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Solar Ponds:

A Selected Bibliography

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A Division of Midwest Research Institute

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Introduction

Anyone who has watched a pot of water come to boil has observed the phenomenon of convection. The heated bottom becomes less dense and rises, permitting the cooler, denser water above to replace it below. Because of this continuous flow, the temperature difference between top and bottom is relatively slight throughout the process. If convection is prevented at any horizontal plane, the heat will build up below, creating a temperature difference between top and bottom. This sometimes occurs naturally in bodies of salt water; the salt increases the density of the water, so fresh water flowing into the lake or sea floats on top of the salt water. Although the sun's energy heats the water at the bottom, the salt concentration makes the water so dense that convection cannot take place; thus, the heat builds up in the lower layer of water.

The modern man-made solar pond exploits this phenomenon for two purposes: to store the heat, and to use the heat for energy production. A properly designed solar pond will reach (or in certain cases exceed) temperatures of close to 100°C (212°F) in the lowest layer. This is sufficient to provide heat for residential or low-temperature industrial use, or to power engines to produce mechanical or electrical energy.

There are several designs that prevent convection and permit the heat build-up. The most widely investigated type of nonconvecting solar pond today is the salt-gradient pond. Increasing salinity with increasing depth suppresses the normal convection patterns and creates what is basically a three-layered pond. The very shallow top layer of fresh or slightly salty water has the same salinity throughout its entire depth, and thus convection takes place. The highly saline bottom storage layer is also a convecting layer due to the relatively strong absorption of solar energy at the bottom of the pond. The central layer, ranging from slightly saltier at its upper boundary to very salty at its lower boundary is nonconvecting because of its salt gradient. This stable middle layer serves partially as heat storage, but more importantly as insulation for the lower storage layer.

The phenomenon of saturated salty ponds is also being examined. Ponds using certain salts (such as salts of magnesium, calcium, and boron compounds) have temperature-dependant solubilities; that is, the hotter the liquid, the greater its capacity to carry the salts in solution. The salt concentration of a saturated solution thus varies directly with the temperature of the solution. In saturated ponds, this temperature dependence creates and maintains the salinity gradient, which in turn maintains the temperature gradient. Although these ponds require significantly more salt than the three-layered ponds, their salinity gradient is theoreticaly self-maintaining and the temperature at the lowest levels (with the most highly-saturated brine) can rise well above 100°C.

Other techniques, physical as well as chemical, are being developed to suppress convection. Transparent membranes are being tested, both horizontally to maintain the nonconvecting layer, and vertically to create a "honeycomb" structure in which each cell is too small for convection to take place. Substances that either thicken the water until it is too viscous for convection to occur or that actually cause the whole pond to gel are also being investigated.

While shallow solar ponds sound like simple variants of solar ponds, they are physically very different since separate storage is needed. They most resemble arrays of flat-plate collectors. They are typically dark plastic water bags of minimal depth, housed in insulated frames and covered with transparent glazing.

There is no capacity in shallow solar ponds for integral storage of solar energy. The pond is filled in the morning and the water is either used for low-temperature applications, or drained into insulated storage in the evening. Most of the research work on shallow solar ponds, which appears as a separate section of the bibliography, is being done by a research group at Lawrence Livermore Laboratory, Livermore, California.

THE LITERATURE

Although the natural phenomenon that is the basis for nonconvecting solar ponds was first reported in Annalen der Physik in 1902 by Kaleczinsky, there was no further interest evidenced in the scientific literature until two decades ago. Beginning only in 1959 (Tabor), individual papers appeared at the rate of perhaps one or two a year; only three papers were presented at conferences prior to 1973. The renewed interest in solar ponds, both for energy storage and for energy production, and the varied activities of research groups are strongly reflected in the growth of the literature in the last decade, and more particularly in the last five years. For example, dissertations and patents are good indicators both of the newness and the growing interest in solar ponds. The first doctoral dissertation on solar ponds in North America was done at McGill University, Montreal, (Chepurniy) in 1976. Three additional dissertations were completed in the United States in 1979 (Hull, Iowa State University; Zangrando, University of New Mexico; and Holmes Virginia Polytechnic Institute). Only 17 patents, issued since 1968, were found in the course of the literature search.

