

SOLAR SALTWORKS: SALT MANUFACTURE FROM AN ENVIRONMENTALLY FRIENDLY INDUSTRY

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ABSTRACT.

This paper is intended to provide information to persons directly involved with salt (sodium chloride) manufacture from seasonal and continuously operated solar saltworks using seawater intake. The paper identifies the mission, construction details, and management methods needed for new and existing solar saltworks to maintain salt manufacture as an environmentally friendly industry. Biological systems produced by microorganisms in each pond able to help or harm salt manufacture are described. Emphasized are new realities that plague salt manufacture, and new concepts that enable coexistence with the new conditions. Details to realize the goals—continuous and economic manufacture of high quality salt at design capacity,—and pitfalls to avoid are discussed.

KEYWORDS: *Aphanothece halophytica* biological management, *Dunaliella salina*, *Artemia*

This contribution is the text of a paper presented at the second CEISSA conference in March 2009, at Merida, Yucatan, Mexico. A solar saltworks (salina, saltfield) is a connected series of shallow ponds (45 to 75 cm) through which seawater flows, evaporates by wind and solar energy, and deposits sodium chloride. Most of the salt is consumed by the industrial chlor-alkali process, but significant quantities are used for direct human consumption and road de-icing.

The annual production of most solar saltworks ranges from ten-thousand tons to several-million tons. In addition to their seaside location, appropriate climate, and adequate shipping facilities—soil impervious to water is also essential. The goal of every solar saltworks—continuous and economic manufacture of high quality salt at design capacity—requires a product whose concentrations of contaminants meet world standards, and crystal characteristics that are most economical to prepare for market. The world standard assay of high quality salt is as follows:

Ca	0.03 – 0.04%
Mg	0.02 – 0.03%
SO ₄	0.11 – 0.12%
H ₂ O	2.50 – 3.00%
Insol.	0.01 – 0.02%

Crystal characteristics of highest quality salt are large, single, solid, and transparent. They have the lowest wash losses, the most economical transport, the shortest residence on stock pile, and the firmest crops and salt floors. (Figure 1)

Characteristics of Crystals Produced in Most Solar Saltworks

These conglomerates of fused hopper (layered, hollow) require higher wash losses, longer stockpile residence, and higher costs for harvest and transport. Cavities, layers, and surfaces of the hopper crystals trap water and contaminants. (Color added for photo. Fig. 2.)



Figure 1. Salt crystals--single, large, clear



Figure 2. Fused hoppers—layered, hollow

Crystal characteristics of the lowest quality salt

These crystals, mostly cubes of 1- to 2-mm on a side, have microscopic cavities and expose large surface areas which become coated with organic substances and trap contaminants. Losses in the wash process required to attain world standards are considerably higher than the losses from solid and conglomerate hoppers.

A properly-designed and correctly-operated solar saltworks is an environmentally friendly industry. Manufacture of salt by solar saltworks ranks high among environmentally friendly industries. Of the attributes that contribute to this status, some outstanding characteristics are noteworthy. The raw material, seawater, is inexhaustible, readily available, and of nearly constant salinity everywhere. This sustainable industry uses cost-free wind and sun to power the evaporation of seawater, the largest energy-using process for salt manufacture. The non-renewal component of the energy requirement—fuel and electrical power for vehicles and machinery—is comparatively low. Waste from the salt manufacturing process, the supernatant from crystallizers (the bittren), can be raw material for industrial processes, retained permanently on salina property, or released gradually at optimum times. Most striking is the wildlife habitat offered by the shallow water, dikes, and lack of human disturbances. In many countries solar saltworks are part of natural preserves maintained in perpetuity for coming generations.

Every solar saltworks has two interlocked systems: a physical system—a series of ponds through which seawater flows, evaporates, and deposits sodium chloride, and **a biological system**—living organisms (microorganisms) in every pond. The organisms either provide essential services, or they result in a constant struggle for continued operation.

A biological system able to help or harm salt production *inevitably* develops in every solar saltworks. A biological system that aids salt manufacture is a helpful biological system, and a biological system that harms salt manufacture is a harmful biological system. A solar saltworks with a helpful biological system achieves continuous and economic manufacture of high quality salt at design capacity, but a solar saltworks with a harmful biological system **does not** achieve this goal. Helpful systems can change to harmful systems, and harmful systems can be changed to helpful systems.

CHARACTERISTICS OF A HELPFUL BIOLOGICAL SYSTEM

Organization consists of organisms suspended in the water—*suspended community*--and organisms on floors in layered mats—*floor community*. Composition of both communities includes many species of algae, bacteria, metazoa, and protozoa. Only the algae and certain bacteria manufacture new organic by photosynthesis; all other organisms consume organic substances.

