INTEGRATION OF SOLAR POND WITH WATER DESALINATION

U. Fisher, J. Weinberg and B. Doron
Ormat Industries Ltd., Yavne, Israel

Keywords : Alternative energy, Binary cycle, Bottoming cycle, Energy conversion, Organic Rankine cycle, Solar pond, SPPP, Sun belt

Contents

Summary

This review section is divided to three parts. First it describes the salt gradient solar pond, then it identifies matching desalination systems amongst few optional possibilities and finally it shows that the combination of a pond with a matching desalination plant can produce fresh water in competitive price.

Salt gradient solar pond history and its emerging from experimental stages toward being large heat collector/storage is thoroughly reviewed. Followed by a listing of the more famous ponds in the world there comes a detailed description of main demands when building a pond such as surface area, make up water supply and brine supply to compensate for the continuous diffusion of salt from the bottom towards the upper layers. Design parameters, construction materials and actual recommendations for initial operation are brought with example cases. Heat losses to the ground, to the gradient

layer and to the air above the pond are discussed as also the disturbances to operation caused by algae, corrosion and wind. Then comes a section that deals with heat extraction, operation and maintenance activities and their costs and finally preferred size and specific investment.

Three desalination processes are evaluated as matching options for the pond: Multi-Stage Flash (MSF), Low-Temperature Multi-Effect Distillation (LT-MED) and Sea-Water Reverse Osmosis (SWRO). The evaluation begins with the solar pond yield and the heat or electrical energy it supplies. Then follows the desalination plants performance considering the impact of daily and seasonal fluctuations. The economical comparison that concludes the evaluation shows that the combination of solar pond with Low Temperature-Multi Effect Distillation plant is the most competitive combination for solar desalination. Hybrid thermal and RO plants can also be considered and preferably plants in which heat is supplied by solar pond and electricity by the grid. Because of the different quality of product water: 500 ppm TDS for RO, 50 ppm TDS for MSF and 20 ppm TDS for MED, equalizing action to bring all product water to 500 ppm using brackish water, if available, may increase production of the thermal plants. Scale factor strongly affects cost and plants of 10 000 m^3 per day are already economical.

1. Introduction

The utilization of solar energy for large scale water desalination systems has become an intriguing issue. This is because, on the one hand, novel saline water distillation processes, operating reliably and efficiently with a variety of energy sources, are available. On the other hand, methods for continuous heat extraction from solar ponds have matured; in spite of which we could not locate even one project of large scale desalination based on solar energy.

Most of the countries that are in great need of water are those in the global "sun belt". Some of them have oil and therefore install electric or thermal driven brackish and seawater desalination plants. In other, particularly developing countries, where the cost of oil is high, the desalination of seawater is prohibitive, due to investment and high production costs.

In recent years the attitude toward renewable energies has changed. Even rich countries are looking to the future, for fear of oil price increase or the desire to preserve fuel reserves. Environmental considerations also contribute to the increase in use of alternative energies, particularly with increasing levels of air pollution. According to WEC (1994) reports, environmental considerations may double the use of alternative energies in the near future. As a result, serious evaluations and more investments (but surely not sufficient) are today channeled into alternative energies, including solar energy.

The use of solar energy for seawater desalination has a long history. It started with solar stills that use flat collectors, as given by Talbert et al. (1970), Cooper (1983) and many others. It can be a bottoming distillation plant combined with a high concentrated energy solar power cycle such as the Luz (1995) power conversion system. Other desalination systems that work in relatively low temperatures can use solar ponds, described by Tabor (1975), Swift and Reid (1987), as also solar diodes by Klier (1986), Schaefer and Lowrey (1992), and others.

The aims of this section are as follows:

Introduce and summarize design and operation aspects related to the salt gradient solar pond technology.
Identify a matching desalination system from amongst several possible options.
Show that the combination of the present solar pond technology with the right seawater desalination technology can bring about production of fresh water at a competitive price.

The salt gradient solar pond is a body of water, which acts as a sun insolation heat collector. It has a high salinity layer at the bottom and a low salinity layer on top of the pond. There are numerous examples of natural and artificial lakes possessing density gradients due to salt concentration gradients that are positive with increasing depth.

In technical language, the salt concentration gradient is called the Halocline. If the Halocline is sufficiently steep, and the top layer is calm enough, incidental solar radiation may penetrate and cause a considerable temperature rise in the lower body of the water.

