© 2016 IJSRSET | Volume 2 | Issue 6 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

# Mathematical Model of a Salinity Gradient Solar Pond

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## ABSTRACT

Solar Energy is the energy that is produced by the sun in the form of heat and light. It is one of the most renewable and readily available source of energy. It is available in plenty and free one of the most important of the non-conventional sources of energy. Mainly, Solar energy can be used to convert it into heat energy or it can be converted into electricity. The solar pond is considered the most reliable and economic solar systems. The collecting and storing of the solar energy is in one system. This paper gives an overview of a Mathematical modeling of a salt gradient solar pond and describes the present solar pond Technology in India.

**Keywords:** Salinity Gradient Solar Pond, solar energy, Mathematical Modeling.

## I. INTRODUCTION

On the Earth there is an abundant source of solar energy globally in which India has been counted for a good sunshine country. Since starting some of legendary contributors designed, modified, and developed many applications to utilize this source (sun) of energy for mankind [1]. A small fraction of this energy comes to earth, but this amount is several thousand times larger than our rate of fossil fuel usage and it drives all the natural ecosystem services of the planet. The fossil fuels presently meet the all global energy needs to some extent. These Fossil Fuels need replacement by renewable energy sources in the view of their depletion rates and emission legislation. The usage of renewable energy sources can cut the pollutant emissions into the atmosphere. Exploration of solar energy plays a vital role in developed and developing countries [2-5]. To meet the increasing world demand for energy, the use of fossil fuel has become wide spread. Unfortunately fossil fuels are non renewable energy sources, and they pollute the environment and are considered as the largest source of emissions of carbon dioxide, which is largely blamed for the global warming and climate changes [6-9]. This can be reduced by the construction of power plants using renewable sources such as solar, wind energy (Zekai, 2004). This paper depicts some useful information regarding solar pond in many aspects. The Fig1.Shows the comparison of power utilization from renewable energy with fossil fuel energy.

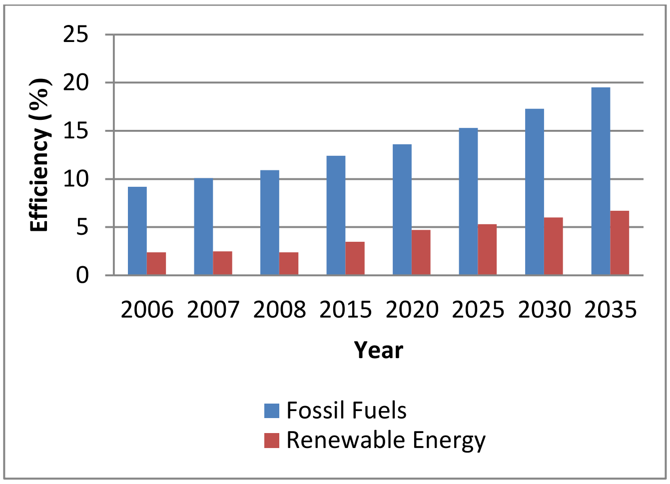


**Figure 1 :** Comparison of World consumption of renewable energy with fossil fuels.

Solar ponds are one of the simplest and less expensive technologies for converting and storing solar energy. The solar pond is unique in its ability to act both as a collection and storage system [10]. Solar ponds can be operated at virtually all latitudes and can provide energy for space heating and cooling, industrial process heating, pre-heating, and power generation via an organic Rankine-cycle engine [11]. It contains layers of salt solutions with increasing concentration (and therefore density) to a certain depth, below which the solution has a uniform high salt concentration. When solar radiation (sunlight) is absorbed, the density gradient prevents heat in the lower layers from moving upwards by convection and leaving the pond. This means that the temperature at the bottom of the pond will rise to over 90 °C, while the temperature at the top of the pond is usually around 30°C [12]. They can be located anywhere that is suitable for building a pond, regardless of the distance to the nearest power outlet, as long as there is access to direct sunlight near the pond site.

There are four basic types of solar ponds viz. (i) salt gradient solar ponds (ii) shallow solar pond (iii) salt-less convecting ponds and (iv) gel and viscosity stabilized pond. Fresh water forms a thin insulating surface layer at the top, and beneath to that is salt water. A salt gradient pond is the most common type of nonconvecting solar pond [13-14].The initiative of creating artificial solar ponds was proposed first by Dr. Rudolph Bloch in 1954.Solar ponds are contributing to various applications by better utilization of solar energy, few of them are shown in Table1.

| Location | Year of Commencement | Area ($m^2$) | Application |
|---|---|---|---|
| Kutch, India | 1987 | 6,000 | Supplying process heat to a dairy |
| Beit Ha Arava, Israel | 1984 | 250000 | Power generation |
| Texas, USA | 1975 | 100000 | Process heat for a Salt Works |
| Ancona, Italy | 1997 | 625 | Providing hot water to desalinator |
| Pyramid Hill, Australia | 2000 | 3000 | Heat generation for Industrial Process |
| Bhavnagar, India | 1971 | 1200 | Power generation |
| Texas USA | 1991 | 210000 | Producing Industrial process heat |