SCOPE

This bibliography is divided into three sections: I. Solar Ponds; II. Shallow Solar Ponds; and III. Patents. Selected references on fluid mechanics have been included in Section I.

References have been included in the bibliography if the documents represented by them have been determined to be available through libraries, bookstores, or other sources. Additional references were located in the literature search, but were not included if the documents are unpublished and/or copies of them are not easily obtainable.

The following citations from Section I have been informally recommended by several reviewers for the reader who wishes to acquire a general understanding of solar ponds technology:

93 (Kooi, 1979);
125 (Nielsen, 1980);
142 (Sargent, Neeper, 1980);
175 (Tabor, Weinberger, 1981);
205 (Zangrando; Bryant, 1978).

For a more detailed review of the research which has been undertaken, the general operational results obtained to date, and the research and development areas which need further investigation, the following references from Section I are recommended:

37 ("Dead Sea Project. . ., 1980);
44 (Edesess, Henderson, Jayadev, 1979);
51 (French, Meitlis, 1980);
54 (Fynn, Short, Shah, 1981);

73 (Hull, 1980);
77 (Huppert, Linden, 1979);
124 (Nielsen, 1980);
129 (Ochs, 1980);
157 (Short, Badger, Roller, 1979);
199 (Wittenberg, Harris, 1981);
206 (Zangrando, Bryant, 1979).

The following citations are recommended for a general understanding of shallow solar ponds from Section II of the bibliography:

11 (Clark, Dickinson, 1980);
25 (Dickinson, Clark, Day, Wouters, 1976).

For an overview of shallow solar ponds research, the reader may wish to refer to the following citations in Section II:

5 (Casamajor, Parsons, 1979);
25 (Dickinson, Clark, Day, Wouters, 1976);
26 (Dickinson, Clark, Iantuono, 1976).

SOURCES

This bibliography was compiled through an extensive literature search by the Solar Energy Information Center, Solar Energy Research Institute. This effort was coordinated by Barbara Schwab and Marilyn J. Shartran.

In addition to references suggested by reviewers, the following bibliographic data bases were searched through March 1981:

1. AGRICOLA (Agricultural On Line Access) - Provides extensive coverage of worldwide agricultural literature from 1970 onward.
2. CA SEARCH - The online version of Chemical Abstracts, this data base provides extensive coverage of the worldwide chemical literature.
3. CLAIMS™ - Contains citations and abstracts for patents issued by the U.S. Patent Office from 1950 forward.
4. COMPENDEX - The machine-readable version of Engineering Index, which indexes the world's significant engineering and technological literature from 1970 to the present.
5. COMPREHENSIVE DISSERTATION ABSTRACTS - A data base containing records of American doctoral dissertations accepted at accredited institutions since 1861.
6. CONFERENCE PAPERS INDEX - Provides an index to papers presented at approximately 1000 scientific and technical meetings worldwide each year. Covers the period 1973 to the present.
7. ENERGYLINE - Provides broad coverage of scientific, engineering, political, and socio-economic aspects of energy policy, resources, conversion, and consumption. Covering the period 1971 to the present, this data base corresponds to the printed Energy Information Abstracts.

8. GPO MONTHLY CATALOG - Corresponds to the printed Monthly Catalog of United States Government Publications. This file indexes public documents published by the U.S. Government from 1976 to the present.

9. INSPEC - Covers the fields of physics, electrical engineering, electronics, computers, and control engineering. Corresponds to the hard copy Physics Abstracts, Electrical and Electronics Abstracts, and Computer and Control Abstracts from 1969 onward.

10. NTIS - Covers government-sponsored research, development and engineering reports, plus analyses, journal articles, and translations prepared by Federal agencies, their contractors, and grantees from 1964 to the present.

11. PAIS INTERNATIONAL - Covers the whole range of the social sciences with emphasis on contemporary public issues and the making and evaluating of public policy. Corresponding to the hardcopy PAIS Bullentin, it covers documents published since 1972.

12. SCISEARCH - A multidisciplinary index to the literature of science and technology. Contains all records published in Science Citation Index from 1974 forward.

13. SPIN (Searchable Physics Information Notices) - Abstracts and indexes a selected set of the world's most significant physics journals form 1975 to the present.

Section I
Solar Ponds

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