leakage of brine, and higher than usual concentrations of suspended and dissolved organic materials. Also promoting the unbalanced condition, particularly in ponds of intermediate salinity, is the overproduction of *Coccochloris* and its attendant mucilage.

Coccochloris grows and reproduces rather well at salinities ranging from seawater to intermediate values. In low salinity water, many organisms compete for the available minerals, and no single species can dominate. At the intermediate salinities, the planktonic alga often favored in the unbalanced condition is *Coccochloris*. This algae can exclude nearly all other planktonic organisms, and produce large amounts of mucilage in the brine. Decomposing at a slow rate, mucilage can render brine quite viscous, materially decreasing evaporation. High concentrations of *Coccochloris* and mucilage in brine ponds create anaerobic conditions at night, excluding the very important brine shrimp. If the *Coccochloris*-mucilage problem develops to serious proportions, then the downstream ponds can be damaged.

In the high salinity ponds and crystallizers, mucilage from the upstream ponds not only decreases brine evaporation, but its accumulation results in slowly-decomposing suspended black material which decreases the sodium chloride crystal size and becomes incorporated into the product. This difficult to remove material may necessitate expensive procedures before the salt can be sold.

BIOLOGICAL MANAGEMENT PROCEDURES

Biological management utilizes a small fraction of the budget and in return provides a service which aids the ecosystem in its function and survival. At salinas properly designed in relation to the environment, and where biologically-essential minerals are adequate in the intake water, the natural organisms and ordinary brine-handling procedures manage the ecosystem; these installations produce high quality product at design capacity. Other salinas can be made to develop and maintain balanced biological systems, and to produce sodium chloride at design capacity with human management. At these salinas, biological management involves correcting the ecosystem problems, and the use of procedures to maintain the desired ecosystem. The numerous conditions leading to unbalanced ecosystems may be complex, slow to develop, and expensive to correct. Corrective procedures have involved major changes in pond layout, changes in pond size, brine depth manipulation, and the introduction of brine animals into the ponds. In salinas with inadequate biological systems, fertilizers have been used to establish adequate ecosystems (Davis, 1978). When fertilizers are judiciously applied to the ponds, a series of ecological events occurs which lead to the production of a biological system able to properly color brine, to prevent leakage, and to perform the other necessary functions. Several years of fertilization are usually needed to secure the desired ecosystem; small applications of fertilizer to the intake water may be required in perpetuity to maintain some ecosystems. Fertilization procedures vary according to location, climate, age of the ponds, and the specific problems of the salina. It must be emphasized that although fertilization can promote the desired ecosystem, the procedure in the hands of unskilled persons can be wasteful, or it can result in an unbalanced ecosystem. After the balanced ecosystem has been established, it must be maintained if continued operations of the salina is desired. Maintenance can be accomplished by faithfully gathering, and implementing the information obtained from the observations and data discussed below.

PREVENTION OF BIOLOGICAL PROBLEMS

Corporations possessing salinas with ecosystems managed by the natural organisms and producing high quality product at design capacity should not be complacent with their situations. Although these salinas may have functioned successfully for a number of years, the biological systems therein are sensitive to internal and external ecological changes that can lead to serious problems. Thus, management officials need to be constantly informed of the condition of the biological system in these salinas.

Certain assays and observations, routinely taken from the water and bottom of the brine ponds, and then graphically displayed and analyzed, serve to help ascertain the biological situation in a saltworks; this information provides warning of future biological problems, and permits early adjustment of the ecosystem to avoid catastrophies. I often recommend assaying dissolved phosphate and nitrogen (ammonium and nitrate), particulate and dissolved organic carbon, brine viscosity, and biological productivity. The latter gives perhaps one of the most valuable estimations of the biological situation in the ponds. Long-term changes in crystal size should be graphically displayed. Management persons should walk through each pond to ascertain brine color, extent of bottom community development, and turbidity. From brine samples, the concentration and names of the dominant organisms should be learned. Some salinas now provide a full-time position to a person qualified in biology and chemistry to obtain and analyze data.

So far, nothing has been mentioned concerning the inclusion of brine biology concepts into the design of a new solar saltworks. A salina constructed with provision for brine biology and the ecological situation of the surrounding area would be largely immune to or could successfully manage biological problems; such biological problems that occur in these salinas could be corrected quickly and inexpensively. The additional cost to engineer biological concepts into the salina design would be well rewarded with the capacity to operate optimally the saltworks over a number of changing ecological conditions within and external to the ponding system.

With the ever increasing importance of solar salt, biological management must be accepted and practiced in existing modern salinas, and biological concepts must be incorporated into the design of new salinas. The alternative is well recorded in a number of marginally operating, deteriorating and defunct saltworks throughout the world. While management officials may credit the fate of these salinas to climate, porous soil, and "other factors," the record of low biological productivity, imbalanced systems, excessive energy input, poor design and inability to cope with changing ecological conditions inside or outside the saltworks is easy for one who knows how to read it.

DISCUSSION

Schneider:

Question: Have you determined nutrients other than phosphates in your different algal mat layers or have you measured the trace element distribution in the different layers?

Answer: No to both questions.

Perinelli:

Question. What is the PO_4 and N concentration in the intake seawater brine at which a biological system starts to be an unbalanced one?

Answer: A properly functioning biological system can tolerate high concentrations of phosphorus and nitrogen in the intake seawater. For example, in the intake water of a saltworks in San Francisco Bay, reported average concentrations of phosphorus and nitrogen were 10 and 47 microgram atoms per liter. To these values add significant quantities of phosphorus and nitrogen from organisms that die soon after they flow into the first pond. The bottom community of the balanced biological system removes potentially harmful minerals. When phosphorus and nitrogen are channelled mainly into the planktonic community, the biological system can become unbalanced.

Muttershead:

Question. In order to maintain levels of *Halobacterium* in the crystallizers as a biological replacement to the injection of solivap or naphthol green dyes, it appears necessary to also maintain high levels of *Coccochloris elabens* and the brine shrimp *Artemia salina*. In view of the known dangers to a salt field which can eventuate if *Coccochloris* proliferates in the absence of *Artemia salina*, would it be possible to eliminate this delicate biological train and replace it with one culminating in the alga *Dunaliella salina* being present in the crystallizers?

Answer. Although *Halobacterium* and *Dunaliella salina* populations furnish valuable color in crystallizer brine, *Halobacterium* is by far the more desirable. In addition to oxidizing organic matter, adequate concentrations of *Halobacterium* denote proper balance between the planktonic and bottom communities in the upstream ponds. This balance serves to control *Coccochloris*, and to trap minerals essential to algae. *Dunaliella salina* dominates the biota when ammonium, nitrate and phosphate concentrations are high; photosynthesis by *Dunaliella* accounts for much of the primary production of organic matter (which is undesirable) in crystallizers. In salinas whose intake is seawater, high concentrations of nitrogen and phosphorus in crystallizers often indicate biological imbalance in certain upstream ponds.

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