**Table 1 :** Solar Pond installation [15]

## II. METHODS AND MATERIAL

### 2. MATHEMATICAL MODEL OF A SOLAR POND:

The Salinity Gradient Solar Pond model may be derived by the following equation,

$$MC_p\left(\frac{dT}{dt}\right) = Q_u \qquad (1)$$

Where t = operating time
M= Mass of water and
T = hourly water temperature

The useful heat is,

$$Q_u = Q_{er} - Q_{cw} - Q_{lt} - Q_{ll} - Q_{es} \qquad (2)$$

Where:
$Q_u$ : Useful heat rate.
$Q_{er}$ : Heat entering the SGSP due to solar radiation.
$Q_{cw}$ : Heat loss from the sides (wall).
$Q_{lt}$ : Heat loss from the top of the SGSP.
$Q_{ll}$ : Heat loss from the bottom of the SGSP.
$Q_{es}$ : Heat extracted from the SGSP.

The Solar pond is well bottom insulated, so that lower layer heat loss may be neglected.

$$i.e.\, Q_{ll} = 0$$

And, at the warming up time, the extracted heat is assumed to be zero.

$$i.e.\, Q_{es} = 0$$

Substituting these terms in above equation, we get

$$Q_u = Q_{er} - Q_{lw} - Q_{lt} \qquad (3)$$

Where, $Q_{er} = (\tau\alpha)A_u H(t)$
$Q_{lw} = U_s A_s[T(t) - T_a(t)]$
$Q_{lt} = U_a A_u[T(t) - T_a(t)]$

Where $A_u$ is the upper Area and $A_s$ is the side area. Thus, the above Equation can be written as:

$$Q_u = (\tau\alpha)A_u H(t) - U_{sl}A_s[T(t) - T_a(t)] + U_{al}A_u[T(t) - T_a(t)] \qquad (4)$$

Where:
$\tau\alpha$: hourly optical coefficient.
$H$: hourly total radiation.
$Cp$: specific heat of water.
$Ua$ : top loss coefficient.
$Usl$: side loss coefficient.
$Ta$: ambient temperature.

Substituting the $Q_u$ value in above equation

$$MC_p\left(\frac{dT}{dt}\right) = (\tau\alpha)A_u H(t) - U_{sl}A_s[T(t) - T_a(t)] + U_{al}A_u[T(t) - T_a(t)] \qquad (5)$$

We know that, M = ρV and V = AL
The side area is very small that can be neglected.

$$\rho V C_p\left(\frac{dT}{dt}\right) = (\tau\alpha)A_u H(t) + U_{al}A_u[T(t) - T_a(t)]$$

$$\rho V C_p\left(\frac{dT}{dt}\right) = A_u[(\tau\alpha)H(t) + U_{al}[T(t) - T_a(t)]$$
(6)

And, $U_{al}$ can be represented by the total U.

$$\rho V C_p\left(\frac{dT}{dt}\right) = A_u[(\tau\alpha)H(t) + U[T(t) - T_a(t)]]$$
(7)

The irradiation can be considered as constant and can be taken as hourly total radiation ($H_t$),

$$\frac{\rho L C_p}{U}\left(\frac{dT}{dt}\right) = \frac{(\tau\alpha)H_t}{U} - T + T_a$$

$$\int_{T0}^{T} \frac{1}{[T - T_a - \frac{(\tau\alpha)H_T}{U}]}\, dT = \int_0^t -\frac{U}{\rho L C_p} dt \qquad (8)$$

Where $T_0$ is the initial temperature.

$$ln[T - T_a - \frac{(\tau\alpha)H_T}{U}] - ln\left[T_0 - T_a - \frac{(\tau\alpha)H_T}{U}\right] = -\frac{U}{\rho L C_p} dt \qquad (9)$$

$$\ln \frac{[T - T_a - \frac{(\tau\alpha)H_T}{U}]}{[T_0 - T_a - \frac{(\tau\alpha)H_T}{U}]} = -\frac{Ut}{\rho L C_p} dt$$

$$\frac{\left[T - T_a - \frac{(\tau\alpha)H_T}{U}\right]}{\left[T_0 - T_a - \frac{(\tau\alpha)H_T}{U}\right]} = e^{-\frac{Ut}{\rho L C_p}} \qquad (10)$$

$$\left[T - T_a - \frac{(\tau\alpha)H_T}{U}\right] = \left[T_0 - T_a - \frac{(\tau\alpha)H_T}{U}\right] e^{-\frac{Ut}{\rho L C_p}}$$

$$T = T_a + \frac{(\tau\alpha)H_T}{U} + \left[T_0 - T_a - \frac{(\tau\alpha)H_T}{U}\right].e^{-\frac{Ut}{\rho L C_p}}$$

$$T = T_a + \frac{(\tau\alpha)H_T}{U} - \left[\frac{(\tau\alpha)H_T}{U} + T_a - T_0\right].e^{-\frac{Ut}{\rho L C_p}} \qquad (11)$$

The above equation gives the hourly temperature of a Salinity Gradient Solar pond.