2. Historical Background

The first natural solar lake was described in literature by Kalecsinsky (1902). The lake is near Szovata, Transylvania. Temperatures near 70°C were recorded at a depth of 1.3 m at the end of summer and a minimum of 26°C was recorded in early spring. Bottom salinity was about 26 per cent NaCl.

Other lakes or ponds were recorded later, such as the "Hot Lake" near Oroville in Washington, reported by Anderson (1958), the solar lake in the Sinai Peninsula, and others.

Research on possible practical utilization of solar pond energy was started in Israel in the 1950s by Dr R. Bloch, research director of the Dead Sea Works. He observed the Halocline phenomenon in the brine ponds of the Works and considered the possible application of that phenomenon in the first artificial solar pond, which was built by Professor Tabor at the Dead Sea Works. Temperatures of above 103°C were measured and collection efficiency of about 15 per cent for heat extraction was predicted. One large pond was constructed in Israel during the 1960s, before the project was abandoned due to budget problems.

In the 1970s solar pond activities were revived and became a national project. Since then four solar ponds have been constructed at different locations in Israel:

1. 1975 - A 1100 m^2 pond at the Dead Sea Works where energy was extracted for the first time ever (by the Scientific Research Foundation).

2. 1977 - A 1000 m^2 in Eilat on the shore of the Red Sea.
3. 1977 - A 1500 m^2 pond in Yavne by Ormat Industries Ltd for testing of complete Rankine cycle for energy conversion with a 6 kW turbine. The surface water was used to cool the turbine condenser.

This was the first time electric power was generated continuously, both day and night, from a solar pond.

4. 1977 - A 6250 m^2 solar pond was constructed at Ein-Boqek, also by Ormat, on the shore of the Dead Sea. Temperatures as high as 93°C were reached and a 150 kW generator was coupled to the grid in 1979 and operated until 1983, when the plant was dismantled [the first desalination experiments were conducted in this pond (Doron 1986)].

The success of the Ein-Boqek demonstration encouraged the Israeli government to sponsor the construction, by Ormat, of a 5000 kW Solar Pond Power Plant (SPPP) with a 250 000 m^2 pond near Beit-Ha'arava in the north of the Dead Sea. The plant was connected to the grid in 1984 and operated continuously for a year. Later, it was operated on and off, for demonstrations and to extract the accumulated heat. This arrangement continued until 1989 when the wind screens were taken away, the water mixed and the plant was shut down for preservation, due to lack of financing. A huge amount of scientific work was done by Professor Tabor, and his early contributions are summarized in the paper of Tabor and Weinberger (1980).

The pioneer of solar ponds research in the US was Professor Nielsen, who initiated the solar pond studies at the Ohio State University in 1974. He later built a few small ponds in Ohio, to test power production and desalination (Nielsen 1975; Nielsen and Rable 1976). Interest in the solar pond option as a large scale solar collector grew in the US, and a 0.8 acre solar pond was built in El-Paso, Texas as a joint venture by the Bureau of Reclamation, the University of Texas at El-Paso and Bruce Foods Corporation. In 1985 the El-Paso pond became the first in the world to deliver process heat to a commercial manufacturer. In 1986, 85°C brine from the pond began supplying thermal energy to a 100 kW Organic Rankine Cycle (ORC) system supplied by Ormat. In 1987 hot brine was also supplied to a multi-stage desalination system (Hightower and Bronicki 1987; Swift and Reid 1987).

A Solar Pond Consortium was established in 1989 to promote the Salt Gradient Solar Pond technology for commercial applications.

A few other ponds exist today, such as the large 25 000 m^2 pond in Italy on the southern Adriatic coast at Marghrita di Savoia, the Alexandria pond in Egypt described by Amer et al. (1986), the 1700 m^2 pond in Kuwait (Al-Homoud et al. 1989) and (Al-Marafie et al. 1991). There is also the 2000 m^2 pond at the University of Illinois, described by Newell et al. (1990), the 6000 m^2 pond in Bhuj in India, and others in Portugal, Mexico, Japan, China and probably other countries as well. See also Sargent and Atkinson (1989).

Today there is limited activity in solar pond development world wide and many previously active projects have been abandoned, mainly due to the present low cost of gas and fossil fuel, but also due to the mistaken point of interest, which in most cases evaluated the pond as a power producing facility, rather than as a heat source.

