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A SOLAR POND FOR HEATING GREENHOUSES[1]

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Greenhouses are heated almost entirely by solar energy by day and fossil fuel by night. It is the fossil fuel requirement at night that is becoming or has become prohibitively costly. The greenhouse almost always accumulates surplus heat during daylight hours — even in Ohio mid-winters. A system that collects solar energy and stores greenhouse surplus heat for nighttime use could be very beneficial. Therefore, a solar pond is being studied as a solar collector and potential storage system along with the appropriate equipment to move heat to and from the greenhouse.

Natural solar ponds were first discovered in the early 1900's in Hungary (2). Temperatures up to 80°C (176°F) have been recorded. It is theorized that such ponds are fed by saltwater springs while fresh rainwater periodically flushes off the surface. The result is a stable pond of solar heated brine at the bottom of which is too dense to circulate to the surface and cool. More recently, researchers believe that a warm lake in Antarctica is a solar pond rather than a previously assumed hot spring lake (1). Tabor (5) has probably done some of the most extensive work to date to make the solar pond economically useful for power generation in Israel. Israel is in a high radiation area and the Dead Sea is a good brine source. Tabor was able to achieve small pond temperatures up to 90°C (194°F), but had numerous technical problems with large ponds. One large pond in a marsh area was destroyed by mud bulges and gas bubbles being generated as the pond warmed. A plastic liner was installed, but the same bubble action lifted the liner in various areas and caused severe mixing of the pond. There were also tedious problems in establishing the pond concentration gradients and the research was essentially stopped. Rabl and Nielsen (4) have studied the solar pond as a solution to space heating of residences in Ohio and similar areas. Rabl calculated that a pond equal in volume to a well insulated three bedroom home could meet all of the winter heat requirements of that home. Nielsen (3) further developed a unique salt gradient establishment procedure using a small pool and laboratory models.

Based on Rabl and Nielsen's work, a full-scale experimental solar pond was constructed adjacent to the Department of Agricultural Engineering greenhouse at the Ohio Agricultural Research and Development Center (OARDC). The pond was designed to meet all of the winter heat requirements of a 2000 ft^2 3 bedroom home or a 1000 ft^2 greenhouse in Wooster, Ohio.

DESIGN AND ESTABLISHMENT OF THE SOLAR POND

The OARDC pond is 12 ft deep, 28 ft wide and 60 ft long. The pond walls are post and plywood construction with a sand bottom. Two 30 mil chlorinated-polyethylene liners with a nylon scrim were fabricated to fit the pit and contain the brine. The side walls were insulated and the bottom is expected to become insulated as the warm pond dries out the surrounding soil.

The pond walls were designed to accommodate a standard clear span, pipe-frame plastic covered greenhouse. An air-inflated double plastic cover was installed over the pipe frame to: 1) help insulate the pond, 2) minimize dirt, trash and contamination, 3) quiet the surface to reduce light scatter and gradient mixing, and 4) raise the humidity above the water surface to control evaporation. A reflector was designed for the inside north greenhouse wall to increase the effective collection area of the pond.

A 6 ft convective zone of approximately 20% salt was established in the bottom half of the pond. The top half has a concentration gradient that varies from 20% at the depth to zero at the surface. No circulation occurs in the top since every layer is lighter than the layer beneath it.

The salt concentration gradient was established according to a technique developed by Nielsen (3). The pond was filled to

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the three-quarter level with a 20% solution. Fresh water was carefully distributed over a floating sheet of plywood until the pond was full. The sizeable density difference of the freshwater and concentrated brine resulted in two distinct sections with little mixing. A pump with two inlets was then used to extract equal amounts of fluid from each section. The pump mixed the 20% solution with the freshwater to get a 10% solution. The 10% solution was injected between the original sections creating a new concentration zone occupying one-third of the top half of the pond. Subsequently, the three (0%, 10%, 20%) zones were used to form five zones (0%, 5%, 10%, 15%, and 20%) and the 5 zones were used to form nine final zones. The nine final zones were approximately 8 inches thick which was small enough for a perfect gradient to eventually form by diffusion and mixing.

RADIATION COLLECTION AND HEAT STORAGE

The solar pond is heated by solar radiation passing through the saltwater to the black liner holding the liquid. As the black liner temperature increases, heat is transferred to the 20% brine in the bottom half of the pond. The heated 20% brine rises no higher than the bottom layer of the gradient and cooler 20% brine moves down to replace it. The upper non-convective region is nearly transparent to incoming ultra-violet and visible radiation and nearly opaque to incoming infra-red and outgoing long-wave re-radiation. One meter of non-convective water is a good insulator with a conductivity equivalent to approximately 6 cm of styrofoam. Since the walls are also insulated, losses are reduced significantly.

A major advantage of the solar pond is that both summer and winter radiation can be collected and stored for later use. After a full summer's radiation, the pond temperature throughout the bottom half should approach boiling. The OARDC pond will be limited to 80°C (180°F) however, to maintain liner stability. This upper temperature limit will be controlled with discharge heat exchangers or by covering the pond with an opaque plastic film.

RESULTS

The gradient has required little maintenance since establishment. Salt diffuses very slowly fromt he more concetrated brine at the bottom to the less concentrated brine at the top. Brine was flushed off the surface and freshwater added two times during the fall of 1975, but mixing from the wind did not make the process seem very successful. Brine flushing was not attempted after the pond was covered and protected with a greenhouse. It is anticipated that flushing might not be necessary if a closed cycle system can be developed.

The maximum temperature for the first year was 45.5°C (114°F) on September 16, 1975. This maximum was far below the desired 82°C (180°F), since 1) the pond was not established until late summer and 2) nearly half of the first year absorbed heat was expected to be lost in drying out the soil under and around the pond. The changes in maximum pond temperature did not fluctuate as much as the radiation or outside air temperatures.

There are still numerous questions to be answered concerning the feasibility of the solar pond for space heating. The first real test of heat extraction is planned for the winter of 1976-77. Pond stability at high temperatures will be tested and evaluated. Solar ponds must be leakproof or be constructed to handle leaks that may occur at any time. Any leaks result in the pond losing both hot brine and dry soil insulation. Likewise, leaking brine may seriously contaminate surrounding water sources and soils. Currently, almost all ponds or pools leak or can be expected to leak at some time. There are no consistently effective ways of identifying and patching brine source leaks without draining the pond. Such problems however, may be solved with new liner technology.

Other problems observed in constructing and operating open ponds are: 1) wind will cause surface mixing, 2) rain water must be removed after storms and water must be added to make up evaporative losses, and 3) organic debris such as leaves will get blown into the pond. Leaves are buoyant at approximately 30 inches below the surface. These leaves can interfere with light transmission for 3 to 4 months before sinking to the bottom.

Much more is yet to be learned about solar ponds. The potential is exciting — the unanticipated problems are frustrating and often costly. The net result will hopefully be an acceptable and economical solution to the utilization of solar energy for space heating greenhouses and rural residences.

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