FUNCTIONS OF COMMUNITIES IN A HELPFUL BIOLOGICAL SYSTEM

Low salinity ponds (Be 3.5 to 9; S.G. 1.025 to 1.067).

The suspended community powers the entire biological system of the salina at desired levels, and exports quantities of nutrients to create helpful biological systems in all the downstream ponds.

The floor community (Fig. 3) removes nutrients from the water, controls seepage, stays in place, maintains desired thickness, and may be anchored by seagrasses and seaweeds.

Intermediate salinity ponds (Be 10 to 21; S.G. 1.075 to 1.170)

The Suspended community. The microorganisms consume much of the imports from upstream, manufacture only small amounts of new organic substances, and export quantities of nutrients to create helpful biological systems in the downstream ponds. A key component—*Artemia* (Fig. 4)—removes nutrients and particulates from the water and lives, grows, and reproduces in this salinity range.

The Floor community is layered, removes nutrients, maintains desired thickness, and controls seepage.

High salinity ponds and crystallizers (Be 22 to 30; S.G. 1.180 to 1.262)

The Suspended Community consumes much of the imports from upstream, but manufactures only small quantities of new organic substances. The key component—red halophilic bacteria (Fig. 5)—remove nutrients and aid evaporation.



Figure 3. Mat



Figure 4. Artemia

The Floor Community. Sediments, microorganisms, and organic substances under gypsum and salt are nutrient removers. Gypsum is deposited in firm sheets on the floors (Fig. 9).

Physical characteristics of saltworks with helpful biological systems: An unchanging salinity at each point in each pond, and unchanging pond volumes and surface areas, achieve stability, which aids both physical and biological systems. Most gypsum deposition is in firm sheets on floors of high salinity ponds. Harvest consists of unchanging salt quantities. Losses from wash are 12 percent or less. Salt assay stays at world standards. A high percentage of crystals are solid, large, and clear, or fused hoppers, and a low percentage of crystals are small cubes. Crops and salt floors remain firm.



Figure 5. Red halophilic bacteria

Biological Characteristics of Saltworks with Harmful Systems: Suspended Communities These consist of large numbers of few kinds of microorganisms. Nutrient removers--*Artemia* and red halophilic bacteria--are ineffective or absent. Organic releasers--*Cladophora*, *Aphanothece halophytica* (Fig. 6) and *Dunaliella salina* (Fig. 7)--become dominant. Organic substances and water viscosities increase in high salinity ponds and crystallizers.

Floor Communities. These also consist of large numbers of few kinds of organisms; the organic-releasing *Aphanothece halophytica* become dominant, the microorganisms are not organized in layered mats and have no ability to remove nutrients, leading to fast accretion of loose deposits on floors and corners.

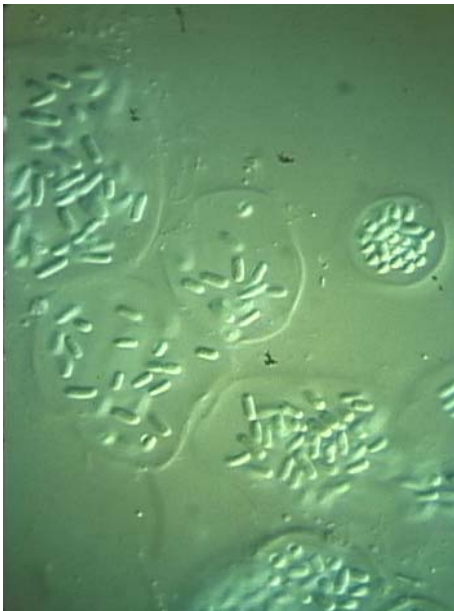


Figure 6. *Aphanothece halophytica*

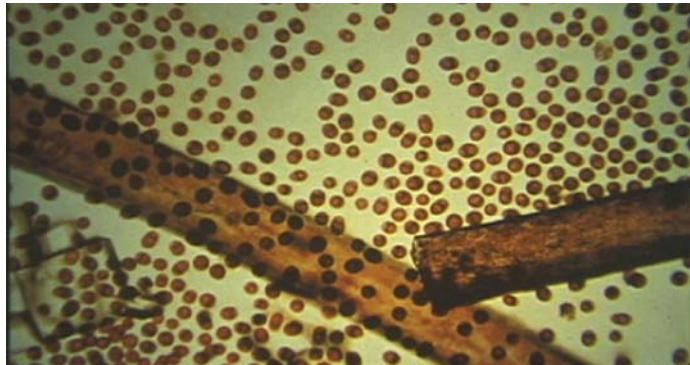


Figure7. *Dunaliella salina*

Gypsum deposition

Firm sheets on floors are absent. In high salinity ponds gypsum occurs in individual microscopic crystals (Fig.9) in the water and on the floors. In crystallizers, deposition

continues as individual microscopic crystals from suspended powder and from dissolved gypsum chelated with organic substances.