## III. RESULTS AND DISCUSSION

### 3. Present Solar Pond Technology

A large number of experimental solar ponds have been constructed around the world. There have also been a considerable number of demonstration solar ponds constructed in Israel, Australia, India and USA which are supplying heat [18].

### 3.1 Bhuj Solar Pond, India

In India, solar pond research dates back to 1971. Solar ponds were constructed in Bhavnagar, Pon dicherry, Bangalore and other places. But while these ponds helped in demonstrating solar pond technology, they were not connected to any end use (Kishore and Kumar, 1996). A 6000 square meter solar pond was constructed and operated at the Kutch dairy, Bhuj, India [19]. The pond supplies hot water to the dairy. An inexpensive lining scheme, consisting of alternating layers of clay and LDPE (low density polyethylene) combination was used for lining the pond. The pond attained a maximum temperature of 99.88 $^0$C under stagnation in the month of May. In this pond the heat extraction system incorporates an external heat exchanger with brine suction and discharge diffusers [20].

**Figure 2:** Bhuj Solar Pond, India (Kumar, 2000)

### 3.2 Israeli Solar Pond

The world's first commercial scale solar pond power plant was installed at Ein Boqek in Israel (Tabor and Doron). The plant was commissioned in December 1979 and was connected to the grid in 1984 (Figure 3.2) .The pond generated 160 KW power for 8 years between 1979 and 1987. Here two solar ponds, with a combined area of the 250000 m$^2$, that is 25 hectares [21], supplied the required thermal energy input to the power plant. But the solar pond power plant was only operated for one year, and was commissioned in 1990. The reason was geopolitical, rather than performance related (Akbarzadeh, Andrews and Golding, 2005).

**Figure 3:** Bet Ha Arava Solar pond power station in the Dead Sea Israel (Ormat, 2002).

There has been renewed interest in solar ponds in Israel in recent years, but the focus has shifted from electricity generation to direct low temperature heating applications such as industrial process heating, space heating and desalination [22].

### 3.3 Pyramid Hill Solar Pond, Australia

In 2000- 2001, a solar pond project was set up at Pyramid Hill Salt Pty Ltd. The Project was supported by funding from the Australian Greenhouse Office under the Renewable Energy Commercialization Program [23]. The project focused on the use of solar ponds for industrial process heating and in particular for the drying process in commercial salt production. The pond is located in northern Victoria and is approximately 200 km north of Melbourne on the Pyramid Hill – Boort Road.

This 3000 square meter solar pond supplies up to 60 KW of process heat for commercial salt production [24]. This demonstration facility is a good example of a solar pond designed for a specific application.

### 3.4 El Paso Solar Pond, USA

The El Paso solar pond became the first in the world to deliver industrial process heat to a commercial manufacturer in 1985, the first solar pond electric power generating facility in the United States in 1986, and the nation's first experimental solar pond powered water desalting facility in 1987. The El Paso Solar Pond sustained record breaking, near-boiling temperatures, developed and tested the new methods of gradient establishment and management, and successfully demonstrated the feasibility of the periodic pond concept [31-37]. Also, new clarity and stability control strategies have been developed that help identify an optimum stability margin for maintaining a high performance solar pond (Figure 2). The solar pond efficiency and thermodynamic conversion efficiency (heat to power) were found to be 65.5%. The pond generated 150 kW power for 7 years [25].

The plant has been in operation since 1983 and has reached a maximum pond temperature of 93 $^{0}$C. Heat extracted upon demand has been used to power an organic Rankine- cycle heat engine (ORC) for electricity production to supply hot water and to supply heat to operate a spin flash desalting unit and a Licon desalting unit for fresh water production [26].

The El Paso solar pond experience has demonstrated that reliable high- performance operation requires continuous automatic monitoring of the key pond data to maintain profiles that do not require speedy attention to any instability in the salinity gradient that might otherwise develop [27].

**Figure 4** : El Paso Solar Pond, Texas, USA (Brown 2002)

### 3.5 Margherita di Savoia Solar Pond

Folchitto (1991) has described the Margherita di Savoia solar pond. The pond was 25,000 square meter and 4 meter deep [28, 29]. 500 KW of process heat were extracted from the pond for 8000 hours. The pipes were of high density PVC and high density polyethylene for bittern or seawater and of insulated fiberglass for hot drive (for carrying hot brine from and to the LCZ in the solar pond [40].

## IV. CONCLUSION

Solar technology is now poised to play a larger role in the future, to new developments that could result in lower costs and improved efficiency. In fact, the solar industry aims to provide half of all new India electricity generation by 2025. More and more architects are recognizing the value of active and passive solar and learning how to effectively incorporate it into building designs. Solar hot water systems can compete economically with conventional systems in some areas. In recent years manufacturing costs of solar systems has dropped by 3-5% per year while government subsidies have increased. While to some such facts about solar energy seem trivial, this makes solar energy an ever-more affordable energy source. In the next few years it is expected that millions of households in the world will be using solar energy.

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