In such cases the electric energy produced by a low temperature, low efficiency power cycle, driven by the pond cannot compete with electric energy produced by high efficiency cycles driven by low cost fuels, and it naturally takes second place. It is different in the case of low temperature heat utilization, where efficiencies are quite high, as will be shown later.

3. The Solar Pond

3.1. Structure

The solar pond consists of three layers of water (see Figure 1).

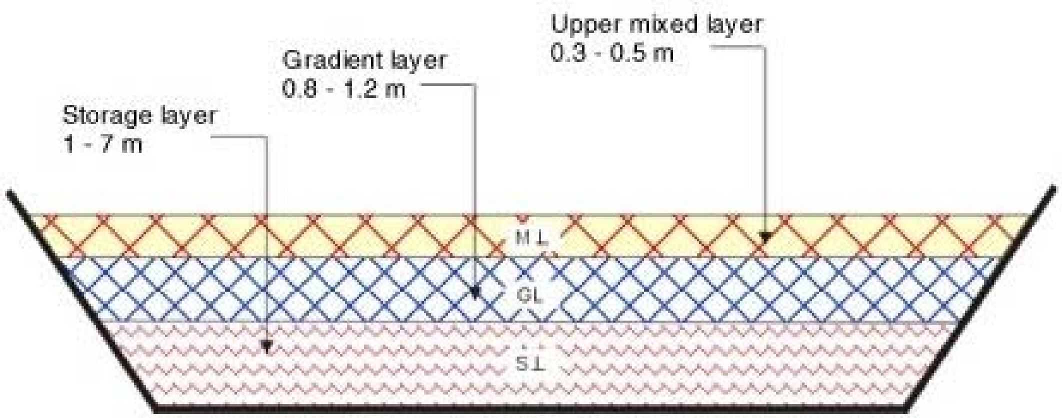

Figure 1. Solar pond layers structure.

The bottom layer: The bottom layer, which is also called the storage zone, consists of high concentration brine which absorbs the heat that reaches this layer by radiation.

The density within the storage zone is quite evenly distributed although the temperature at the very bottom is higher before heat is extracted and drops during the heat extraction period (see Figure 5) The thickness of the bottom layer determines the amount of heat which can be stored there and which can be used later on a daily, weekly, monthly or even seasonal basis. Three to seven meters is a practical storage thickness. This means that during certain periods, heat can be extracted from the pond in amounts higher than the insolation intensity at the time of extraction.

The top layer: The thickness of the top layer is about 0.3 to 0.5 m. This is the convective zone, and is also called the upper mixed zone. Convection is caused by the wind, which continuously evaporates water into the air thus mixing the top layer and causing a quite even distribution of temperature, close to the wet bulb temperature. It should consist of relatively low salinity water, such as fresh or brackish water. However, seawater can also be used at the top, because of its relative low salinity compared with the high salinity of the bottom concentrated brine.

The intermediate layer: The thickness of the intermediate layer is about 0.8 to 1.2 m. This layer is actually the insulator between the bottom heat storage and the top convective zone. It is also called the non-convective gradient zone and within it both the salinity and the temperature gradients have nearly the same profile. Salinity and temperature are low at the top near the upper mixed zone and they gradually increase toward the storage zone as shown in Figure 2.