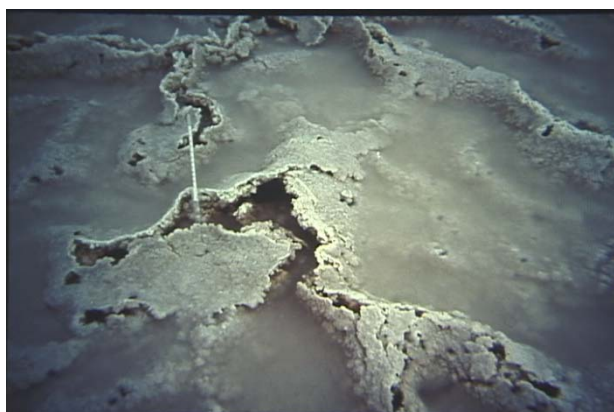


Figure 8. Gypsum deposition in firm sheets

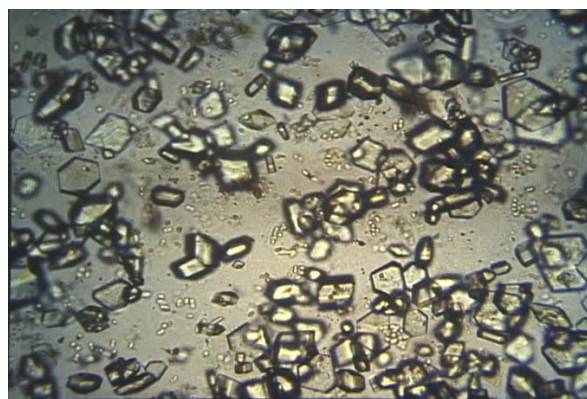


Figure 9. Gypsum deposition in microscopic crystals

Salt deposition

Massive quantities of organic substances released by *Aphanothece halophytica* and *Dunaliella salina* adversely affect evaporation and crystal size: Salt is deposited in small, layered, hollow hoppers and small crystals; the entire crop may be small cubes. Crops and soft salt floors are soft, often unable to support machinery.

Why are new solar saltworks and well established solar saltworks experiencing serious difficulties?

Current difficulties include decreased production of salt, decreasing surface areas and pond volumes, accumulating organic substances, soft crops and soft salt floors in crystallizers, harvest consisting of hoppers and small crystals only, excessive wash losses to reach desired assay, and increased costs for harvest, stockpiling, and transport. Most solar saltworks with these problems were constructed by reputable firms and managed by persons well experienced with solar salt. In fact, many of the problematic saltworks had an initial period with salt at full production, high quality and good economy. However, construction and operation of those problematic saltworks did not include provision or knowledge to manage the biological systems that developed. Also, ecological and demographic conditions at that time were much different than the new conditions of the present. Fortunately, new technology to cope with the new conditions has developed. Solar saltworks with helpful biological and physical systems can be created in a new solar saltworks or restored in an existing solar saltworks by awareness of the **New Realities** and by use of the **New Concepts** for construction and management. **The new realities** that plague most saltworks exist almost everywhere, but use of the **NEW CONCEPTS** enables successful co-existence with the New Realities.

THE NEW REALITIES

The intake seawater has increasing concentrations of nutrients in the form of combined nitrogen, phosphate, and organic substances (from microorganisms, human wastes, natural origin, and disturbances). Use of disinformation and outdated methods for construction and management fail to deal with increasing nutrients that result from a changing environment and demographics. Failure to incorporate into the design and operation features to manage the biological system that will develop, Increasing opposition for continued operation, difficulties for licensing new saltworks, and expanding existing saltworks, contribute to current problems.

Purpose of the new concepts

These concepts integrate biological systems with physical systems, create, preserve and restore helpful biological and physical systems in new and problematic saltworks, and enable a saltworks to coexist with the new realities. Also, the concepts allow anticipation of developing problems, and permit adjustments before disasters occur, increase biodiversity, aid nutrient removers, and suppress organic producers. The new concepts maximize evaporation and salt manufacture.