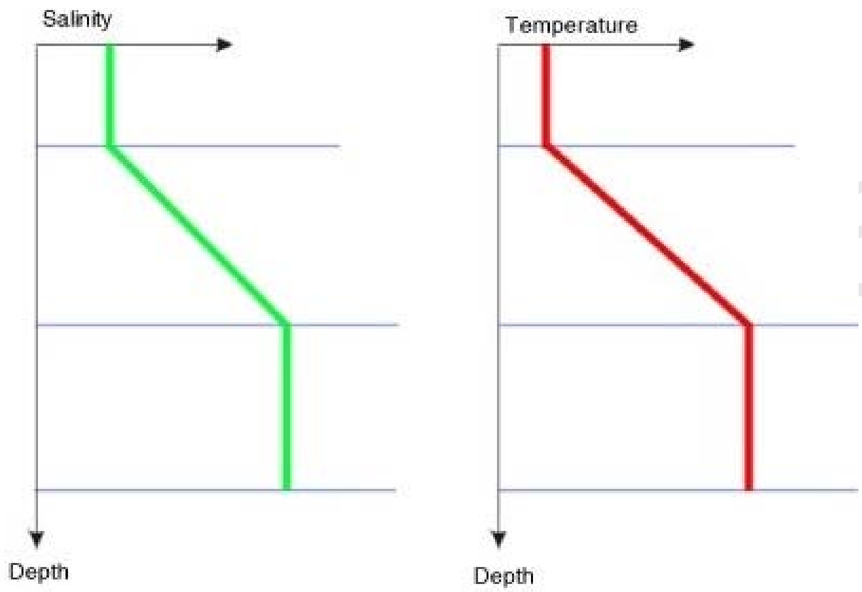

Figure 2. Salinity and temperature profiles.

3.2. Heat Absorption and Storage

The physics of solar ponds was first studied by Weinberger (1964) and later by Kooi (1979), who analyzed the steady-state performance of the pond.

Due to haziness, solar insolation, both direct and diffused, penetrates the upper layers and heats up the floor and bottom layers of the storage zone. Here the heat is trapped by the gradient zone, as its density is higher than that of the brine on top of it, even after being heated near to boiling temperature.

3.3. Main Demands when Building a Pond

Before dealing with design and control requirements, it seems important to make some quick calculations to evaluate the possibility of using solar ponds for power or desalination. Three main demands should be fulfilled before a solar pond can be built in a site:

1. Surface area for collection of solar radiation.
2. Make-up water, fresh or relative low salinity water for the upper mixed zone.
3. Concentrated brine for the initiation of the storage zone and in the case of electricity production continuous supply of concentrated brine.

3.3.1. Surface Area

The intensity of solar radiation depends on the latitude of the considered site location, time of the day, season of the year and clarity of the atmosphere. Between latitude 40° north and 40° south of the equator, the radiation seems high enough for recuperation.

Assuming an average annual insolation of 2000 kWh m^{-2} year and net pond efficiency of 18 per cent, the collected energy is about 360 kWh m^{-2} year.

The Carnot efficiency of a power system operating between 85°C and 25°C is 16.7 per cent. However, a practical Rankine cycle has a smaller temperature difference, due to a temperature drop in the evaporator and condenser. Assuming turbine efficiency of about 80 per cent, the resulting effective cycle efficiency is about 10 per cent. This means that in cases of power production, each m^2 will produce 36 kWh per year. With different data the results will have to be corrected respectively.

Based on the same assumptions, a 1000 kW generator, operating about 8000 h per year, requires a pond with surface area of about

$$1000 \times 8000/36 = 222\,000 \text{ m}^2$$

Considering a water desalination system that uses a Multi-Effect Distillation plant with an economy-ratio of 10:1, 1 m^2 of surface area can produce about 5.6 m^3 year of desalinated water as follows:

$$10 \times 360 \times 860 \text{ (kcal m}^{-2}\text{ per year)}/550\,000 \text{ (kcal m}^{-3}\text{)} = 5.62 \text{ m}^3 \text{ m}^{-2} \text{ per year}$$

which means that a 1000 m^3 per day desalination plant will need a pond with a surface area of about

$$1000 \times 365/5.62 = 65\,000 \text{ m}^2$$

3.3.2. Surface Water Make-up

The surface water, which is relatively low salinity water i.e. brackish or even seawater, evaporates at a rate dependent on the geographic and climatic conditions at the site. Evaporation can vary between 2.5 m per year near the equator, to about 1 m per year at a latitude of about 40°. Another part of the water will continuously diffuse into the brine, while at the same time there is a continuous upwards diffusion of salt, which has to be got rid of by flushing.

Assuming an average evaporation rate of 1.5 m^3 m^{-2} per year, the amount of surface water needed for surface make-up and flushing to maintain a certain low salinity on top, is about 30 per cent higher, i.e. about 2 m^3 m^{-2} per year.
For the above examples, if one considers a solar pond for an inland power plant of 1000 kW, it has been demonstrated that the land required is 222 000 m^2 and the amount of fresh water required for make-up is about 450 000 m^3 per year.

In the case of water desalination, the availability of surface water is naturally not a problem, since seawater is used for this purpose. However, in the case of an inland solar power plant the availability of make up water is a crucial factor.

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