THE NEW CONCEPTS CONCEPT NUMBER ONE

Physical and biological systems work best with unchanging salinity at each point in each pond, a narrow salinity gradient in each pond, small salinity differences between ponds, uniform pond depths, and shallow, quiet waters.

CONCEPT NUMBER TWO

Maintain continuous control of the physical and biological system.

Structural requirements: Needed are sufficient numbers of ponds with adequate surface area in the circuit, adjustable gates of appropriate size, adjustable devices to dampen waves, decrease backmixing, and prevent short circuits, standby pumps at each pump station, and fast access by vehicle to all parts of the pond system.

Information requirements—personnel and equipment: An educated chief biologist, his crew, and sufficient support, close and continuous liaison between chief biologist and the salina manager, and adequate laboratory facility with equipment and computers.

Data gathering—numerical and analytical at strategic locations: Twice weekly--Secchi depth and actual water depth, salinity, temperature; evaporation and rainfall—at centrally located station. Twice each season--analyses of total nitrogen and phosphorus from the water in the center of selected ponds.

Anecdotal Requirements: Enter data from complete inspection of the pond system on spread sheet. Include usual and unusual events, measured accumulations of deposits on floors and corners, thickness of floor community, and perimeter widths of mushy salt in crystallizers.

Data utilization and processing

Purchase or construct a computer program to graph all data for proper display. Use data to adjust pumps and gates for desired depths, flow, wash efficiency, crystal characteristics and size distribution, changes in species composition, and changes in key organisms.

CONCEPT NUMBER THREE

Avoid apparent advantages that lead to permanent burdens. For the intake, avoid use of deep lagoons, small bays, river water, lake water, subterranean brines, or combinations of these sources. Avoid using dike material from inside of a pond, and disposing of organic substances or mushy salt perimeters on dikes.

Avoid removal of a pond from the circuit, use of green dyes in crystallizers, major modifications of the salt washing equipment, batch flow rather than continuous flow, and increasing water levels in ponds to increase salt production.

CONCEPT NUMBER FOUR

Deal with loss of nutrient removers.

Floor Communities (layered mats)

Add more surface area to the low salinity range, decrease depths, moderate wave fetch, install decanters, construct a nutrient-removing system.

Artemia

Locate and correct upstream causes; begin and maintain massive and frequent reinoculation until the new population is self recruiting.

Red halophilic bacteria

Locate and correct upstream causes, discard and flush out old brine, replace old salt floors, and remove mushy perimeters

CONCEPT NUMBER FIVE

Deal with accumulations. Remove floating filamentous and mucilaginous algae on a regular schedule; remove deposits from corners, peripheries, and floors. Discard all accumulations well away from the ponds.

Crystallizer Ponds

Remove and replace salt floors on a regular schedule, remove immediately spills of fuel, grease, and hydraulic fluid. With every harvest, remove mushy perimeters. Don't leave vehicles in crystallizers overnight.

CONCEPT NUMBER SIX

To saltworks owners desiring official permission to expand their existing saltworks, and to persons desiring to construct new solar saltworks: Study carefully the Environmental Impact Statements of successful and non successful applicants. Hire a professional staff to gather highly detailed, pertinent data at the proposed site and to prepare and submit your impact statement. Personally visit successful and non successful applicants.

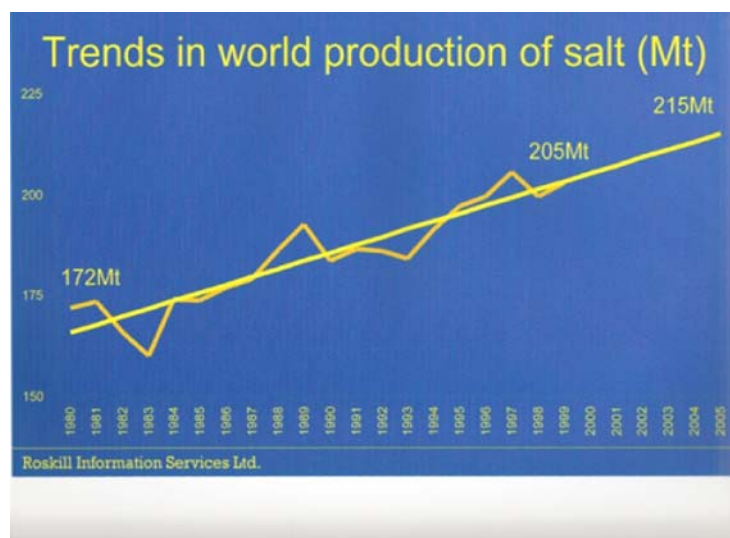


Figure 10. Correlation of salt production with world population growth

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